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Edited by Vincent T. Covello, Joshua Menkes, and Jeryl Mumpower

Risk Evaluation and Management

Edited by

Vincent T. Covello

and

Joshua Menkes

National Science Foundation
Washington, D.C.

and

Jeryl Mumpower

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Contributors

Michael S. Baram School of Public Health and School of Law, Boston University, Boston, Massachusetts 02118

David M. Buss Department of Psychology, University of Michigan, Ann Arbor, Michigan 48109

P. Collins Clark University, Worcester, Massachusetts 01610

Vincent T. Covello Division of Policy Research and Analysis, Policy Sciences Section, National Science Foundation, Washington, D.C. 20550

Kenneth H. Craik Institute of Personality Assessment and Research, University of California—Berkeley, Berkeley, California 94720

Karl M. Dake Institute of Personality Assessment and Research, University of California—Berkeley, Berkeley, California 94720

Donald R. DeLuca The Roper Center, Yale University, New Haven, Connecticut 06510

Lynn D. Disney Department of Environmental and Occupational Health, University of Michigan, Ann Arbor, Michigan 48109

James S. Dyer Management Department, The University of Texas, Austin, Texas 78712

Karen S. East Department of Environmental and Occupational Health, University of Michigan, Ann Arbor, Michigan 48109

Ward Edwards Social Science Research Institute, University of Southern California, Los Angeles, California 90089

John A. Ferejohn Department of Political Science, Stanford University, Palo Alto, California 94305

Baruch Fischhoff Decision Research, a branch of Perceptronics, Eugene, Oregon 97401

R. Goble Clark University, Worcester, Massachusetts 01610

A. Goldman Clark University, Worcester, Massachusetts 01610

John D. Graham Harvard School of Public Health, Boston, Massachusetts 02115

C. Hohenemser Clark University, Worcester, Massachusetts 01610

Wendy Horowitz The Roper Center, Yale University, New Haven, Connecticut 06510

Martin V. Jones Impact Assessment Institute, Rockville, Maryland 20850

Richard M. Jones Impact Assessment Institute, Rockville, Maryland 20850

J. X. Kasperson Clark University, Worcester, Massachusetts 01610

R. E. Kasperson Clark University, Worcester, Massachusetts 01610

R. W. Kates Clark University, Worcester, Massachusetts 01610

Ralph L. Keeney Systems Science Department, University of Southern California, Los Angeles, California 90089

Michael E. Kraft Department of Public and Environmental Administration, University of Wisconsin, Green Bay, Wisconsin 54301

Lester B. Lave Graduate School of Industrial Administration, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213

Edward W. Lawless Environmental Systems Department, Midwest Research Institute, Kansas City, Missouri 64110

M. Layman Decision Research, a branch of Perceptronics, Eugene, Oregon 97401

Sarah Lichtenstein Decision Research, a branch of Perceptronics, Eugene, Oregon 97401

Douglas MacLean Center for Philosophy and Public Policy, University of Maryland, College Park, Maryland 20742

Miley W. Merkhofer Applied Decision Analysis, Inc., Menlo Park, California 94025

J. Raymond Miyares School of Public Health and School of Law, Boston University, Boston, Massachusetts 02118

Jeryl Mumpower Department of Public Administration, State University of New York at Albany, Albany, New York 12222

David Okrent Department of Mechanical, Aerospace, and Nuclear Engineering, University of California at Los Angeles, Los Angeles, California 90024

Arthur Oleinick Department of Environmental and Occupational Health, University of Michigan, Ann Arbor, Michigan 48109

R. Talbot Page Environmental Quality Laboratory, California Institute of Technology, Pasadena, California 91125

Lloyd L. Philipson J. H. Wiggins Company, Redondo Beach, California 90277

Howard Raiffa Harvard Business School, Cambridge, Massachusetts 02138

Rakesh K. Sarin Graduate School of Management, The University of California—Los Angeles, Los Angeles, California 90024

Kristin Shrader-Frechette Department of Philosophy, University of Florida, Gainesville, Florida 32611

Paul Slovic Decision Research, a branch of Perceptronics, Eugene, Oregon 97401

Jan A. J. Stolwijk The Roper Center, Yale University, New Haven, Connecticut 06510

James W. Vaupel Hubert Humphrey School of Public Affairs, University of Minnesota, Minneapolis, Minnesota 55455

Detlof von Winterfeldt Social Science Research Institute, University of Southern California, Los Angeles, California 90089

Marx W. Wartofsky Department of Philosophy, Baruch College, City University of New York, New York, New York 10010

Rae Zimmerman Graduate School of Public Administration, New York University, New York, New York 10003

Preface

Public attention has focused in recent years on an array of technological risks to health, safety, and the environment. At the same time, responsibilities for technological risk assessment, evaluation, and management have grown in both the public and private sectors because of a perceived need to anticipate, prevent, or reduce the risks inherent in modern society. In attempting to meet these responsibilities, legislative, judicial, regulatory, and private sector institutions have had to deal with the extraordinarily complex problems of assessing and balancing risks, costs, and benefits.

The need to help society cope with technological risks has given rise to a new intellectual endeavor: the social and behavioral study of issues in risk evaluation and risk management. The scope and complexity of these analyses require a high degree of cooperative effort on the part of specialists from many fields. Analyzing social and behavioral issues requires the efforts of political scientists, sociologists, decision analysts, management scientists, economists, psychologists, philosophers, and policy analysts, among others.

Papers by authors from each of these disciplines are included in this volume. The papers share a focus on one or more of the following questions that are generic to the social and behavioral study of risk:

1. How do we determine how safe is safe enough?
2. How good are the knowledge base and methods for estimating the risks associated with different technologies?
3. How are estimates of risk incorporated into decision making?
4. How do decision makers treat uncertainties associated with different risks and hazards?
5. How do features of the institutional context affect decision-making bodies concerned with risk and uncertainty?
6. What factors influence individual perceptions of risk?
7. How are perceptions of risk and benefit incorporated into public policies?
8. How does society cope with risks that are unacceptable to some segments of the population?
9. How are normative considerations such as equity and social justice balanced in decision making about risk?
10. What are the criteria for comparing and evaluating different risk management policies?

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Vincent T. Covello
Joshua Menkes
Jeryl L. Mumpower

Washington, D.C.

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Public Perceptions of Risk

People's attitudes toward risks and their behaviors in response to them are strongly influenced by how they perceive and understand the risks from various hazards. Despite the importance of the topic, comparatively little is known about the cognitive and social processes that determine the perception and evaluation of risk. The papers in this section address this need by providing state-of-the-art knowledge about (a) the psychological, social, and institutional factors affecting risk perception and choice; (b) the conditions or events under which risk perceptions and preferences remain stable or change; (c) how information about risk is communicated to and understood by decisionmakers and the lay public; and (d) the process by which individual perceptions of risk are aggregated and translated into social perceptions of risk and decisionmaking. The common objectives of these papers are to identify better means for communicating information about risk and develop improved methods for predicting public response and involvement in the risk management process.

1

The Psychometric Study of Risk Perception

Paul Slovic, Baruch Fischhoff, and Sarah Lichtenstein

INTRODUCTION

In industrialized societies, the question "How safe is safe enough?" has emerged as a major policy issue of the 1980s. The frequent discovery of new hazards and the widespread publicity they receive is causing more and more individuals to see themselves as the victims, rather than as the beneficiaries, of technology. These fears and the opposition to technology that they produce have perplexed industrialists and regulators and led many observers to argue that the public's apparent pursuit of a "zero-risk society" threatens the nation's political and economic stability (Harris, 1980; Wildavsky, 1979).

In order to understand this problem, a number of researchers have begun to examine the opinions that people express when they are asked, in a variety of ways, to evaluate hazardous activities and technologies. This research has attempted to develop techniques for assessing the complex and subtle opinions that people have about risk. With these techniques, researchers have sought to discover what people mean when they say that something is (or is not) "risky," and to determine what factors underlie those perceptions. If successful, this research should aid policy makers by improving communication between them and the lay public, by directing educational efforts, and by predicting public responses to new hazards, events (e.g., a good safety record, an accident), and management strategies (e.g., warning labels, regulations, substitute products). A broad agenda for this research includes the following questions:

(1) *What are the determinants of "perceived risk"?* What are the concepts by which people characterize risks? How are those concepts related to their attitudes and behavior toward different technologies? To what extent are risk perceptions affected by emotional factors? For example, are they really sensitive, as is often claimed, to perceived controllability of risks and the dread they evoke? How adequate are the methods used to study perceptions of risk?

(2) *How accurate are public perceptions?* When lay people err, is it because they are poorly informed or because they were unable to do better? Are people so poorly informed

Paul Slovic, Baruch Fischhoff, and Sarah Lichtenstein • Decision Research, a branch of Perceptronics, Eugene, Oregon 97401.

(and uneducable) that they require paternalistic institutions to protect them? Would they be better off letting technical experts make most of the important decisions? Or do they know enough to be able to make their own decisions in the marketplace? When experts and lay people disagree about risk, is it always the latter who are in error?

(3) *What steps are needed to foster enlightened behavior with regard to risk?* What information do policy makers and the public need? How should such information be presented? What indices or criteria are useful for putting diverse risks in perspective? How can the news media and the schools help to educate people about risk and its management?

(4) *What is the role of judgment in technical assessments of risk?* When experts are forced to go beyond hard evidence and rely on educated intuition, do they encounter judgmental difficulties similar to those experienced by lay people? How well do experts assess the limits of their own knowledge? How can technical judgments be improved?

(5) *How do people perceive the benefits of risky technologies?* Almost all questions asked about risk perceptions have analogs with benefit perceptions.

(6) *What determines the relative acceptability of hazardous technologies?* How are assessments of their various risks and benefits combined subjectively? What role do considerations such as voluntariness, catastrophic potential, and equity play? What risk–benefit considerations motivate people to political action? Are some kinds of risks unacceptable, no matter what benefits they are expected to bring?

(7) *What makes a risk analysis "acceptable"?* Some analyses are able to guide society's responses, whereas others only fuel debate. Are these differences due to the specific hazards involved, the political philosophy underlying the analytical methods, the way that the public is involved in the decision-making process, the results of the analysis, or the manner in which the results are communicated? Can policy makers responsibly incorporate social values into risk analysis?

(8) *How can polarized social conflict involving risk be reduced?* Can an atmosphere of trust and mutual respect be created among opposing parties? How can we design an environment in which effective, multiway communication, constructive debate, and compromise can take place?

The Psychometric Paradigm

One broad strategy for studying perceived risk is to develop a taxonomy for hazards that can be used to understand and predict responses to their risks. A taxonomic scheme might explain, for example, people's extreme aversion to some hazards, their indifference to others, and the discrepancies between these reactions and experts' opinions. The most common approach to this goal has employed the *psychometric paradigm* (Fischhoff, Slovic, Lichtenstein, Read, and Combs, 1978; Slovic, Fischhoff, and Lichtenstein, 1982), which uses psychophysical scaling and multivariate analysis techniques to produce quantitative representations or "cognitive maps" of risk attitudes and perceptions. Within the psychometric paradigm, people make quantitative judgments about the current and desired riskiness of diverse hazards and the desired level of regulation of each. These judgments are then related to judgments about other properties, such as (1) the hazard's status on characteristics that have been hypothesized to account for risk perceptions and attitudes (e.g., voluntariness, dread, knowledge, controllability), (2) the benefits that each hazard provides to society, (3) the number of deaths caused by the hazard in an average year, (4) the number of deaths caused by the hazard in a disastrous year, and (5) the seriousness of each death from a particular hazard relative to a death due to other causes.

The remainder of this paper briefly reviews some of the results obtained from psycho-

metric studies of risk perception, including some previously unreported results. In doing so, it examines a few of the methodological and substantive issues surrounding the basic approach and outlines some potentially fruitful directions for future research.

PREVIOUS WORK

Revealed and Expressed Preferences

The original impetus for the psychometric paradigm came from the pioneering effort of Starr (1969) to develop a method for weighing technological risks against benefits in order to answer the fundamental question "How safe is safe enough?" His *revealed preference* approach assumed that, by trial and error, society has arrived at an "essentially optimum" balance between the risks and benefits associated with any activity. One may therefore use historical or current risk and benefit data to reveal patterns of "acceptable" risk–benefit trade-offs. Examining such data for several common industries and activities, Starr concluded that (1) acceptability of risk from an activity is roughly proportional to the third power (cube) of the benefits for that activity, and (2) the public will accept risks from voluntary activities (e.g., skiing) that are roughly 1000 times greater than it would tolerate from involuntary hazards (e.g., food preservatives) that provide the same level of benefit.

The merits and deficiencies of Starr's approach have been debated at length (see, e.g., Fischhoff, Lichtenstein, Slovic, Derby, and Keeney, 1981). We shall not go into them here, except to note that concern about the validity of the many assumptions inherent in the revealed preferences approach stimulated Fischhoff et al. (1978) to conduct an analogous psychometric analysis of questionnaire data, resulting in *expressed preferences*. In recent years, numerous other studies of expressed preferences have been carried out within the psychometric paradigm (see, for example, Brown and Green, 1980; Gardner, Tiemann, Gould, DeLuca, Doob, and Stolwijk, 1982; Green, 1980; Green and Brown, 1980; Johnson and Tversky, in press; Lindell and Earle, 1982; Macgill, 1982; Renn, 1981; Slovic, Fischhoff, and Lichtenstein, 1980a, 1984; Tiemann and Tiemann, 1983; Vlek and Stallen, 1981; von Winterfeldt, John, and Borcherding, 1981).

Although the results of these studies differ somewhat, they have shown that perceived risk is quantifiable and predictable. Psychometric techniques seem well suited for identifying similarities and differences among groups with regard to risk perceptions and attitudes (see Table 1). They have also shown that the concept "risk" means different things to different people. When experts judge risk, their responses correlate highly with technical estimates of annual fatalities. Lay people can assess annual fatalities if they are asked to (and produce estimates somewhat like the technical estimates). However, their judgments of "risk" are sensitive to other factors as well (e.g., catastrophic potential, threat to future generations) and, as a result, tend to differ from their own (and experts') estimates of annual fatalities.

Another consistent result from psychometric studies of expressed preferences is that people tend to view current risk levels as unacceptably high for most activities. The gap between perceived and desired risk levels suggests that people are not satisfied with the way that market and other regulatory mechanisms have balanced risks and benefits. Across the domain of hazards, there seems to be little systematic relationship between perceived existing risks and benefits. However, studies of expressed preferences do seem to support Starr's claim that people are willing to tolerate higher risks from activities seen as highly beneficial. But whereas Starr concluded that voluntariness of exposure was the key mediator of risk acceptance, expressed preference studies have shown that other characteristics such as fa-

Table 1. Ordering of Perceived Risk for 30 Activities and Technologies[a,b]

	League of Women Voters	College students	Active Club members	Experts
Nuclear power	1	1	8	20
Motor vehicles	2	5	3	1
Handguns	3	2	1	4
Smoking	4	3	4	2
Motorcycles	5	6	2	6
Alcoholic beverages	6	7	5	3
General (private) aviation	7	15	11	12
Police work	8	8	7	17
Pesticides	9	4	15	8
Surgery	10	11	9	5
Fire fighting	11	10	6	18
Large construction	12	14	13	13
Hunting	13	18	10	23
Spray cans	14	13	23	26
Mountain climbing	15	22	12	29
Bicycles	16	24	14	15
Commercial aviation	17	16	18	16
Electric power (nonnuclear)	18	19	19	9
Swimming	19	30	17	10
Contraceptives	20	9	22	11
Skiing	21	25	16	30
X rays	22	17	24	7
High school and college football	23	26	21	27
Railroads	24	23	20	19
Food preservatives	25	12	28	14
Food coloring	26	20	30	21
Power mowers	27	28	25	28
Prescription antibiotics	28	21	26	24
Home appliances	29	27	27	22
Vaccinations	30	29	29	25

[a] The ordering is based on the geometric mean risk ratings within each group. Rank 1 represents the most risky activity or technology.
[b] Source: Slovic, Fischhoff, and Lichtenstein (1981).

miliarity, control, catastrophic potential, equity, and level of knowledge also seem to influence the relationship between perceived risk, perceived benefit, and risk acceptance (see, e.g., Fischhoff et al., 1978; Slovic et al., 1980a).

Various models have been advanced to represent the relationships between perceptions, behavior, and these qualitative characteristics of hazards. As we shall see, the picture that emerges from this work is both orderly and complex.

Factor-Analytic Representations

Many of the qualitative risk characteristics are highly correlated with each other, across a wide range of hazards. For example, hazards rated as "voluntary" tend also to be rated as "controllable" and "well-known"; hazards that appear to threaten future generations tend also to be seen as having catastrophic potential, and so on. Investigation of these interrelationships by means of factor analysis has shown that the broader domain of characteristics can be condensed to a small set of higher-order characteristics or factors.

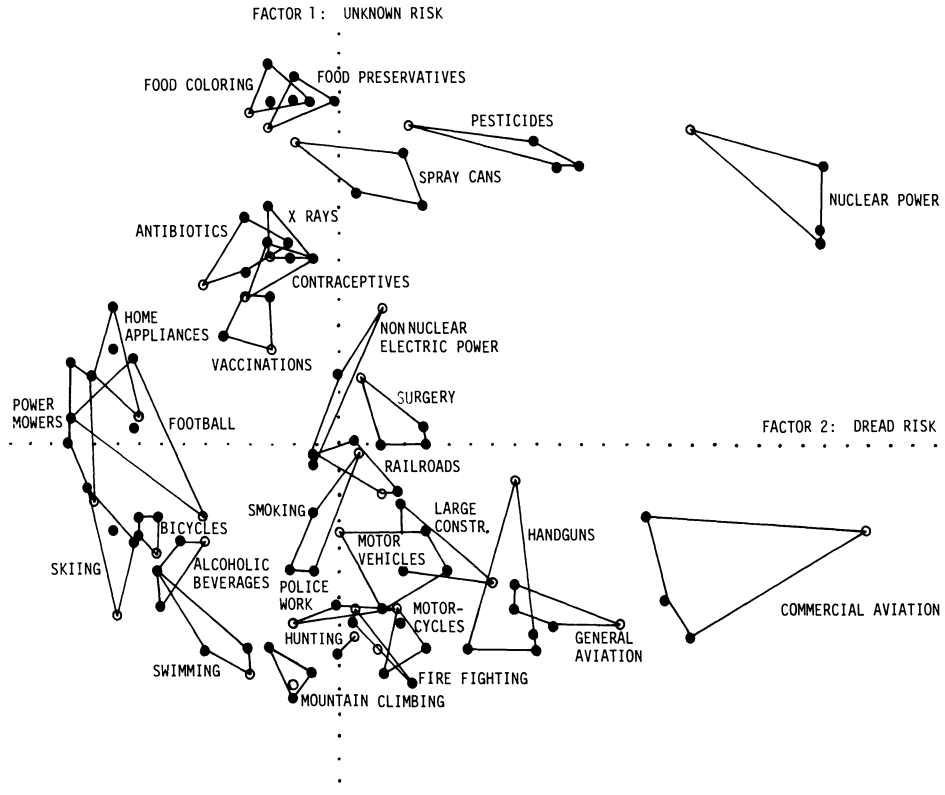
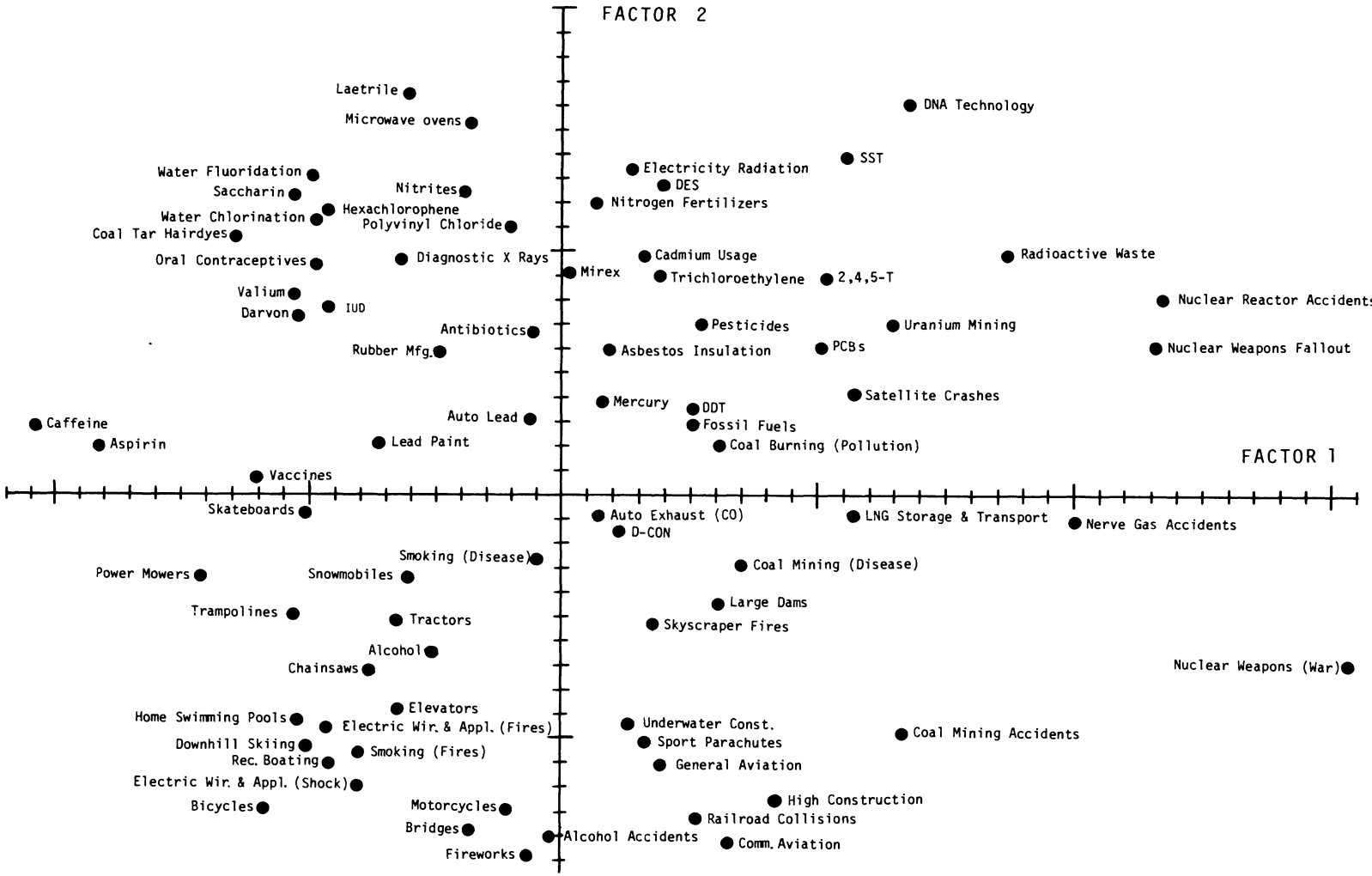


Figure 1. Location of 30 hazards within the two-factor space obtained from League of Women Voters, student, Active Club, and expert groups. Connected lines join or enclose the loci of four group points for each hazard. Open circles represent data from the expert group. Unattached points represent groups that fall within the triangle created by the other three groups. Source: Slovic, Fischhoff, and Lichtenstein (1981).

The factor spaces presented in Figures 1 and 2 have been replicated across groups of lay persons and experts judging large and diverse sets of hazards. The factors in this space reflect the degree to which a risk is understood and the degree to which it evokes a feeling of dread. A third factor, reflecting the number of people exposed to the risk, has been obtained in several studies. Making the set of hazards more specific (e.g., partitioning nuclear power into radioactive waste transport, uranium mining, nuclear reactor accidents) has had little effect on the factor structure or its relationship to risk perceptions (Slovic, Fischhoff, and Lichtenstein, 1985).

The story that has emerged from factor-analytic studies of perceived risk has been so consistent that one is tempted to believe in its universality. However, there are additional facets to the story, as indicated by other recent studies. For example, Tiemann and Tiemann (1983) used a factor-analytic technique that allowed them to study individual differences in risk and benefit orientations toward a set of hazards. Four major themes (or cognitive maps) emerged from these analyses, allowing subjects to be categorized as (1) benefit-oriented, (2) risk-oriented, (3) trade-off-oriented, or (4) polarized. The trade-off respondents perceived some activities as both risky and highly beneficial and other activities as both low in risk and low in benefits. The polarized individuals saw activities having high benefit as having low risk and vice versa.


FACTOR 2
FACTOR 1
Laetrile
Microwave ovens
Water Fluoridation
Saccharin
Water Chlorination
Coal Tar Hairdyes
Nitrites
Hexachlorophene
Polyvinyl Chloride
Oral Contraceptives
Diagnostic X Rays
Valium
Darvon
IUD
Antibiotics
Rubber Mfg.
Caffeine
Aspirin
Auto Lead
Lead Paint
Vaccines
Skateboards
Power Mowers
Snowmobiles
Smoking (Disease)
Trampolines
Tractors
Alcohol
Chainsaws
Home Swimming Pools
Elevators
Electric Wir. & Appl. (Fires)
Downhill Skiing
Rec. Boating
Smoking (Fires)
Electric Wir. & Appl. (Shock)
Bicycles
Motorcycles
Bridges
Fireworks
DNA Technology
SST
Electricity Radiation
DES
Nitrogen Fertilizers
Cadmium Usage
Radioactive Waste
Mirex
Trichloroethylene
2,4,5-T
Nuclear Reactor Accidents
Pesticides
Uranium Mining
Asbestos Insulation
PCBs
Nuclear Weapons Fallout
Satellite Crashes
Mercury
DDT
Fossil Fuels
Coal Burning (Pollution)
Auto Exhaust (CO)
LNG Storage & Transport
Nerve Gas Accidents
D-CON
Coal Mining (Disease)
Large Dams
Skyscraper Fires
Nuclear Weapons (War)
Underwater Const.
Coal Mining Accidents
Sport Parachutes
General Aviation
High Construction
Railroad Collisions
Alcohol Accidents
Comm. Aviation

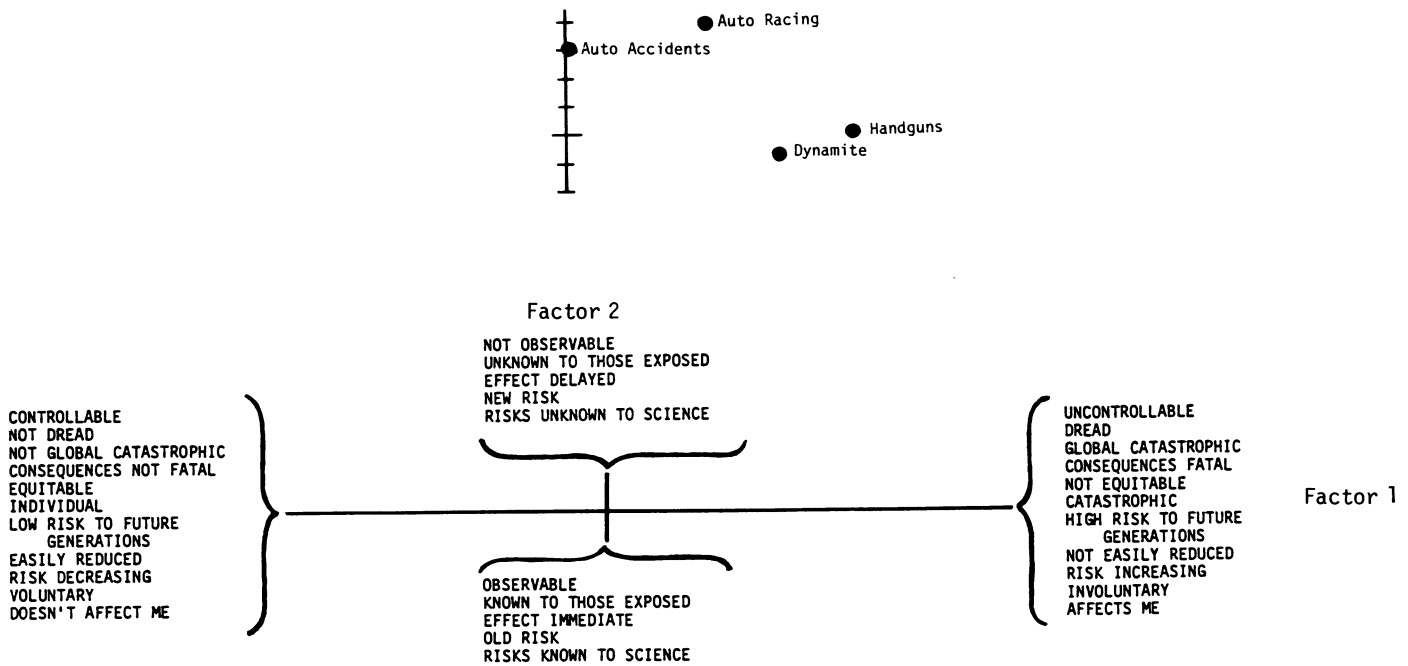


Figure 2. Hazard locations on Factors 1 and 2 derived from the interrelationships among 18 risk characteristics. Each factor is made up of a combination of characteristics, as indicated by the lower diagram. Source: Slovic, Fischhoff, and Lichtenstein, 1985.

Similarity-Based Representations

Whereas factor-analytic studies provide respondents with a predetermined set of risk characteristics to rate, an alternative approach asks for ratings of the overall similarity between pairs of hazards. Multidimensional scaling techniques are then used to derive a dimensional representation of the similarity space. Multidimensional scaling of similarity judgments for small sets of hazards by Vlek and Stallen (1981) and Green and Brown (1980) has produced two-dimensional representations similar to those obtained in our factor-analytic studies. However, Vlek and Stallen found substantial individual differences in the weighting of the dimensions.

Johnson and Tversky (in press) have compared factor-analytic and similarity representations derived from the same set of 18 hazards. The hazards differed from those in Figures 1 and 2 in that they included natural hazards and diseases as well as activities and technologies. They found that the factor space derived from this set of hazards resembled the space derived from earlier studies. However, they found that the space obtained from the multidimensional scaling of similarity judgments differed from the factor-analytic space. Further analysis showed that judgments of similarity based on direct comparisons of hazards were, in most cases, quite different from similarity indices obtained by comparing the hazards across the set of characteristics supplied by the experimenter. For example, homicide was judged to be similar to other acts of violence (war, terrorism) despite having a very different profile on the various risk characteristics. Although similarity judgments are not constrained by characteristics selected by the researcher, they may be susceptible to influence from considerations that are not relevant to risk. Thus, Hutchinson (1980) found that nuclear power and nonnuclear electric power were judged quite similar, perhaps because of their common element of power production.

In addition to producing a multidimensional representation of the similarity data, Johnson and Tversky constructed a tree representation (Figure 3). The risks are the terminal nodes of the tree and the distance between any pair of risks is given by the length of the horizontal parts of the shortest path that joins them; the vertical part is included only for graphical convenience. Figure 3 exhibits a distinct hierarchy of clusters which Johnson and Tversky called hazards, accidents, violent acts, technological disasters, and diseases.

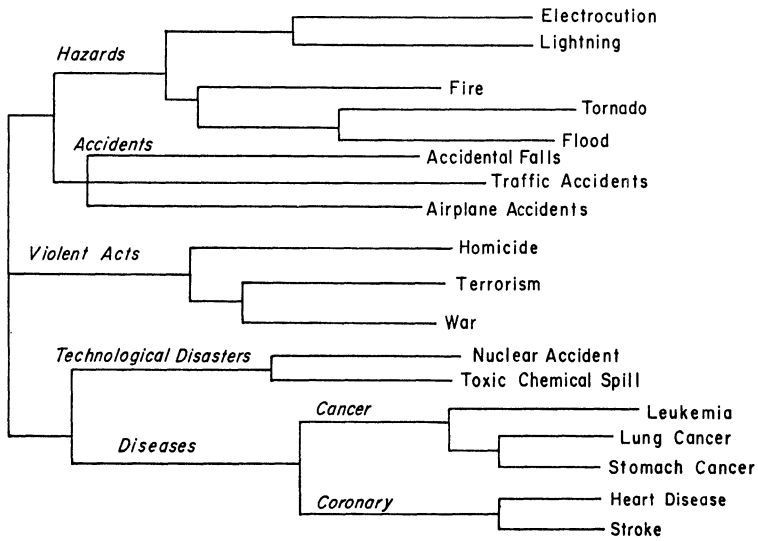


Figure 3. Tree representation of causes of death. Source: Johnson and Tversky (1984).

Implications of Psychometric Research

The social and policy implications of this research have been a matter of lively debate, taking up most of the June 1982 issue of the journal *Risk Analysis*. Douglas and Wildavsky (1982) argued that psychometric studies, with their cognitive emphasis, ignore the social processes that play a major role in determining which risks society fears and which it ignores. Otway and Thomas (1982) have taken a particularly cynical view, arguing that this research is being used as a tool in a discourse which is not concerned with risks *per se,* nor with perceptual and cognitive processes. Rather, the hidden agenda is the legitimacy of decision-making institutions and the equitable distribution of hazards and benefits.

Our view (Slovic, Fischhoff, and Lichtenstein, 1982) is that an understanding of how people think about risk has an important role in informing policy, even if it cannot resolve all questions. Moreover, risk perception research can be used to challenge social-political assumptions as well as to reinforce them (e.g., Fischhoff, Slovic, and Lichtenstein, 1983). The psychometric studies described above provide the beginnings of a psychological classification system for hazards that may help explain and forecast reactions to specific technologies, such as nuclear power or genetic engineering (e.g., Slovic, Lichtenstein, and Fischhoff, 1984) or provide guidelines for managing the social conflicts surrounding hazardous technologies (von Winterfeldt and Edwards, 1983). For example, even the present rudimentary state of knowledge about mental representations of hazards has proven relevant for evaluating proposed safety goals for nuclear power (Fischhoff, 1983; Slovic, Fischhoff, and Lichtenstein, 1984).

As for the different representations that have been derived from different methods of analysis, it now seems apparent that there is no one way to model risk perception, no universal cognitive map. People maintain multiple perspectives on the world of hazards. What remains to be determined is how these diverse perspectives influence their attitudes

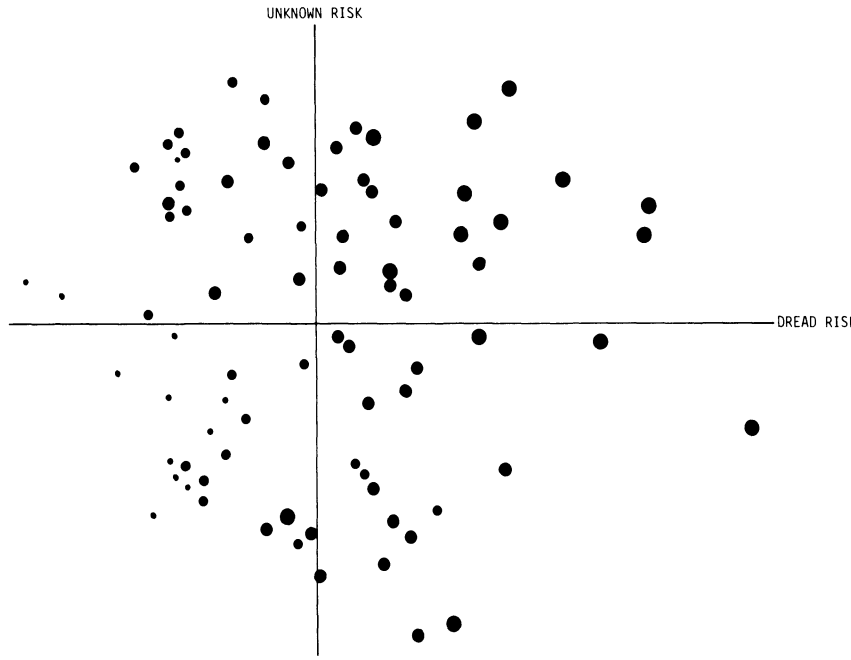


Figure 4. Attitudes toward regulation of the hazards in Figure 2. The larger the point, the greater the desire for strict regulation to reduce risk.

and behaviors. For example, we have found that, for lay people, both the level of perceived risk associated with a particular hazard and attitudes toward regulating these risks can be predicted quite well from knowledge of where that hazard falls within the space derived from factor analysis (see Figure 4). Most important is the factor "Dread Risk." The higher a hazard's score on this factor, the higher its perceived risk, the more people want to see its current risks reduced, and the more they want to see strict regulation employed to achieve the desired reduction in risk. Experts' perceptions of risk, however, seem much less closely related to the factor space. Instead, experts appear to focus on expected annual mortality when judging riskiness and, presumably, when considering the need to regulate (Hohenemser, Kates, and Slovic, 1983; Slovic, Fischhoff, and Lichtenstein, 1979). As a result, some conflicts over "risk" may result from experts and lay people having different definitions of the concept.

Johnson and Tversky (in press) hypothesize that similarity-based representations may play an important role in predicting people's responses to new risks or to new evidence about risk. For example, the Tylenol poisoning appeared to provoke fears concerning over-the-counter drugs but not other products (such as foods) that could easily be subject to tampering. They also speculated that the similarity between nuclear power and nuclear warfare might fuel much of the public debate about the acceptability of nuclear power reactors.

CURRENT RESEARCH

Our most recent work has used psychometric techniques to investigate three distinct topics. The first study considers how the social consequences of an accident are affected by the number of deaths it causes. The second study examines the concept of risk and the possibility of constructing a comprehensive measure of risk. The third study addresses an important methodological question regarding the degree to which cognitive representations derived from analyses of group mean data across diverse hazards can be generalized to individuals' perceptions of particular hazards.

Modeling the Societal Impact of Fatal Accidents

A frequently asked question in the application of formal analysis to safety decisions is: "How should a single accident that takes N lives be weighted relative to N accidents, each of which takes a single life?" Because safety resources are limited, assigning disproportionate weight to multiple fatality accidents would emphasize prevention of such accidents at cost of increasing the risk from smaller accidents.

In our approach to this problem (Slovic, Lichtenstein, and Fischhoff, 1984), we followed Keeney's (1980) distinction between the personal impacts of a fatal accident and the societal impacts. The former include the pain, suffering, and economic hardship of the victims and their friends and relatives, whereas the latter include the public distress and the political, social, and economic turmoil that may result from an accident. Our focus was on the societal impacts.

A number of proposals have been put forth regarding the proper way to model the societal impact of fatal accidents. Most of these describe the social cost of losing N lives in a single accident as a function of N^{α}. A common view is that a single large accident is more serious than many small accidents producing the same number of fatalities, hence the exponent α is greater than 1.

The complex nature of risk perception revealed in the psychometric studies made us doubt that any simple function of N could adequately capture the societal importance of a fatal accident. Perhaps the most dramatic anecdotal evidence in support of these doubts comes from the societal response to the accident at the Three Mile Island (TMI) nuclear reactor in 1979. Although it caused no immediate deaths and is expected to produce few if any latent cancer fatalities, this accident has greatly affected the structure and the viability of the entire nuclear power industry (Evans and Hope, 1982). Its enormous societal impact would never have been predicted by the N^{α} model or any other model based solely on the number of fatalities.

Reflection on the factor-analytic model in Figures 1 and 2 suggests that, although the N^{α} model may capture some aspect of Factor 1, the dread evoked by an event, it does not consider Factor 2, the degree to which the risks are thought to be known or understood. As a result, we hypothesized that one ingredient missing in the N^{α} models is recognition of the role that accidents play in providing information about possible future trouble. Thus, the social impact of an accident may be large, regardless of its death toll, if the accident shows the hazard to be poorly understood and, hence, signals a large increase in its risk. In this view, the accident at TMI was seen as an informative and ominous signal, raising fears that this technology was not understood well enough to be adequately under control. As a result, the accident led to a strong sociopolitical reaction whose consequences (stricter regulation of the nuclear industry, reduced operation of reactors worldwide, increased costs of reactor construction and operation) dwarfed the more direct costs (possible latent cancers, property damage, repairs, cleanup), significant as these were.

The potential importance of viewing accidents as signals goes beyond the domain of nuclear power. The generality of this concept is demonstrated by a study (reported by Slovic, Fischhoff, and Lichtenstein, 1980a) in which we asked 21 women (median age = 37) to rate the seriousness of 10 hypothetical accidents. Several aspects of seriousness were rated, including (1) the total amount of suffering and grief caused by the loss of life in each mishap; (2) the number of people who need to be made aware of the mishap via the media; (3) the amount of effort (and money) that should be put into investigating the cause of the mishap and preventing its recurrence; and (4) the degree to which hearing about the mishap would cause one to be worried and upset during the next few days.

Respondents also rated the informativeness of these incidents, defined as the degree to which the mishap told them (and society) something that may not have been known about the hazardousness of the specific activity.

The accidents were constructed so as to vary with respect to total fatalities and informativeness (see Table 2). The five less informative accidents represented incidents that were generated by reasonably familiar and understood processes. The more informative mishaps

Table 2. Accident Scenarios Designed to Vary in Informativeness[a]

Low information value	High information value
Bus skids on ice and runs off road (27 killed)	Nuclear reactor accident: Partial core meltdown releases radiation inside plant but not outside (1 killed)
Dam collapse (40 killed)	Botulism in well-known brand of food (2 killed)
Hundred-year flood (2700 killed)	New model auto steering fails (3 killed)
Meteorite hits stadium (4000 killed)	Recombinant DNA workers contract mysterious illness (10 killed)
Two jumbo jets collide on runway (600 killed)	Jet engine falls off on takeoff (300 killed)

[a] Source: Slovic, Fischhoff, and Lichtenstein (1980b).

were designed to signal a change in riskiness (perhaps caused by a breakdown in the system controlling the hazard) and some potential for the proliferation of similar mishaps. For example, a bus skidding on ice represented a low information mishap because its occurrence did not signal a change in motor vehicle risks (except for a limited time at that site), whereas an accident caused by a poorly designed steering system in a new model automobile would be informative about all such vehicles.

In general, the personal impact of an accident, as measured by the amount of suffering and grief attributed to it, was found to be closely related to the number of people killed. All other (societal) aspects of perceived seriousness were, however, more closely related to the accident's information content. Accidents signaling a possible breakdown in safety control systems and the possibility of proliferation were judged more worrisome and in need of both greater awareness and greater public effort to prevent recurrence. The number of people killed was not related to these aspects of seriousness.

In order to test our speculation about the relationship between accident impact and the risk factors, we conducted a second study comparing ratings of informativeness and seriousness with the location of the hazard within the factor structure shown in Figure 2. Our stimuli were 30 hazards, distributed across the four quadrants of the factor space. From the high dread, high unknown quadrant, we selected hazards such as DNA technology, nuclear

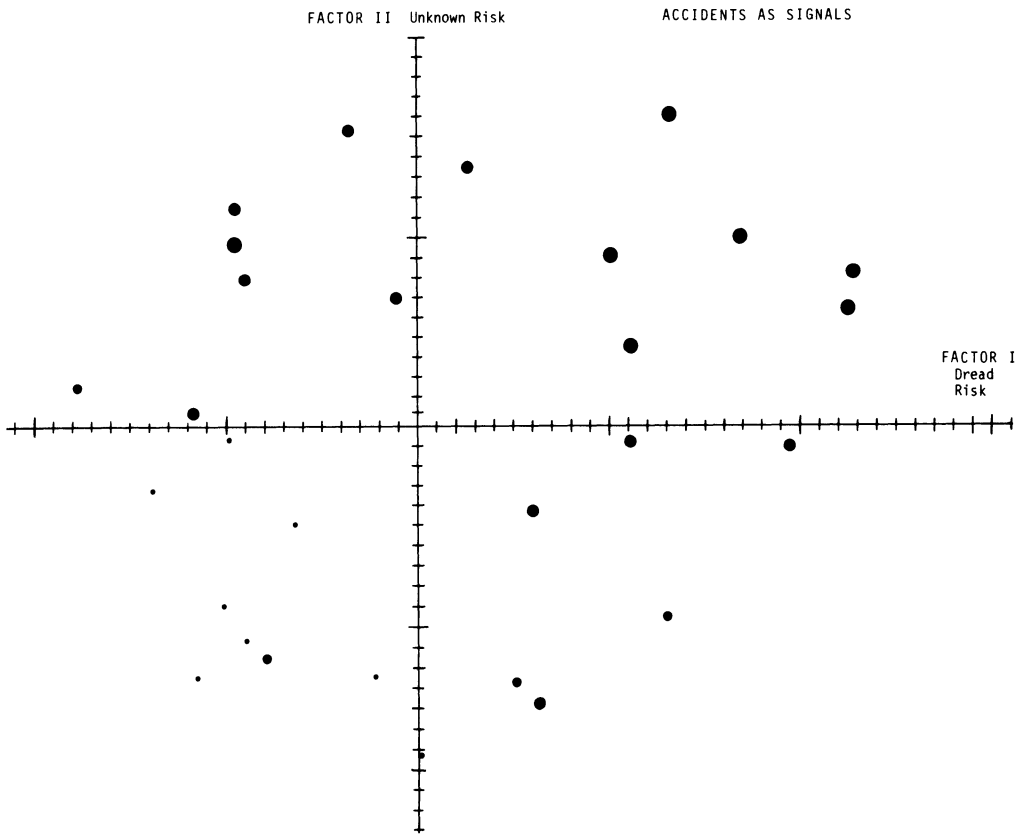


Figure 5. Relation between signal potential and risk characterization for 30 hazards in Figure 2. The larger the point, the greater the degree to which an accident involving that hazard was judged to"serve as a warning signal for society, providing new information about the probability that similar or even more destructive mishaps might occur within this type of activity." Source: Slovic, Lichtenstein, and Fischhoff (1984).

reactors, orbiting space satellites, and radioactive waste. Highly unknown but not dread hazards included microwave ovens, contraceptives, water chlorination, and antibiotics. Known and dread hazards included coal mining, nerve gas, dams, and commercial aviation. Known but not dread hazards included power mowers, bicycles, automobiles, and recreational boating.

The participants in this study were 78 university students who rated each hazard according to the degree to which an accident taking one or two lives "serves as a warning signal for society, providing new information about the probability that similar or even more destructive mishaps may occur within this type of activity." The participants also rated the overall "seriousness" of an accident involving each of those hazards (holding fatalities and other damages constant).

Each hazard is represented, in Figure 5, by a point whose size reflects its mean rating of signal potential. It is apparent that the judged signal potential of a hazard is closely related to location within the space. Signal potential correlated with the "dread" factor ($r = 0.58$), the "unknown" factor ($r = 0.71$), and their linear combination ($r = 0.92$). It also correlated 0.94 with mean ratings of the overall seriousness of an accident.

This analysis has led us to a number of specific conclusions. First, the societal impact of fatal accidents cannot be modeled solely by a function of N. As a result, models based on such functions should not be used to guide policy decisions.

Second, accident impact models need to consider signal potential. Unlike N^{α} models, which reflect attitudes regarding how deaths are clustered, signal potential involves an informational variable that should be central to any reasonable planning analysis.

Third, the concept of accidents as signals helps explain society's strong response to some nuclear power mishaps. Because reactor risks tend to be perceived as poorly understood and catastrophic, accidents with few direct casualties may be seen as omens of disaster, thus producing indirect or "ripple" effects resulting in immense costs to the industry and to society. One implication of signal value is that great effort and expense might be warranted to minimize the possibility of small but frightening reactor accidents.

Finally, when attempting to model the societal impacts of high signal-value accidents, we see no alternative but to elaborate the various events and consequences that may result from such accidents, the consequences of those consequences, the probabilities of all these direct and higher-order effects, and some measures of their costs. Although such detailed modeling may appear unmanageably complex, even a rough attempt to anticipate possible higher-order consequences of an accident is preferable to the use of simpler models with known inadequacies. Psychometric studies may enable analysts to forecast which classes of accidents will be the most potent signals, hence most in need of complex modeling.

Defining Risk

Technical experts tend to view risk as synonymous with mortality and morbidity. This is evident not only in their responses to psychometric surveys (Slovic, Fischhoff, and Lichtenstein, 1979), but in the ways that they conduct risk analyses (U.S. Nuclear Regulatory Commission, 1975) and in the presentations they create to "put risks in perspective." These presentations typically involve elaborate tables and even "catalogs of risk" in which some unidimensional index of death or disability is displayed for a broad spectrum of life's hazards. These indices include risks per hour of exposure (Sowby, 1965), annual probabilities of death (Wilson, 1979), and reductions in life expectancy (Cohen and Lee, 1979; Reissland and Harries, 1979). Those presenting these data typically assume that such information will aid decision makers, even though such comparisons have no logically necessary implications for the acceptability of risks (Fischhoff et al., 1981).

Psychometric studies of perceived risk imply that mortality and morbidity statistics will not, by themselves, be satisfactory indices of risk. People's perceptions and attitudes are determined by a variety of quantitative and qualitative characteristics such as those underlying Figure 2. Attempts to characterize, compare, and regulate risks must be sensitive to the broader conception of risk that underlies people's concerns.

We shall describe next a recent attempt by Fischhoff, Watson, and Hope (1984) to demonstrate a general approach for constructing a more elaborate definition of risk. Such an index cannot dictate decisions but can provide necessary input to them, along with measures of nonrisk costs and benefits. Other uses for an index of risk would be to educate one's intuition, set standards, help agencies allocate resources for risk management, and help institutions evaluate and defend their actions (Fischhoff, in press; Watson, 1983).

Fischhoff et al. emphasized that the definition and measurement of risk is inherently controversial, because of the value issues raised in specifying the concept and the power of those specifications to influence important decisions. Furthermore, no one definition is correct, or suitable, for all problems. Choice of a definition is a political act, reflecting the perceived importance of different adverse effects in a particular situation. As a result, choosing a measure for risk should not be the exclusive province of scientists, who have no special insight into what society should value. The approach suggested by Fischhoff et al. is, therefore, general enough to be adjusted to diverse problems and value systems.

The approach was demonstrated within the context of evaluating energy technologies. Its first step is determining what consequences should be included in the measure. The illustrative index included mortality, concern, and morbidity. Mortality risks were subdivided into risks to the general public and risks to workers. Concern was similarly partitioned into two dimensions based upon psychometric studies: unknown risk and dread risk. The former expresses aversion to uncertainty. The latter captures a risk's ability to evoke a visceral response.

The next step is to aggregate these components into an overall measure of risk. Here Fischhoff et al. relied on multiattribute utility theory (Keeney and Raiffa, 1976), which provides a framework for determining the relative weights (trade-offs) among the various components and integrating them into a single numerical index. Given the validity of certain assumptions, it becomes possible to express the risk index R in terms of the equation $R = \sum_i w_i x_i$ where x_i is the measure on component i and w_i is the weight for that component.

Fischhoff et al. presented a detailed application of this technique in the context of evaluating energy technologies. The application demonstrated how sensitive the overall index of risk is to the component attributes included in the definition of risk and to the weights assigned judgmentally to these attributes. As a result, the relative riskiness of these technologies depends upon what is meant by "risk." The analysis was not intended to produce a "correct" definition—which is a practical and political matter. Rather, it pointed to the issues that must be addressed if a politically acceptable and logically sound measure is to be created. In addition, it offered a highly flexible methodology with which to address these issues. Because the process of defining and measuring risks requires a variety of explicit value judgments, the present analysis highlights the need for effective public debate about what sorts of consequences are legitimate components of "risk."

Modeling the Perception of Individuals

Psychometric studies grew out of an interest in understanding why the risks from some hazardous activities appear to be treated differently from the risks of other activities. In most of these studies, after many subjects have evaluated many technologies, the mean rating for

each technology and each risk aspect, calculated across subjects, becomes the unit of analysis. Thus, information about how individuals differ is lost, in return for a more stable look at differences between technologies.

From these studies a theory of risk perception has emerged: lay people's risk judgments are based not just on their beliefs about fatalities, but also on their beliefs about several risk characteristics such as the technology's catastrophic potential, dreadedness, and severity of consequences should an accident occur. Further, people's desire for reduction of risk seems closely related to their perception of how much risk now exists.

If this theory is valid for a group, it should also be valid for many of the individuals in the group. Further, it may be that a number of people all share the same theory yet differ in their judgments of the risk characteristics of a particular hazard. For example, some people may not consider pesticides risky because they believe that pesticides do not present any catastrophic potential, whereas others who perceive such potential in pesticides will judge them as highly risky.

This possibility suggests that the unit of analysis be single individuals' ratings of risk aspects. As Gardner et al. (1982) have pointed out, there is no logical necessity that the relationships found across hazards will also be found within a single hazard across individuals. However, if such similarities were to be found, the theory would be strengthened and expanded. Additionally, we would have a better understanding of the so frequently observed disagreements among members of our society about the risk of hazards such as nuclear power. Finally, adopting the individual as the unit of analysis would enable researchers to study the effect of individual differences such as level of education or attitudes about the effectiveness of governmental intervention on risk perception.

Countering these advantages are difficulties encountered in using the individual differences approach. First, occasional mistakes or carelessness in ratings can produce an error component large enough to obscure genuine relationships among the ratings. This source of error is lessened when the ratings are averaged across individuals. A second source of error comes from individual differences in the way people use response scales. For example, one person may feel very strongly about some things yet be reluctant to use extreme numbers, while another person whose beliefs are more neutral may make finer discriminations and thus tend to use extreme responses. Finally, variation in beliefs across individuals is a necessary (although not sufficient) condition for detecting correlations. If all respondents, for example, believe that nuclear power is a dreaded technology and thus give it a high rating on the scale of dreadedness, this scale cannot show a correlation with perceived risk when the correlation is computed across individuals. If the tested group is homogeneous, individual analysis will fail even if the theory is true.

In designing a study to explore individual differences in perceptions of the risk of nuclear power, Gardner et al. (1982) recognized the need for a maximal variation in opinions. Their subjects included Sierra Club members, students, car wash attendants, Rotary Club members, and nuclear power engineers. Using many of the same scales as had been used in cross-hazard research, they found, in correlations across 367 respondents, many of the same relationships between perceived risk, desired risk, and risk characteristics as were found in the cross-hazard studies by Fischhoff et al. (1978) and Slovic et al. (1979, 1980a). Gardner et al. concluded that the similarity of results was noteworthy, given the differences in the procedures that produced them.

Pursuing this question, we have reexamined some of our original data, looking at correlations between perceived risk, desired risk reduction, and risk characteristics across individuals within hazards. The subjects were the 95 lay people whose responses were previously used in grouped, cross-hazard analyses reported by Slovic, Fischhoff, and Lich-

Table 3. Correlates of Perceived Risk

Variable	Correlations across 30 hazards	Correlations within hazards		
		Mean	Nuclear power	Bicycles
Voluntariness	−0.05	−0.08	−0.20	−0.15
Immediacy	0.09	0.04	−0.01	0.08
Known to exposed	0.24	0.00	−0.24	−0.08
Known to science	0.24	0.01	0.02	−0.13
Controllability	−0.07	−0.09	−0.14	0.10
Familiarity	0.05	−0.09	−0.01	0.04
Catastrophic potential	0.30	0.11	0.32	0.08
Dread	0.68	0.19	0.24	0.07
Severity (consequences fatal)	0.71	0.26	0.37	0.16
Desire for risk reduction	0.81	0.43	0.58	0.48

tenstein (1985). The subjects came from three groups: members of the League of Women Voters and their spouses, members of the Active Club (a business and professional group), and college students. For the present analyses the three subgroups were combined.

For each of the 30 hazards listed in Table 1, individual judgments of the riskiness of the hazard were correlated, across the subjects, with ratings, for that hazard, of nine risk characteristics (e.g., voluntariness, immediacy of effects) and with a measure of desire for reduction in the risk of that hazard. Thus, for each hazard the individual risk ratings were correlated with 10 other variables, as listed in Table 3.

In order to reduce the possible effects of response bias, all 11 variables were standardized before the correlations were computed. The original risk measure was a ratio-scale judgment in which the subjects assigned a score of 10 to whichever hazard the subject believed was less risky; other hazards were judged relative to that least risky hazard. For the present analysis, the risk judgments were ranked, within each individual across the 30 hazards, and these rank scores were used in the correlations. The original risk characteristic measures were 7-point rating scales. For each of these nine scales, each individual's ratings were transformed by a linear function that produced a new scale with mean of 0 and standard deviation of 1 across the 30 hazards. These standard scores were used for the correlations. The original measure of desire for risk reduction was a ratio judgment. A judgment greater than 1.0 indicated that "*serious action*, such as legislation to restrict its practice, should be taken [to reduce the risk]"; a judgment less than 1.0 meant that "the risk of death could be higher than it is now before society would have to take serious action" (Fischhoff et al., 1978, p. 132). These adjustment factors were ranked across hazards for each individual for the present analysis.

Results of the within-hazard analyses are shown in Table 3. For comparison, the first column presents the cross-hazard correlations based on the same data. For these cross-hazard correlations, the variables were not standardized. For perceived risk and desire for risk reduction, geometric means were taken across the 95 subjects; for the nine risk characteristics, mean ratings were used.

In the cross-hazard analyses, perceived risk correlated most highly with dread and severity of consequences and secondarily with catastrophic potential, all key components of the dread factor that emerged from the factor analyses of these data. Also, perceived risk correlated highly (0.81) with desired risk reduction.

The second column of Table 3 presents a summary of the individual difference analyses: the mean of the 30 correlations for each variable. For the first six variables, these means

accurately summarize the lack of correlation found across all 30 hazards. Only one of these correlations exceeded 0.30: for pesticides, perceived risk correlated −0.32 with voluntariness, indicating that, to a slight degree, those who viewed exposure to pesticides as more involuntary also viewed them as more risky.

The mean correlation of 0.11 for catastrophic potential reflects, in part, the many hazards with little possibility of catastrophe; individual differences thus did not appear in the catastrophe ratings of these hazards. Four hazards showed correlations between 0.30 and 0.40: nuclear power, nonnuclear electric power, antibiotics, and spray cans.

The dread variable was correlated 0.20 or greater with perceived risk for 13 of the 30 hazards; the severity of consequences variable showed such correlations for 22 hazards. As suggested by the mean of 0.43, the measure of desire for risk reduction was consistently related to perceived risk; for only 2 hazards was the correlation less than 0.20. Thus, for most hazards, those people who believed a hazard was more risky also believed that there was a greater need for risk reduction.

The last two columns show the individual-difference correlations for nuclear power and bicycles. The former is typical of the hazards for which individual differences were found. The latter illustrates the lack of correlation in hazards having only small individual differences.

In sum, the present analysis provides modest support for the application of risk perception theory to individual differences. As expected, the correlations were low. Because of the problems associated with within-hazard correlations studies, it might be more fruitful to use a quite different design to study the attributes of risk perception in individuals. This possibility is explored in the next section.

ISSUES FOR FUTURE RESEARCH

Although much progress has been made toward understanding the nature and implications of risk perception, we still lack definitive answers to the lengthy list of questions presented in the introduction to this paper. One obvious need is to conduct psychometric surveys of the general population and special populations of interest (such as hazard victims, technical experts, neighbors of hazardous facilities, legislators, journalists, and activists). Cross-national surveys would also be of interest. Some of this broader sampling is currently under way, as indicated by the accompanying chapters in this section. Among the many research directions worth pursuing, we shall concentrate here on three: designing new approaches to modeling cognitive representations of risk, extending the factor-analytic approach, and moving toward educating people, rather than just studying them.

New Methods for Modeling Risk Perceptions

The previous section discussed the possibilities and limitations of modeling the perceptions of individuals with correlational methods. Other techniques may be applied to this problem. One that has proven useful elsewhere is the analysis-of-variance approach to capturing judgmental policies (Anderson, 1981; Slovic and Lichtenstein, 1971). This approach starts by identifying a set of critical characteristics or dimensions. Next, a set of stimulus items (hazards in this case) are constructed in terms of their status on these various dimensions or characteristics. Thus, item (hazard) x_1 might be defined in terms of its catastrophic potential (y_1), the level of scientific uncertainty regarding its risks (y_2), the dread it evokes (y_3), some aspects of its benefits (y_4, y_5, . . . , y_i) and other dimensions selected

by the researcher ($y_{i+1} \ldots y_n$). The items are constructed so that across the set, any pair of dimensions (y_j, y_k) are uncorrelated. Factorial combinations of the stimulus dimensions are used to accomplish this. Each individual judges every hazard in the set on some criterion variable such as riskiness or acceptability of risk, after which analysis of variance methods are used to model the relative importance of each stimulus dimension in producing the overall judgments.

This general approach has been used to model a wide variety of judgments (Slovic and Lichtenstein, 1971; Hammond, Stewart, Brehmer, and Steinmann, 1975; Anderson, 1981). The advantage here is that the same basic design can be used to model the importance of hazard characteristics in determining judgments both across hazards and within hazards. In fact, the identical set of stimuli (hazard profiles) could be used in both studies. For example, to study individual perceptions of a single hazard, the various profiles could be said to represent the assessments of different individuals, each viewing the same hazard. The subject would be asked to predict how each of these individuals would judge the criterion (say, risk) from knowledge of the way that individual perceived the hazard profile. In the cross-hazard design, these same stimuli would be said to represent different hazards. The subject would be asked to judge their riskiness (or rate how others would judge their riskiness). Thus, models describing the importance of various hazard characteristics could be derived on the basis of judgments about the same stimuli under two different cover stories. Comparison of the resulting models would indicate whether or not the cross-hazard judgments and the within-hazard judgments appeared to be generated in the same way. Of course, there are many variations possible with this basic design. For example, one might name the hazards and vary those names, holding the hazard characteristics constant, to see whether the model people use to weigh and combine the characteristics varies as a function of the type of hazard being evaluated.

One limitation of the analysis-of-variance approach is that it sometimes creates combinations of characteristics that may not exist in reality and, hence, may be hard to judge. A second limitation is that it asks people to judge a rather abstract profile. A feature that the analysis-of-variance approach shares with the factor-analytic approach is that the researcher forces the respondent to consider a set of well defined characteristics when judging each hazard. This feature is a strength if the set spans the universe of important characteristics, a weakness if it does not. Similarity-based techniques do not specify the characteristics for the respondents, and should be used to supplement the more structured methods. Another supplementary technique is the *repertory grid*, used by Green and Brown (1980) to study hazards. Respondents were shown three hazards and were asked to indicate a characteristic that two of the hazards shared with each other but not with the third. An extensive set of characteristics was generated by this method, including many not studied previously. The repertory grid could be used as a starting point for factor-analytic or analysis-of-variance studies.

The repertory grid is one of a large class of "free-response" techniques, which allow respondents to generate their own response alternatives. Earle and Lindell (1984) have used such open-ended survey questions to study public perceptions of hazardous industrial facilities. Although many of their results replicate those from studies using structured response alternatives, they obtained some important new findings as well. One was that their respondents exhibited no spontaneous concern for future generations, in contrast to the concern shown in factor-analytic studies that explicitly forced consideration of this variable. Other possibilities lie in the family of "process-tracing" techniques, which attempt to make explicit the detailed operations people employ when making a judgment or decision (Raaij, 1983; Svenson, 1979). These methods require people to "think aloud" or search for information

as they make their judgments. In this way, the characteristics that people deem important can be "observed" without having first been primed by the researcher.

There is, obviously, no method for modeling cognitive processes that does not have some disadvantage. The choice depends upon the particulars of the scientific or policy problem being addressed. In many cases, several techniques will have to be used in concert in order to get a comprehensive picture of risk perceptions.

Elaborating Factor-Analytic Representations

Within the factor-analytic paradigm, one important topic is to look further at the generality of the recurrent two-factor structure shown in Figures 1 and 2. To date, this structure has been found with heterogeneous sets of hazards, selected in a variety of ways. An open question, of both theoretical and practical significance, is whether the structure would also pertain to a set of hazards all falling within the same category. For example, one point in both figures represents the item "railroads." But all railroad accidents are not the same. They differ with regard to (1) type of accident (collisions, derailments, fires, or explosions), (2) cause of accident (unknown, mechanical failure, operator error, or environmental problem, such as a mudslide), and (3) nature of consequences (deaths, injuries, property damage, or environmental damage).

If a diverse set of railroad mishaps were judged on the various risk characteristics, would the same two- or three-factor space emerge as was obtained across the broader domain of hazards? With whatever space emerged, could the social cost or seriousness of an accident be predictable on the basis of where it falls within the factor space (as in Figure 5)? Such a possibility would be extremely useful for setting safety standards or addressing such specific design questions as: What sort of safety systems, at what cost, should a company install on a rail line going through a long mountain tunnel? How would different types of rail accidents, causing about equal damage to people and the environment, be perceived? How costly would they be to the railroad company? The same general sorts of questions could be raised about other classes of hazards such as genetic engineering or space flight.

Educating Risk Perceptions

Research to date has taken risk perception as a given fact of life that policy makers must anticipate, satisfy, and cope with. The results of this research, however, suggest a number of possibilities for aiding people's intuitive perceptions. These possibilities should be pursued in the interests of increasing the applied potential of this work.

If the two-factor solution is interpreted as an indication of how people naturally think about hazards, then it provides a framework for presenting them with the information they need to participate in risk management decisions. Thus, they should feel a need for good information about how well a hazard is known to science and the extent of its catastrophic potential. If people examine accident reports for their signal value, then methods are needed to assess informativeness and communications techniques are needed to express it meaningfully.

The multivariate character of risk that has emerged in psychometric studies suggests that there are many things to be considered when thinking about"risk"and many incommensurable factors to bear in mind when assessing the relative riskiness of different hazards. The need for some convenient summary measure of risk seems apparent. The attempt to develop a general purpose index of risk was intended to address that need. Although reliance on multiattribute utility theory ensured the conceptual soundness of that effort, empirical

research is needed to estabish its practicality. Can people provide the explicit judgments needed to create such an index? If an index is created, can people absorb the information that it summarizes in a way that will be meaningful? Even if they endorse the index in principle, will they be willing to accept decisions based upon it? Would they feel more comfortable being shown, in matrix form, the information that it summarizes, leaving them to perform the integration in their heads?

An important theme in the psychometric literature has been establishing why lay and expert perceptions of risk differ. As described earlier, one cause of these differences is in the definitions of risk that lay people and experts use. Once these sources of disagreement have been clarified, one can examine the accuracy of lay perceptions regarding those aspects of risk that are of importance to them. In some cases, lay people's disagreements with experts can be defended (e.g., on grounds of their having access to information that the experts lack, or their being more sensitive to the inconclusiveness in current scientific knowledge than those who produce it). When lay people's views cannot be defended, it becomes important to provide them with the information needed to make decisions in their own best interests (Fischhoff, 1985; Slovic, Fischhoff, and Lichtenstein, 1980b). The foundation of knowledge laid by psychometric studies could serve as the springboard for research showing how best to communicate risk information and improve people's perceptions.

CONCLUSIONS

Individual and societal response to hazards is obviously multidetermined. Political, social, economic, psychological, and technical factors interact in complex and as yet incompletely understood ways to produce this response. Nevertheless, research aimed at understanding how people think about risk can play an important role in guiding policy decisions. Psychometric techniques seem capable of highlighting the concerns of people at risk and forecasting reactions to hazards and their management. The knowledge provided by these techniques may prove essential to helping people cope with the risks they face in their daily lives and ensuring the success of risk management policies at the societal level.

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REFERENCES

Anderson, N.H., *Foundations of information integration theory*. New York: Academic Press, 1981.

Brown, R.A., & Green, C.H., Precepts of safety assessments.*Journal of the Operational Research Society,* 1980, *11,* 563–571.

Cohen, B., & Lee, I., A catalog of risks. *Health Physics,* 1979, *36,* 707–722.

Douglas, M., & Wildavsky, A., *Risk and culture*. Berkeley and Los Angeles: University of California Press, 1982.

Earle, T.C., & Lindell, M.K., Public perception of industrial risks: A free-response approach. In R.A. Waller and V. T. Covello (Eds.), *Low-probability/high-consequene Risk Analysis*. New York: Plenum, 1984.

Evans, N., & Hope, C.W., *Costs of nuclear accidents: Implications for reactor choice*. Energy Research Group Report, 82/17. Cavendish Laboratory, Cambridge University, 1982.

Fischhoff, B., Acceptable risk: The case of nuclear power. *Journal of Policy Analysis and Management,* 1983, *2,* 559–575.

Fischhoff, B., Cognitive and institutional barriers to"informed consent." In M. Gibson (Ed.), *Risk, Consent, and Air*. Totowa, N.J.: Rowman & Allenheld, 1985.

Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S.L., & Keeney, R.L., *Acceptable risk*. New York: Cambridge University Press, 1981.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B., How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. *Policy Sciences,* 1978, *8,* 127–152.

Fischhoff, B., Slovic, P., & Lichenstein, S., The "public" vs. the "experts": Perceived vs. actual disagreement about the risks of nuclear power. In V. Covello, G. Flamm, J. Rodericks, and R. Tardiff (Eds.), *Analysis of actual vs. perceived risks*. New York: Plenum, 1983.

Fischhoff, B., Watson, S., & Hope, C., Defining risk. *Policy Sciences,* 1984, *17,* 123–139.

Gardner, G.T., Tiemann, A.R., Gould, L.C., DeLuca, D.R., Doob, L.W., & Stolwijk, J.A.J., Risk and benefit perceptions, acceptability judgments, and self-reported actions toward nuclear power. *Journal of Social Psychology,* 1982, *116,* 179–197.

Green, C.H., Risk: Attitudes and beliefs. In D.V. Canter (Ed.), *Behaviour in fires*. Chichester: Wiley, 1980.

Green, C.H., & Brown, R.A., *Through a glass darkly: Perceiving perceived risks to health and safety*. Research paper, School of Architecture, Duncan of Jordanstone College of Art, University of Dundee, Scotland, 1980.

Hammond, K.R., Stewart, T.R., Brehmer, B., & Steinmann, D., Social judgment theory. In M.F. Kaplan and S. Schwartz (Eds.), *Human judgment and decision processes*. New York: Academic Press, 1975.

Harris, L., *Risk in a complex society*. Public opinion survey conducted for Marsh and McLennan Companies, 1980.

Hohenemser, C., Kates, R.W., & Slovic, P., The nature of technological hazard. *Science,* 1983, *220,* 378–384.

Hutchinson, J.W., *Data structure and psychological structure in risk perception research: Some comments on psychometric approaches*. Unpublished manuscript, Dept. of Psychology, Stanford University, 1980.

Johnson, E.J., & Tversky, A., Representations of perceptions of risks. *Journal of Experimental Psychology: General,* in press.

Keeney, R.L., Evaluating alternatives involving potential fatalities. *Operations research,* 1980, *28,* 188–205.

Keeney, R.L., & Raiffa, H., *Decisions with multiple objectives: Preferences and value trade-offs*. New York: Wiley, 1976.

Lindell, M.K., & Earle, T.C., *How close is close enough: Public perceptions of the risks of industrial facilities*. Unpublished manuscript, Battelle Human Affairs Research Center, Seattle, 1982.

Macgill, S.M., *Exploring the similarities of different risks*. Working paper, the School of Geography, University of Leeds, 1982.

Otway, H.J., & Thomas, K., Reflections on risk perception and policy. *Risk Analysis,* 1982, *2,* 69–82.

Raaij, W.F. van, Techniques for process tracing in decision making. In L. Sjöberg, T. Tyszka, and J. Wise (Eds.), *Human decision making*. Bodafors, Sweden: Doxa, 1983.

Reissland, J., & Harries, V., A scale for measuring risks. *New Scientist,* 1979, *83,* 809–811.

Renn, O., *Man, technology, and risk: A study on intuitive risk assessment and attitudes towards nuclear power*. Report Jul-Spez 115, Julich, Federal Republic of Germany: Nuclear Research Center, June 1981.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Rating the risks. *Environment,* 1979, *21,* 14–20; 36–39.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Facts and fears: Understanding perceived risk. In R. Schwing and W.A. Albers, Jr. (Eds.), *Societal risk assessment: How safe is safe enough?* New York: Plenum, 1980a.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Informing people about risk. In L. Morris, M. Mazis, and I. Barofsky (Eds.), *Product liability and health risks,* Banbury Report 6, Cold Spring Harbor, New York, 1980b.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Perceived risk: Psychological factors and social implications. In F. Warner and D.H. Slater (Eds.), *The assessment and perception of risk*. London: The Royal Society, 1981.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Why study risk perception? *Risk Analysis,* 1982, *2,* 83–93.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Behavioral decision theory perspectives on risk and safety. *Acta Psychologica,* 1984, *56,* 183–203.

Slovic, P., Fischhoff, B., & Lichtenstein, S., Characterizing perceived risk. In R.W. Kates, C. Hohenemser and J.X. Kasperson (Eds.), *Perilous Progress: Managing the Hazards of Technology*.. Boulder, Colorado: Westview, 1985.

Slovic, P., & Lichtenstein, S., Comparison of Bayesian and regression approaches to the study of information processing in judgment. *Organizational Behavior and Human Performance,* 1971, *6,* 649–744.

Slovic, P., Lichtenstein, S., & Fischhoff, B., Modeling the societal impact of fatal accidents. *Management Science,* 1984, *30,* 464–474.

Sowby, F.D., Radiation and other risks. *Health Physics,* 1965, *11,* 879–887.

Starr, C., Social benefit versus technological risk. *Science,* 1969, *165,* 1232–1238.

Svenson, O., Process description of decision making.*Organizational Behavior and Human Performance,* 1979, *23,* 86–112.

Tiemann, A.R., & Tiemann, J.J., *Cognitive maps of risk and benefit perceptions*. Paper presented at the Annual Meeting of the Society for Risk Analysis, New York, 1983.

U.S. Nuclear Regulatory Commission. *Reactor safety study: An assessment of accident risks in U.S. commercial nuclear power plants*. (WASH 1400 NUREG-75/014). Washington, D.C.: The Commission, 1975.

Vlek, C.A.J., & Stallen, P.J.M., Judging risks and benefits in the small and in the large. *Organizational Behavior and Human Performance,* 1981, *28,* 235–271.

von Winterfeldt, D., & Edwards, W., *Patterns of conflict about risky technologies*. Working paper, Social Science Research Institute, University of Southern California, 1983.

von Winterfeldt, D., John, R.S., & Borcherding, K., Cognitive components of risk ratings. *Risk Analysis,* 1981, *1,* 277–287.

Watson, S.R., *Using perceptions of risk in risk management*. Paper presented at the Annual Meeting of the British Association for the Advancement of Science, Brighton, England, 1983.

Wildavsky, A., No risk is the highest risk of all. *American Scientist,* 1979, *67,* 32–37.

Wilson, R., Analyzing the daily risks of life. *Technology Review,* 1979, *81,* 40–46.

2

Public Perceptions of Technological Risks

A Methodological Study

Donald R. DeLuca, Jan A. J. Stolwijk, and Wendy Horowitz

INTRODUCTION

Technology that is developed for benefits and profits will always produce risks and costs. Although technology assessments evaluate and compare these consequences, balancing the trade-offs and distributing the contrary effects require political decisions, which traditionally have been carried out by "stakeholders" representing special interests. With the emergence of new "public" interest organizations, the risk management system has been confronted with additional voices seeking ways to have their points of view included in risk management decision making. Hence, intervention in the form of organized opposition to, or support of, specific technologies, installations, or products—sometimes expressed in the name of the public—has become increasingly pivotal in the outcome of policy debates (Nelkin, 1979).

Although researchers recently have begun to study the risk management process in greater detail, there is little understanding of elite, compared to public, perceptions of risks, benefits, and the acceptability of technology. Even less is known about the interactive role (if any) each does, can, or should play in improving or hindering the efficiency or quality of hazard management, while maximizing equity in the distribution of technology's effects.

This study compares advocates and the general population in the United States with respect to perceptions of technology—its benefits, risks, and efforts to mitigate its ill effects—and the extent to which each group has become involved in activities, which support or oppose technology's development and deployment. More specifically, the study explores the pattern of factors which best explain differences in individuals with regard to (1) perceptions of technology's positive and negative consequences; (2) perceptions of safety standards, established to control technology and make it more acceptable; and (3) personal involvement in activities, pro and con, to specify the conditions for developing, maintaining, or utilizing technological products. These analyses will compare and contrast subgroups of

Donald R. DeLuca, Jan A. J. Stolwijk, and Wendy Horowitz • The Roper Center, Yale University, New Haven, Connecticut 06510.

advocates and the general population, located in two distinct regions of the country, with respect to six specific technology referents. The complex survey research design and analysis strategy is presented in the project's "Analysis Manual" (1982).

Goals of This Study

The study's contribution to the growing literature on technology assessment and risk analysis is both substantive and methodological. The research proceeds from an interdisciplinary perspective. It identifies elements from its varied disciplines and combines them into an emergent framework, loosely anchored by conceptual roots found in the respective bodies of social science research literature. Although grounded in prior risk perception research, the theoretical framework redirects the focus of inquiry both forward and backward. Therefore, the first major research goal was to develop and elaborate a new theoretical framework.

To develop a new theoretical framework, however, required adapting and refining appropriate, available research methodologies, since the new conceptualization represented a rather significant departure from existing techniques reported in the risk perception literature. The modifications needed ranged from issues of measurement, instrument construction, sample frame construction, and data collection to generalizability of results, units of analysis, statistical inference, and the analysis strategy.

Hence, the second major research goal was to develop methodological techniques for empirically testing the theoretical framework. While many of the methodological issues are discussed elsewhere (Gardner et al., 1982; Analysis Manual, 1982), operationalization and measurement will be discussed below.

A natural component of the first goal is to determine the extent to which findings apply from earlier studies of risk perception, when the hypotheses are recast into this study's population-based research design. As a consequence of the second goal, this body of risk perception research is supplemented with additional explanatory factors and has the capacity to uncover the relative magnitude of relationships between individual and collective variables. Beyond this, however, lies the central focus of the research. Since the basic research problem of this investigation is to improve understanding of interventions in risk management decision making, a theoretical framework is devised to account for behavioral responses, if any, elicited by favorable or opposing technologies.

THEORETICAL FRAMEWORK

Relevant Findings from the Literature

Interdisciplinary literature reviews, discussions by the senior investigators, and a separate preliminary study conducted primarily to answer methodological questions (cf. Stolwijk et al., 1981; Gardner et al., 1982) have yielded a number of propositions, which when combined into time-ordered sequence, constitute the theoretical framework for the present study. Relevant hypotheses and results from the research literature are referenced below.

Studies on behavior, personal involvement, or action, as well as research on social participation, collective behavior, or social movements, are found in the various literatures of psychology, sociology, economics, and political science. Research by Kreitler and Kreitler (1976), Fishbein and Ajzen (1974), Weigel and Newman (1976), Otway and Fishbein (1977), and other works summarized by Schuman and Johnson (1976) provide insights on the relationships between attitudes, values, cognitive orientations, and behavior. Studies on

social change and strategies of community organization (Gamson, 1968; Lenski, 1966; Cox et al., 1974), community politics (Bonjean, Clark, and Lineberry, 1971), and citizen participation (Bachrach and Baratz, 1970) suggest factors and conditions related to the propensity for, and the intensity of, personal action, as well as social participation and intervention. Also relevant to the study of personal involvement in the risk management process (and more directly relevant because of its substantive content) is the literature from environmental sociology, especially research on the environmental movement (cf. Humphrey and Buttel, 1982, Chapter 5), studies of attitudes toward energy, especially nuclear power and energy conservation (e.g., Zetterberg, 1980; Melber et al., 1977; Farhar et al., 1979), and applied studies reporting social impact assessments of various development projects (e.g., Finsterbusch and Wolf, 1981).

For present purposes this literature may be summarized as propositions incorporated into the theoretical framework as determinants of personal involvement or actions taken to influence risk management decision making, as follows:

Action Hypotheses. (1) Attitudes about general objects (e.g., technology, the environment) predispose people to perform a variety of different behaviors directed toward that object, rather than any given specific behavior. (2) Actions directed toward specific objects are strongly related to the salience of the issues involved and the perceived probability of successful outcomes. (3) The salience of an issue is strongly influenced by media exposure and content. (4) In the absence of high salience or controversy, risks and benefits of a technology will be regarded with passive acquiescence, not action. (5) The general population, especially when compared to elite subgroups, will tend toward fatalistic submission (less intensive or no action), even in the situation of relatively high controversy over the technology. (6) The greater the inequity in the distribution of negative or positive effects, the greater the probability for personal involvement. (7) The greater the possibility for personal gain, the greater the probability for personal action. (8) The greater the confidence in institutions and the leaders of these institutions, the less the probability for personal action. (9) The older the object or situation, and therefore the more familiar it is, the less likely it is to be the source of intensive action. (10) The greater the stake in existing conditions, the greater the probability for personal involvement to maintain the status quo. (11) Some actions are unpredictable as they are more nearly a function of unique situational forces. (12) Voting behavior (i.e., on a nuclear referendum) is related to values (of reproduction or inner growth and quality of life) and mildly related to sociodemographic variables (e.g., social class, age, and gender). (13) In general, demographic and social characteristics play a noticeable but subordinate role in the development of attitudes toward technology.

Obviously, prior risk perception research utilizing macro- and microanalytic approaches has helped to guide the formulation of the theoretical framework. The macro approach infers public sentiments about technology from historical, cost-benefit data (Starr, 1969; Starr and Whipple, 1980). The micro approach measures people's perceptions directly using quasi-experimental, pencil-and-paper research designs (e.g., Fischhoff et al., 1978; Slovic, 1979, 1980; Green, 1980) or through surveys (Otway and Fishbein, 1977; Vlek and Stallen, 1979; Renn, 1981). The relative strengths and weaknesses of these research approaches have been debated extensively (e.g., Otway and Cohen, 1975; Green, 1980; Fischhoff et al., 1981). Attempts also have been made to incorporate risk perception research into the broader study of technology assessment and risk analysis (Hohenemser and Kasperson, 1982), the management of its hazards (Kates and Hohenemser, 1981; Baram, 1982), and the cultural sources of risk perception (Douglas and Wildavsky, 1982).

One major focus of risk perception research has been influenced by earlier studies on

human decision making under conditions of risk or uncertainty, to help find factors that explain cognitive processes involved in personal assessments of technology safety (for a review see, e.g., Slovic et al., 1977, 1982; Kahneman and Tversky, 1979; Kahneman et al., 1982). More recent and ongoing decision research redirects the analysis to personal preferences of various decision approaches (e.g., cost-benefit analysis, political judgment, expert judgment) for societal determinations of acceptable levels of risk from technology (Buss and Craik, 1982; Buss, Craik, and Dake, 1982).

The following findings from the risk perception literature are incorporated into the theoretical framework, to determine the extent to which these results can be replicated under a different research design and analysis strategy. If these results are confirmed as expected, major conceptual variables from these studies are hypothesized as explanatory factors of personal actions to influence risk management decisions.

Technology Perception Hypotheses. (1) Risk perceptions are quantifiable, orderly, and predictable. (2) Subgroups (e.g., experts, advocates, students) define risks differently. (3) Risk judgments are related not only to estimates of fatalities, but also to a number of qualitative technology characterizations such as its catastrophic potential. (4) Judgments about the "acceptability" of technology have a strong negative relationship to perceived risk. (5)"Acceptability" judgments are positively related to perceived benefit. (6)

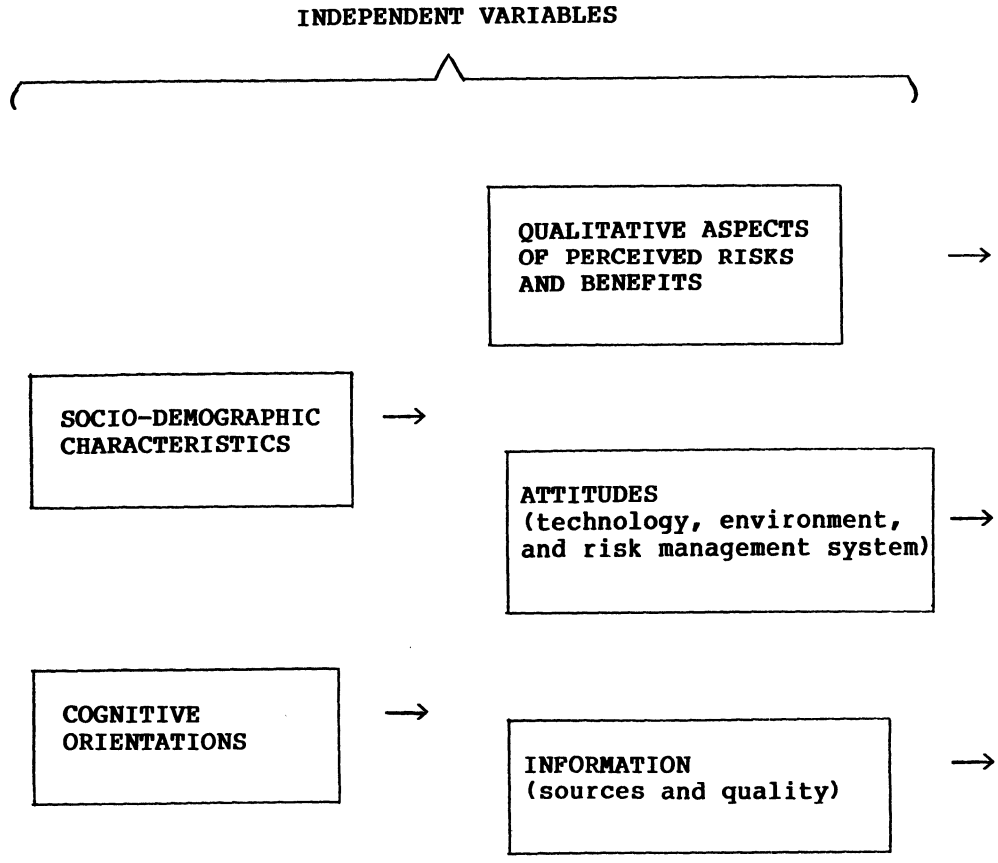

Figure 1. Schematic diagram of explanatory model.

Judgments of "acceptability" are affected by qualitative technology characterizations both directly and indirectly through risk perceptions. (7) The qualitative technology characterizations vary in the degree to which they relate to the "acceptability" judgments of different subgroups.

The following hypotheses are stated in terms of findings from the literature (especially Renn, 1981; Zetterberg, 1980), which are examined in the present study: (8) Most people utilize relatively homogeneous evaluation criteria in making risk assessments and arrive at similar results in the evaluation of risk-benefit relations for different risk sources. (9) The evaluation of risks is related to (a) perceived consequences generally relative to health, safety, and the future scope of freedom; (b) personal possibilities of influencing the risk; and (c) personal readiness to take risks. (10) Cognitive orientations and general values and attitudes are of significance only if the risk consequences relate to society, the economy, or future lifestyle. (11) Pronuclear advocates have heterogeneous and, in part, contradictory beliefs; their behavioral intentions are accordingly limited and more diffuse. (12) Antinuclear advocates have a very homogeneous attitude structure and stronger behavior motivation, although their pessimistic view of the future can be socially destabilizing. For example, their views may be expressed by either withdrawing from society or practicing rigorous activism. (13) Antinuclear advocates have less confidence in institutional reference groups and feel more strongly attracted to information groups, such as local environmentalists.

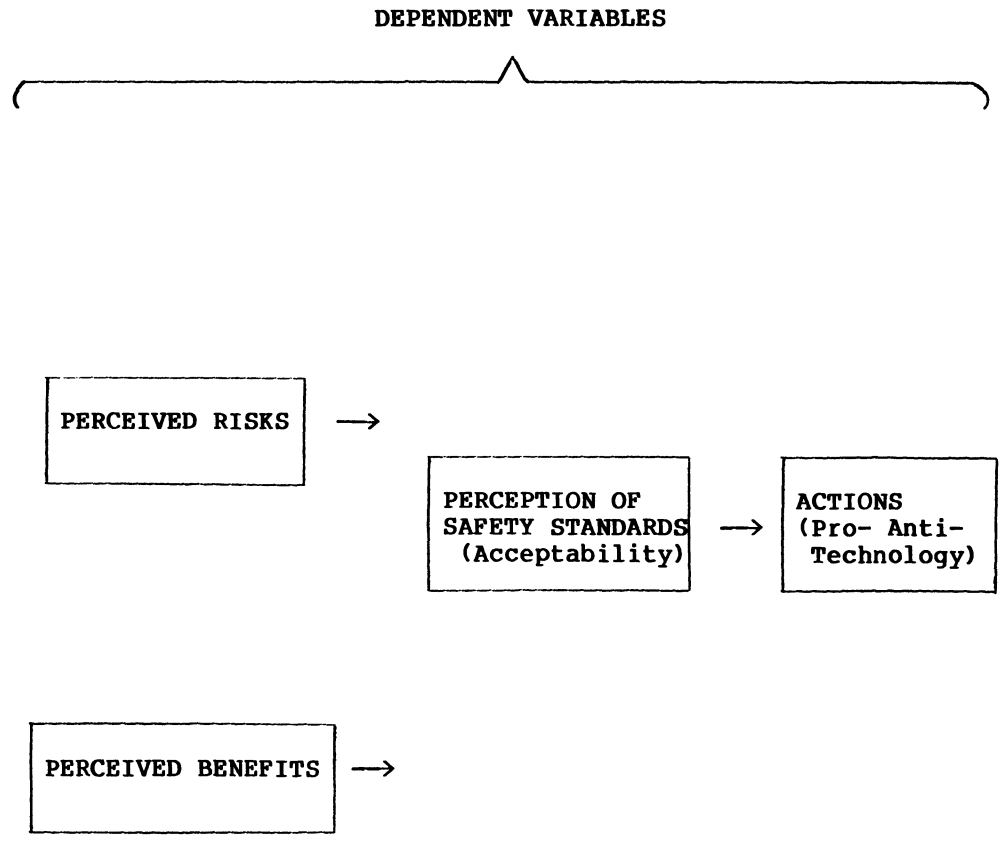

Figure 1. (*continued*)

An Exploratory Model

The theoretical framework, which has guided the selection of propositions and findings from the literature, also provides the impetus for arranging the variables and hypotheses into logical sequence. The theory can be expressed more formally in the statement of an exploratory model, as depicted in the schematic diagram (Figure 1).

The model shows that the variables to be explained are advocate and general population differences in actions and perceptions regarding technology. Differences in these variables are hypothesized to be dependent on the relative explanations provided by all factors appearing to their left, and by each other as specified. All variables relate to the others, both singly and in combination as direct or indirect effects, but always as temporally indicated. Although the direction of the hypothesized relationships (i.e., the sign) is suggested in statements from the literature above, as is the relative weight or strength of each relationship, precise specifications are not indicated in each instance of direction and magnitude.

MODEL DEVELOPMENT, OPERATIONAL DEFINITIONS, AND MEASUREMENT

Although the model is explicit, it is nonetheless a theoretical proposition. Therefore, it is necessary to test the proposed general model against reasonable alternatives to determine the best "fit" to the data for each of the six technologies studied: automobile travel, commercial air travel, nuclear electric power, industrial chemicals, nuclear weapons, and handguns. These technologies or products have been chosen for two reasons. First, they represent a range of technological sectors: energy, transportation, industrial production, and personal and national security. Second, there is the need to study technologies which provide the maximum opportunity for variance in the dependent variables. Since it is hypothesized that the models for each of the six technologies will have very similar patterns, it is expected that a single overall model will emerge that is generally representative of the perception of technology and the propensity to act on this perception.

Each box in Figure 1 refers to major conceptual variables, which, thus far, have been discussed only in the abstract as theoretical constructs. They are converted into operational definitions, as constrained by the survey research design, by way of specific measurement items developed for a face-to-face, personal interview questionnaire. After the heading for each variable, the most relevant of the Action and Technology Perception Hypotheses are given in parentheses. Many of the hypotheses, however, are not cited in this manner because they suggest relations between sets of variables.

To illustrate the manner in which the variables in the model are measured, examples are presented of the specific questionnaire items used to acquire some of them.

Actions

(See all Action Hypotheses and also Technology Hypotheses numbers 2, 11, 12, 13.)

The first observation with regard to measuring personal actions of the general population is that relatively few people become involved in activities of any kind. For this reason, the study's sample design incorporates a specially selected stratum of people who, by definition, have acted to influence a policy decision. The indicators used to measure action are 10 self-reported activities, which range from mild expressions of approval or disapproval to rigorous interventions. All 10 items are repeated six times—separately for each technology—and are

always preceded by a reference to the restrictions or standards that apply to each respective technology. These indicators will be combined into a composite index for each technology. A summary of the items as they appear in the questionnaire is found in Appendix A.

Perceptions of Safety Standards: "Acceptability"

(See Technology Perception Hypotheses numbers 1–11.)

"Acceptability" has been conceptualized and measured variously in past risk perception research. Unfortunately, the earliest work was carried out in the context of professional risk managers' concerns about the public's "misconceptions" of the magnitude of risks from various technologies (Otway, 1980). Since the public sometimes judged "perceived" risks quite differently than "actual" risks, as calculated by scientists and technical experts, it was assumed they must be poorly informed at best, or at worst, base their perceptions on inaccurate information. Hence, the elusive search was begun for the determinants of the perceived "absolute level of acceptable risk." Later, it was recognized that rather than accepting or rejecting risks, people accept or reject technology as a whole. Since risks are not judged in isolation, absolute levels of acceptable risk cannot be meaningfully defined. Most recently, measures have been developed to more closely address the policy issues of technology management.

The indicators used to measure "acceptability," as guided by these theoretical orientations, are summarized as follows: (1) Measures of the "absolute level of acceptable risk." (a) The mean of perceived risk ratings divided by a mean "risk adjustment" estimate (i.e., the number of times safer or riskier a technology can be to be acceptable). (b) Ratings of "acceptability" levels of risk on graphic continua. (2) General measures of the "acceptability" of technology. (a) Semantic differential scales of the overall attitudes toward (energy) technologies. (b) Q-sort based on the rankings of the degree to which the risks outweigh the benefits of technologies. (3) More policy-relevant measures of "acceptable" technology. (a) Summated scales that evaluate current and desired restrictions and standards imposed on technology.

The present study operationalizes "acceptability" of technology in the policy-relevant context of present and desired perceptions of safety restrictions and standards for each technology. These scales of the level of technology regulatory strictness "now" and as it "should be" will be analyzed separately and as a combined indicator, expressed either as a difference or as an index of dissimilarity. These questions are positioned at the beginning of the questionnaire to preclude sensitizing the respondents. The prompt of "not having thought much about the topic" is intentionally emphasized as an acceptable response.

Furthermore, several additional measures were developed to reflect the complexity and idiosyncracies of policy issues associated with each technology studied. Thus, as a supplement to the general questions on regulatory strictness, specific qualitative policy characterizations were devised in the form of alternative policy trade-off options for each technology. Specific examples from the questionnaire appear in Appendix B.

Perceived Risks

(See all Technology Perception Hypotheses, especially numbers 3 and 6.)

Perceived risks are measured directly on a 7-point scale, with instructions to the respondent to think broadly about the risks associated with each technology (Appendix C). Ratings on four qualitative risk characteristics immediately follow the overall risk scale. These items were selected because of their high correlation with overall risk scores and

because they represented separate, identifiable dimensions of risks, as reported in prior research (Slovic et al., 1981).

Perceived Benefits

(See Technology Perception Hypothesis number 5.)

Less is known about the determinants of benefit perceptions than about other variables. The scales in Appendix D are modeled after the risk perception measure. Included are qualitative benefit characteristics, which were selected on the basis of their expected high correlation with overall benefits.

Attitudes

(See Technology Perception Hypotheses numbers 8 and 10.)

Two types of attitudes are measured (Appendix E). First, attitudes toward risk management and other institutions and actors are gauged using a 3-point scale on the confidence in the people running these institutions. Second, general attitudes toward the environment are quantified using the measure adapted from McKechnie's Environmental Response Inventory (1974). The subscales, along with a reference to the items that accompany each, are (1) Pastoralism (C,J,K,M,N,P,Q,U), (2) Urbanism (D,E,G,H,I,L,T,V), and (3) Environmental Adaption (A,B,F,O,R,S,W).

Information

(See Action Hypothesis number 3.)

The extent to which technology-related information is received from four sources of the mass media is assessed (Appendix F). These questions are borrowed from the University of Michigan National Election Study. In addition, respondents are asked to reveal whether they receive information they trust on technology issues directly from friends, relatives, coworkers, and "experts."

Cognitive Orientations

(See Technology Perception Hypothesis number 10.)

The predispositions or cognitive orientations of an individual are significant determinants of behavior for two reasons. They affect what an individual is able or willing to perceive, and, following the perception of an event or a communication, they influence the ways in which the individual stores and eventually retrieves what has been perceived. For the present model this cognitive orientation is among the determinants of (1) the information a person possesses concerning various technologies; (2) the person's attitudes toward those technologies; and (3) the ways in which the technological risks and benefits are perceived.

Within the past decade or so, there have been a number of attempts to relate that orientation, however variously labeled or defined, to other predispositions and especially to behavior (e.g., Fishbein, 1975; Schwartz, 1968). These attempts have one characteristic in common: they obtain a measure of at least three or four predispositions. For present purposes, the conceptualization of Kreitler and Kreitler (1976, 1980; Lobel, 1982) looks especially promising: it concentrates not on a single belief, but upon four beliefs. Its authors have had noteworthy success in predicting overt, objective behavior from those beliefs they have operationalized in terms of the behavior to be predicted. They assign "equal weights to the

four" beliefs because they consider that procedure "methodologically not only the most conservative but also the safest" (1976: 390).

The four beliefs can be categorized as pertaining to the self or pertaininng to the nonself (e.g., persons, society, events). The cognitive definitions of the four subscales are given below. For the sake of comparability, all but three items have been deliberately borrowed from scales currently in use (Appendix G):

A. Beliefs about the self
   1. The nature of the self (D,I,N,O,Q)
   2. The self's goals (B,F,M,R,T)
B. Beliefs about nonself
   1. People, situations, events, etc. (A,E,H,L,S)
   2. Norms, rules, standards, values (C,G,J,K,P)

Salience

(See Action Hypotheses numbers 3 and 4.)

Although salience is not a variable that appears in the diagram of the model (Figure 1), it is an important contextual factor, which distinguishes between an important and an unimportant attitude or opinion. Salience is directly measured with specific reference to the policy trade-off alternatives. For each technology, respondents are asked to report the extent to which the positions they have taken on the issues related to that technology are firm as opposed to volatile. An adaptation of the index developed by Yankelovich, Skelly, and White (Keene and Sackett, 1981) is used. There are four scales, which are combined into a composite index (Appendix H.)

Sociodemographic Characteristics

A wide range of sociodemographic variables is measured. In addition to those included as hypothesized determinants of the dependent and intervening variables, other factors are needed for methodological and descriptive purposes. Standard state-of-the-art questions are asked concerning each of the following characteristics: employment status, socioeconomic status (e.g., a composite of income, occupational prestige, and education), union membership, ethnicity, nativity, political party preference, a self-reported liberal–conservative scale, voting behavior in the last presidential election, religious preference and strength of beliefs, voluntary group memberships, geographical mobility, gender, marital status, number of children, and age.

Sample Design

The models for advocates are hypothesized to be similar to those of the general population, although the strength of the relationships is expected to be greater. Advocates are defined as individuals who have testified either for or against technology-related issues at public hearings. (In the case of the Southwest study region, some of the advocates only attended such hearings.)

Although residents of the two regions of the country studied (Connecticut in the Northeast and the greater Phoenix, Arizona, area from the "sun belt" Southwest) are expected to regard the specific technologies differently (e.g., handguns, nuclear weapons), the hypothesized pattern of relationships should be very similar. That is, technologies perceived as high risk and low benefit by the respondents will result in judgments of lower acceptability,

Table 1. Sample Design by Region

Samples	New England	Southwest	Total
General population[a]			
Completed interviews	542	479	1,021
Response rate	77.3%	62.5%	—
Advocates sampled	150	149	299
Total completed interviews	692	628	1,320

[a] Both general population samples are "full-probability samples."

which, in turn, predisposes a greater likelihood for action. Selection of the two locations for conducting the surveys was based on the premise of maximizing the possibility for differences in attitudes toward technology, while minimizing demographic differences (e.g., urban, rural, suburban; population size).

Table 1 shows the sample design for each region and by type of sample. The general population samples were "full-probability" samples in each region. The Yale Roper Center conducted the interviewing in Connecticut, while the National Opinion Research Center (NORC) completed the field work for area probability sample selection and interviewed respondents in Arizona. The advocate samples were "purposive samples" in both regions; hence, the respondents in these samples were selected for convenience, and cannot be considered as having been chosen with a known probability. The questionnaire took approximately 45 minutes to administer on the average.

RESULTS

As of this writing, the analysis of the data from the New England region has only begun, and the data from the Southwestern region have not yet been evaluated at all.

The following discussion reports the frequencies of various responses of each of the New England samples: general population, environmental advocates, and technology advocates. Specifically, social and demographic characteristics of the three samples studied in the Northeast are summarized (Table 2). In addition, for each of the six technologies studied—automobile travel, commercial air travel, nuclear electric power, handguns, nuclear weapons, and industrial chemicals—the responses of the general population sample, the environmental advocate sample, and the technology sample are examined in relation to various key perceptions. The specific perceptions presented here are magnitude of risk, magnitude of benefit, perception of strictness of current standards and safeguards, desired level of strictness of standards and safeguards, and the frequency of intervenor actions taken by individuals.

Demographic Characteristics

More than half of the respondents in the random sample are females, which is considerably higher than for each of the advocate groups. All samples included in the study are predominantly white. The general population is significantly less educated, has a lower income, and is more often Catholic than the advocates sampled. In addition, members of the general public are less likely to be married, somewhat less committed to either the

Table 2. Social and Demographic Characteristics for Connecticut Samples[a]

Demographic characteristics	General population (n = 542)	Pro-technology advocates (n = 75)	Pro-environmental advocates (n = 75)
Mean age	44.7	49.9	45.8
Gender			
Male	45.2	92.9	64.0
Female	54.8	8.0	36.0
Race			
White	94.4	94.5	100.0
Nonwhite	5.6	5.5	—
Gross family income			
Under $15,000	21.7	—	7.0
$15,000–$29,999	35.9	9.8	22.6
$30,000–$74,999	35.8	71.9	63.4
Over $75,000	6.6	18.3	7.0
Median income[b]	$24,750	$38,600	$33,530
Education			
Mean years of school	13.2	16.4	16.5
High school diploma	81.7	97.3	100.0
College degree	30.8	84.0	80.0
Religious preference			
Protestant	36.9	53.3	42.7
Catholic	43.4	30.7	28.0
Jewish	3.3	4.0	9.3
Other	5.0	2.7	4.0
None	11.3	9.3	16.0
Married	68.0	84.0	81.3
Lived in a different state 5 years ago (1977)	11.6	6.7	4.0
Self-designated liberal/ conservative views			
Liberal	29.8	26.0	50.0
Moderate	35.4	17.8	18.9
Conservative	34.8	56.2	31.1
Political party affiliation			
Democrat	28.7	18.7	38.7
Republican	25.7	50.7	28.0
Independent	38.1	29.3	32.0
No preference/other	7.5	1.3	1.3
Voted in 1980 presidential election	74.5	97.3	97.3

[a] Data in the table are percentages (adjusted for missing values) except where otherwise indicated (e.g., mean).
[b] Median income is approximate since it was interpolated from grouped income categories ordered on a scale from 1 to 18.

Republican or Democratic parties, and voted in relatively fewer numbers in the 1980 presidential election than did the advocates. Finally, the random sample is more highly mobile than the advocates, the former group having moved from another state in the last 5 years about twice as often.

The mean age of the technology advocates was somewhat higher than either of the other groups. Technology advocates also were relatively more likely to be male, Protestant, Republican, and to have a higher gross family income. The environmentalist sample contained nearly twice the proportion of Jews as the other samples; members of this group also were most likely to designate themselves as liberal.

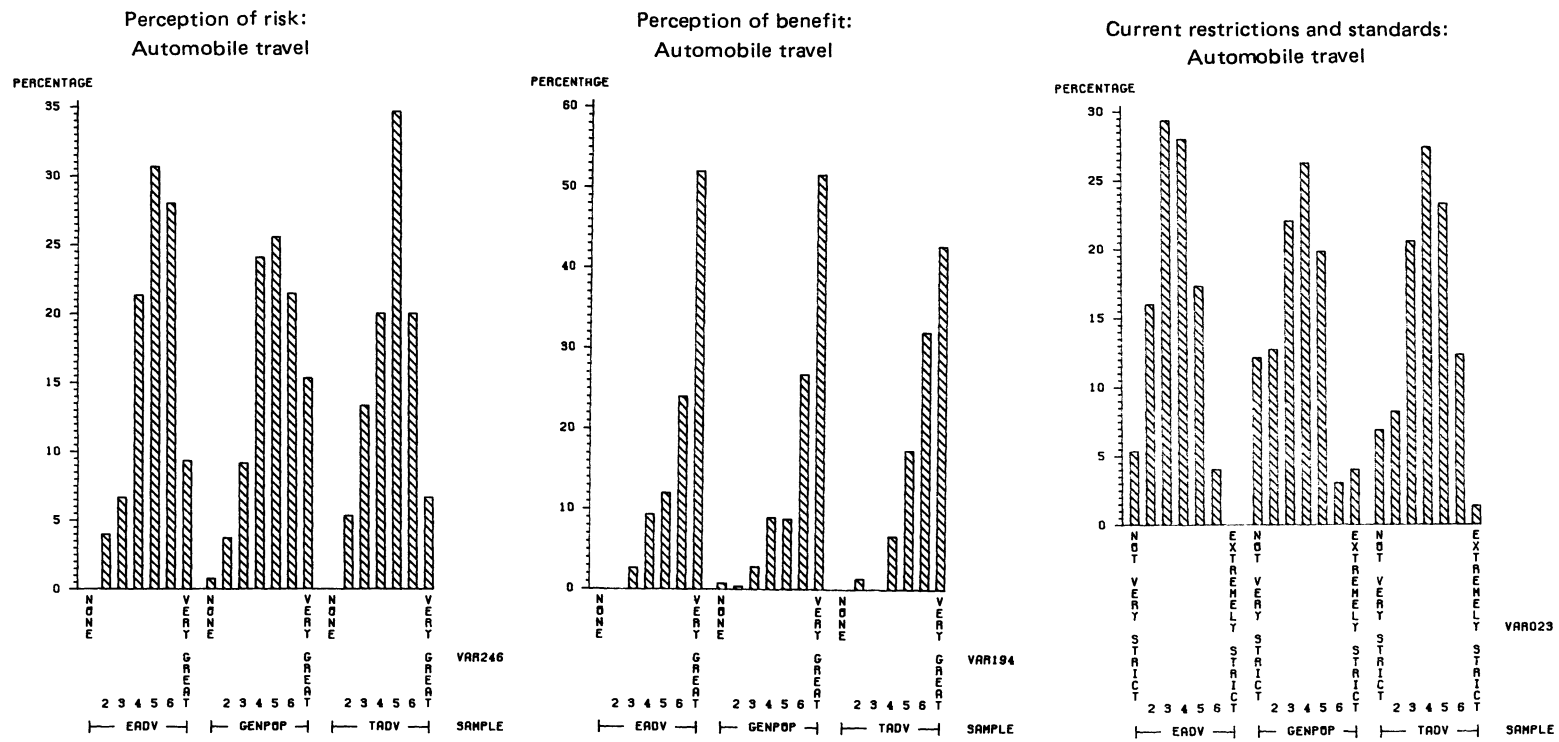

Figure 2a. Frequency distributions of perceptions of risks, benefits, and current restrictions and standards associated with automobile travel, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

Automobile Travel

Risks. The histograms for the perceived risks associated with the safety of automobile travel are fairly normal in shape (Figure 2a). Few of the respondents in the three samples perceive risks to be of very low magnitude (points 1 to 3 on the scale). Most respondents rate the safety of automobile travel as a moderately high risk (scale points 4, 5, and 6).

Benefits. The perception of benefit histograms for automobile travel are fairly uniform across the three samples, the distributions being highly skewed toward the "very great benefits" end of the scale. Most environmental advocates, technology advocates, and general population respondents perceive the benefits of automobile travel to be "very great" with about equal frequency; approximately three-fourths of the respondents from each sample rate the automobile's benefits at the two highest points on the scale. When the data for risks and benefits of automobile travel are compared, it is apparent that the perception of benefits greatly outweighs the magnitude of the perceived risks.

Current Restrictions and Standards. Few respondents in the sampled populations expressed a strong sentiment concerning the current restrictions and standards pertaining to automobile travel. The responses for each sample approximate a normal distribution, with nearly three-fourths of the environmental and technology samples, and just over two-thirds

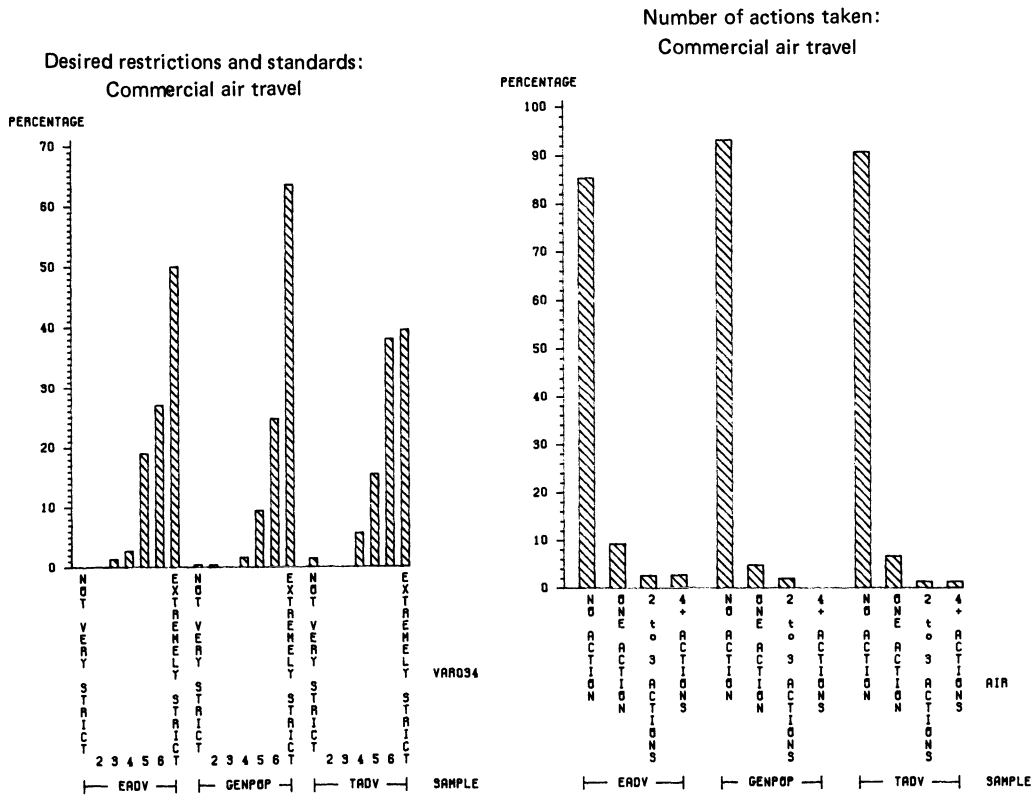

Figure 2b. Frequency distributions of perceptions of desired restrictions and standards and the number of actions taken associated with automobile travel, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

of the general population sample, falling into the middle three categories on the 7-point scale. This intersample consensus with regard to the current rigorous restrictions dealing with automobile travel safety most likely reflects the fact that automobiles are a familiar technology, which has been an integral part of most people's lives for a long time. Hence, safety standards are generally well understood and accepted by all layers of the study populations.

Desired Restrictions and Standards. Although respondents generally seem to feel that the current restrictions and standards imposed on automobile travel fall around the middle of the scale (the mean for all three samples combined is 3.6), the response pattern for the desired restrictions and standards is for even stricter measures (combined mean 5.8) (Figure 2b). This is especially the case for the general population, since more than 40% of these respondents stated a desire for the highest scale point—"extremely strict" restrictions and standards. Of all respondents combined, less than 1% chose the desired restrictions scale point—"not very strict." All samples, therefore, clearly expressed continued support for strict auto safety standards, and perhaps a willingness to increase them. We take these findings as relative indicators, partially reflective of instrumental bias, since the questions asked are without any reference to cost considerations.

Actions. Each of the histograms for actions pertaining to automobile travel is highly skewed, indicating a uniform lack of action within each of the three groups. For each sample, most respondents have taken "no action"; this includes nearly two-thirds of the environmental and technology advocates, and 8 out of 10 from the general population. Overall, only 23% of the composite group have participated in any such actions. Only 12% of the environmental group, 11% of the protechnologists, and less than 2% of the general population have been involved in four or more actions pertaining to the restrictions and standards for automobile travel. Except for commercial air travel, the respondents reported less action for automobile travel than for any other technology examined in this study. However, the automobile is a relatively mature technology, and perhaps less controversial than the other five technologies studied. In addition, the proposed model states that the predisposition for maximum action is increased when a given technology is perceived to be of high risk and low benefit (one of many hypotheses to be tested later); this is not the case for the data reported above on the perceived risks and benefits of automobile travel. Of the few actions taken pertaining to the safety of automobile travel, the most common for each of the three groups was to "write a letter, telephone, or send a telegram to an editor, public official or company."

Commercial Air Travel

Risks. The general population respondents are divided with regard to their perceptions of the risks associated with commercial air travel (Figure 3a). As many persons chose the first three "low risk" scale points (37.5%) as chose the highest three "great risk" scale points (39.7%). The technology advocates, however, are much more likely to perceive air travel to be fairly safe. The environmental advocates cluster at the moderate perceived risk level (three-fourths rated risks at scale points 3, 4, and 5).

Benefits. Commercial air travel is also generally perceived to be quite beneficial. Although the distributions of frequencies is not as skewed as that for electricity, nearly three-quarters of the respondents from the three samples combined chose the two highest benefit

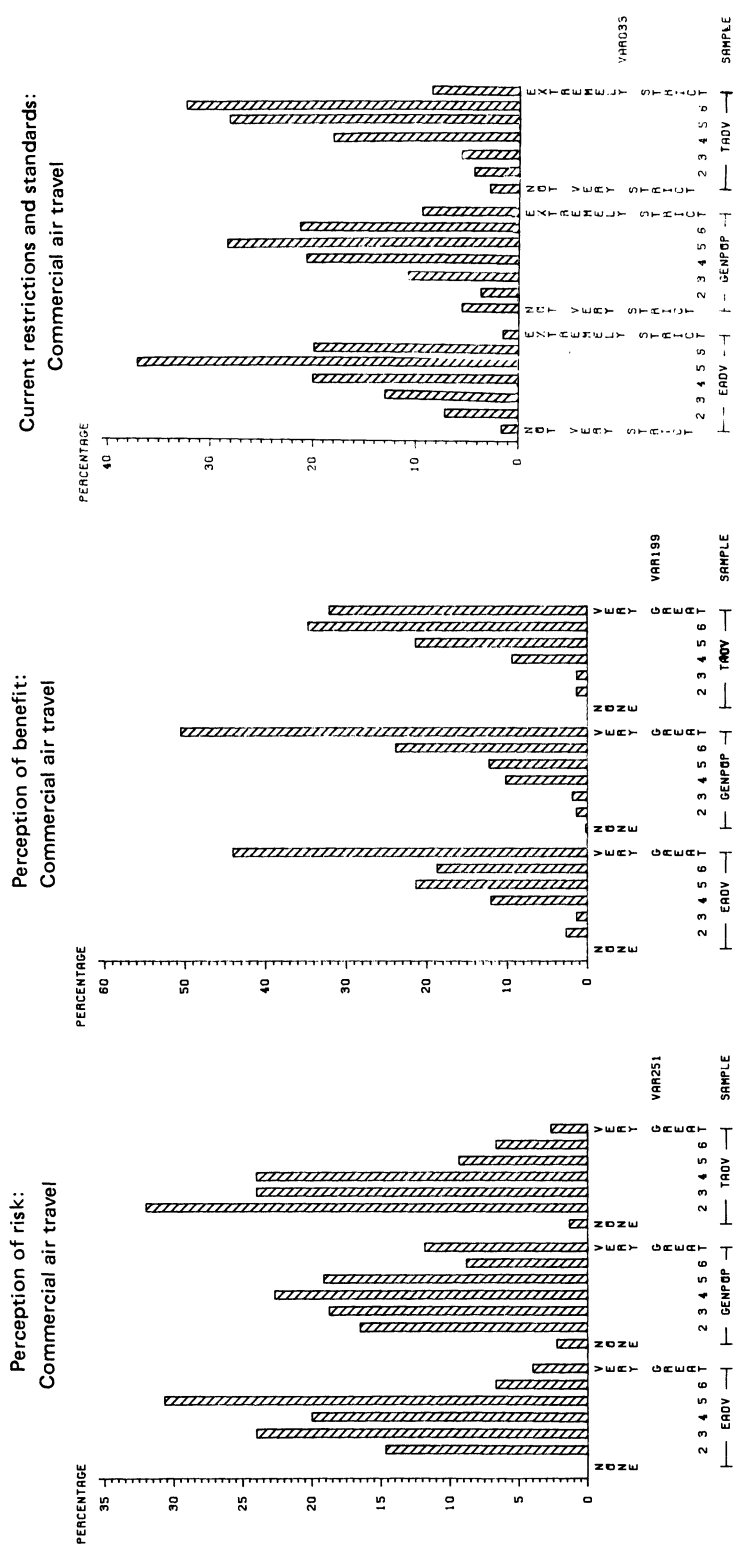

Figure 3a. Frequency distributions of perceptions of risks, benefits, and current restrictions and standards associated with commercial air travel, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

scale points. For commercial air travel, the public was more likely to rate the benefits higher than members of either advocate sample. All three samples generally agreed that air travel was beneficial; relatively few people perceived the risks involved to be particularly great.

Current Restrictions and Standards. The data on current restrictions and standards for commercial air travel form a response pattern which is fairly consistent between samples, although the responses of the teechnology advocates tend to fall somewhat more toward the "strict" end of the scale. Each of the distributions is fairly normal in shape, indicating that, generally, none of the three groups had formed a consensus of strong feelings one way or the other.

Desired Restrictions and Standards. The distributions for desired restrictions and standards on commercial air travel are skewed toward the "extremely strict" end of the scale for each of the three samples (Figure 3b). For the general population sample, which exceeds the environmental advocates in this regard, nearly two-thirds felt that these restrictions should be "extremely strict," while only one-half of the environmental sample and just over one-third of the technology advocates chose this extreme point on the scale. Therefore, as was the case for automobile travel, the respondents seemed to express continued support for existing restrictions and standards on commercial air travel. Moreover, in the absence of discussion about the various economic and social costs associated with increasingly strict regulation and standards, people tend to desire restrictions and standards that are even more strict.

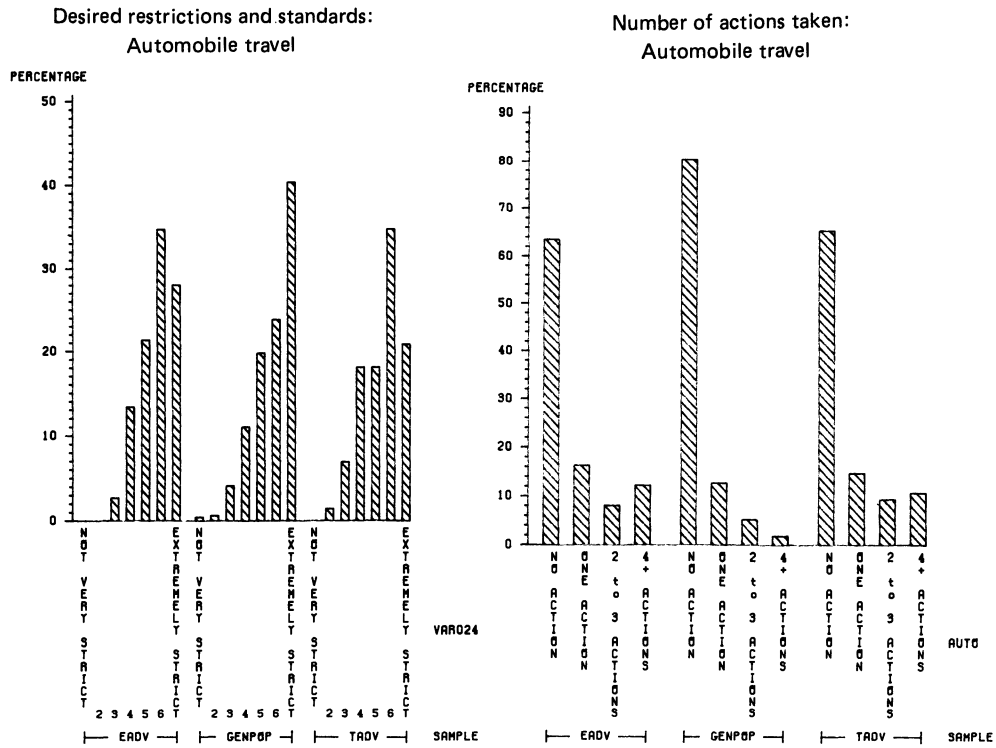

Figure 3b. Frequency distributions of perceptions of desired restrictions and standards and the number of actions taken associated with commercial air travel, as reported by environmental advocates (EADV, left $n=75$), the general population (GENPOP, center, $n=542$), and technology advocates (TADV, right, $n=75$).

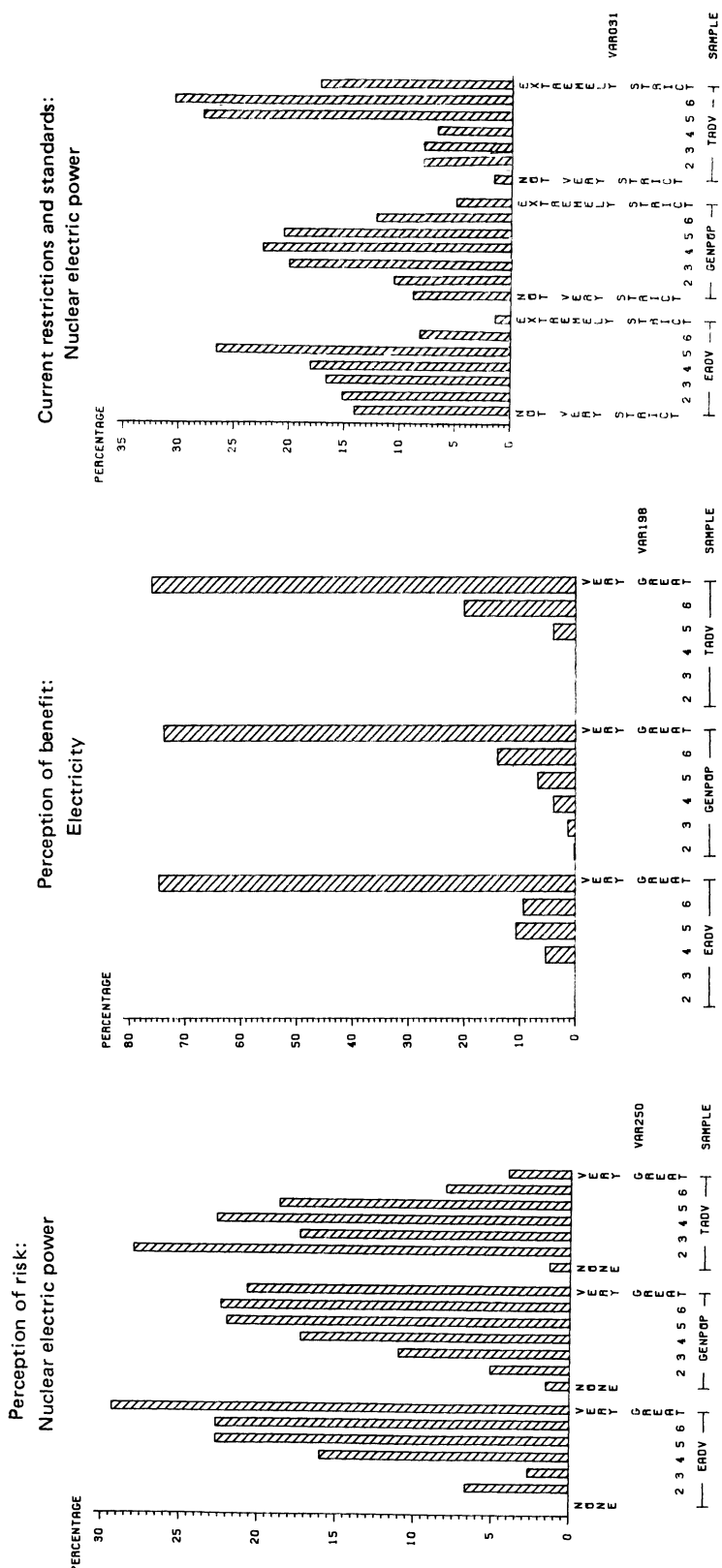

Figure 4a. Frequency distributions of perceptions of risks, benefits, and current restrictions and standards associated with nuclear electric power, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

Actions. For each of the three samples, there have been significantly fewer actions taken involving commercial air travel than any other technology studied. Of the composite group, less than 8% have engaged in the 10 activities measured. This lack of self-reported personal involvement can have a number of explanations, many of which will be analyzed by this study (e.g., the catastrophic nature of airplane accidents, confidence in risk management and other institutions, perceived risk and benefit relationships).

Nuclear Electric Power

Risks. There was some disagreement among the three samples with regard to the magnitude of the risks associated with nuclear electric power (Figure 4a). The frequency distribution for the general population tends to be skewed toward the greatest risk end of the continuum (43% of the respondents rated the risks at the two highest scale points). The histogram for the environmental advocates shows a similar pattern, with even greater relative numbers of these individuals perceiving nuclear electric power as a "very great risk" (52% chose the two highest scale points). The data for the technology sample, on the other hand, are more heavily loaded in the opposite direction—over one-quarter of the technology advocates rated the risks associated with nuclear electric power at the two lowest points on the 7-point scale.

Benefits. The response pattern for the benefits of electricity is clear: virtually everyone agreed that electricity is of high value. In each sample, the distribution of responses is heavily weighted toward the "very great" benefit end of the scale. This finding is perhaps magnified (in comparison to other risk perception studies) by virtue of the fact that the benefits of electricity were rated without reference to the fuel from which it was generated (i.e., the benefits of nuclear electric power). This approach was deliberate so that the benefit of technology could be measured separately from its perceived risks. In Connecticut, approximately two-thirds of the electricity consumed is generated from nuclear power plants.

Current Restrictions and Standards. The technology advocates consistently perceived the current restrictions and standards for nuclear electric power to be quite strict. The response patterns for the other two groups, however, indicate less within-sample agreement. The data from the general population form a normal distribution (i.e., the current standards are generally seen as falling somewhere in the middle of the strictness continuum). The histogram for the environmental advocates, however, shows a much flatter response pattern. The environmentalists do not agree among themselves on the current state of the restrictions and standards for nuclear electric power. The mean response for each sample on this 7-point scale is general population 3.9, environmental advocates 3.6, and technology advocates 5.1.

Desired Restrictions and Standards. There is, however, consensus both within and between samples with regard to the desired restrictions and standards for nuclear electric power. For each of the three groups, each histogram is highly skewed toward the "extremely strict" end of the scale (Figure 4b). The distribution for the general population is almost identical to that of the environmental advocates, while the technology advocates are less likely to fall into the "extremely strict" category. More than two-thirds of the environmentalists and the general population and about one-half of the technology advocates felt that the standards pertaining to nuclear electric power should be "extremely strict." However, the current standards were perceived as being fairly strict already, unlike the situation for handgun regulations.

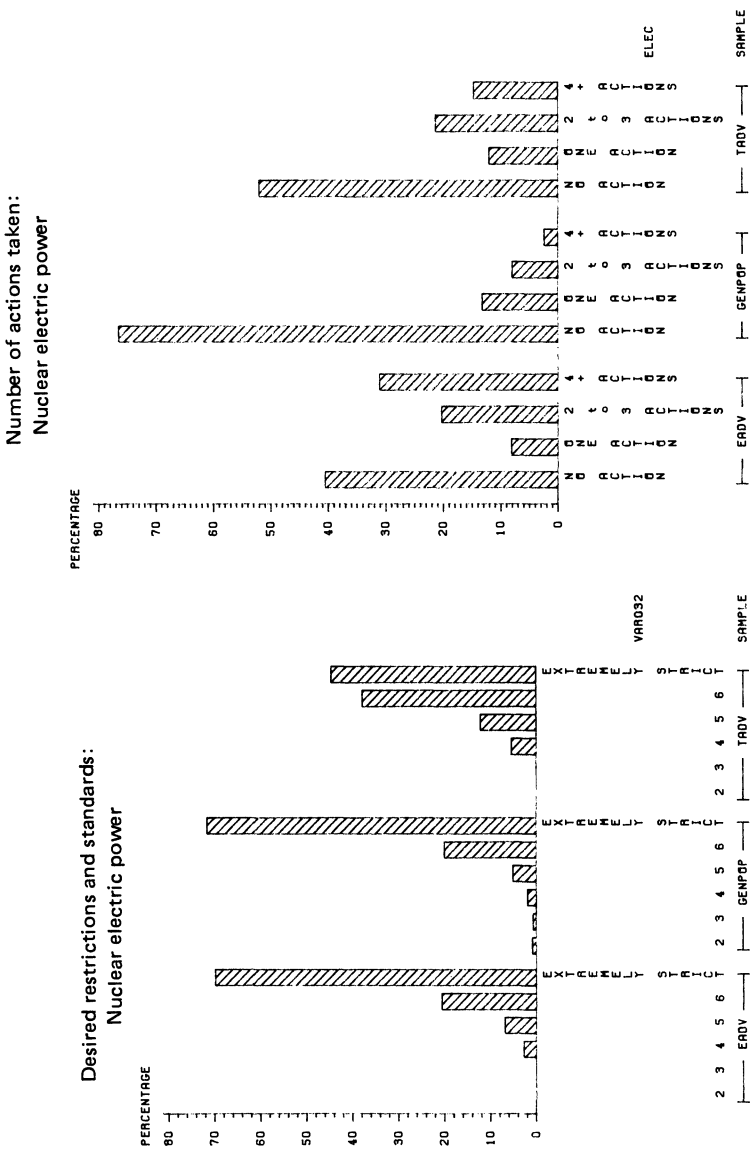

Figure 4b. Frequency distributions of perceptions of desired restrictions and standards and the number of actions taken associated with nuclear electric power, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

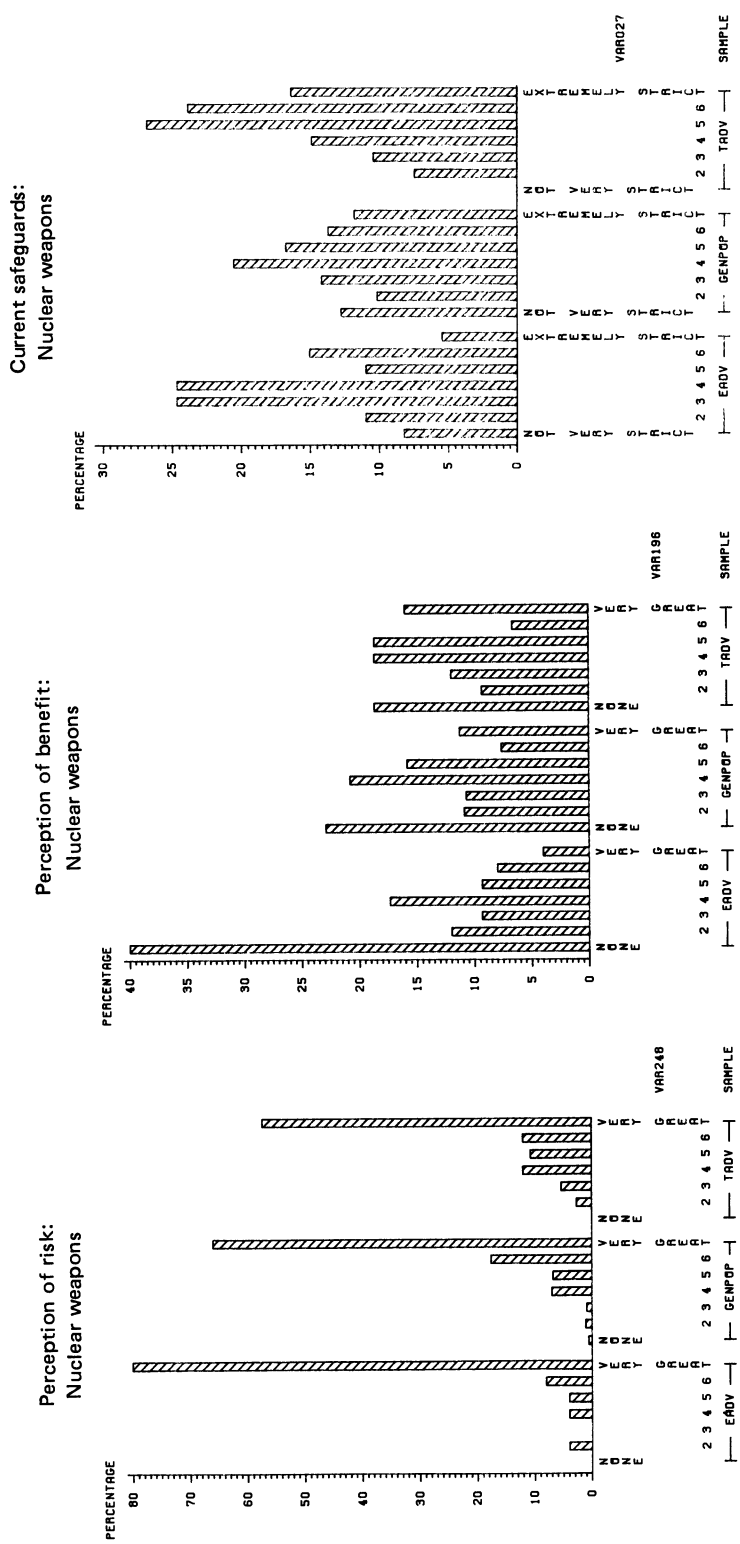

Figure 5a. Frequency distributions of perceptions of risks, benefits, and current safeguards associated with nuclear weapons, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

Actions. The extent to which both of the advocate groups have been personally involved in activities related to nuclear electric power was second only to actions dealing with industrial chemicals. Similarly, a greater proportion of the general population has taken actions on nuclear electric power than any other technology examined in this study, except handguns. Sixty percent of the environmental group, one-fourth of the random sample, and nearly half of the technology advocates have engaged in at least 1 of the 10 actions pertaining to nuclear electric power. Once involved, the environmentalists were also more likely to take more than 1 action with regard to this technology: one-half were involved in 2 or more actions, while one-third reported having participated in more than 3. The comparatively high activity level for members of the environmental group with regard to nuclear electric power is consistent with findings from other studies, and provides the opportunity for more detailed analytical explanation when the various hypotheses of the model are examined.

Nuclear Weapons

Risks. The perception that nuclear weapons involve great risks to society was nearly unanimous, both within and between samples. The histograms for each sample show the same pattern of responses: extremely skewed toward the "very great risks" end of the scale (Figure 5a). Since measures of perceived risks and benefits were made independently, respondents were not asked individually to evaluate the trade-offs of each. In the aggregate, however, the balance between the perceptions of the risks and benefits of nuclear weapons (or lack thereof) should be noted especially for the environmental advocates.

Benefits. There is no true pattern, either across or within samples, with regard to the perceived magnitude of benefits of nuclear weapons. The histogram for the environmentalists has an odd shape: while 40% see absolutely no benefits, the height of the remaining bars forms an irregular pattern. This is also the case for the general population; the "no benefits" scale point contains the highest proportion of respondents (nearly one-quarter) followed by a random distribution over the remaining scale points. There is great disagreement over the value of having nuclear weapons as part of the national defense. Finally, the frequency distribution for the technology advocates is essentially flat—a lack of consensus.

Current Safeguards. The response distributions are not very pronounced for the current safeguards for nuclear weapons: a rather normal distribution for environmental advocates and a somewhat flat pattern for the general population sample. The distribution for the technology advocates, however, is somewhat more skewed toward the "strict" end of the scale. Unlike the other groups, few of the technology sample respondents felt the current safeguards to be on the "not very strict" end of the scale. The greater consensus among the technology sample, as opposed to the more widespread response patterns for the other samples, is further indication that the technology advocates, as a whole, represent the belief that technology can be contained as it provides its intended benefits.

Desired Safeguards. The response distributions for the question about desired safeguards for nuclear weapons are quite consistent both within and between samples (Figure 5b). Eighty-six percent of the environmental advocates, 79% of the general population, and over two-thirds of the technology advocates felt that these safeguards should be "extremely strict." In the absence of thoughtful debate on the meaning of strict safeguards and their associated costs, there was agreement among the three groups that desired safeguards (combined mean 6.7) can be stricter than current safeguards (combined mean 4.2).

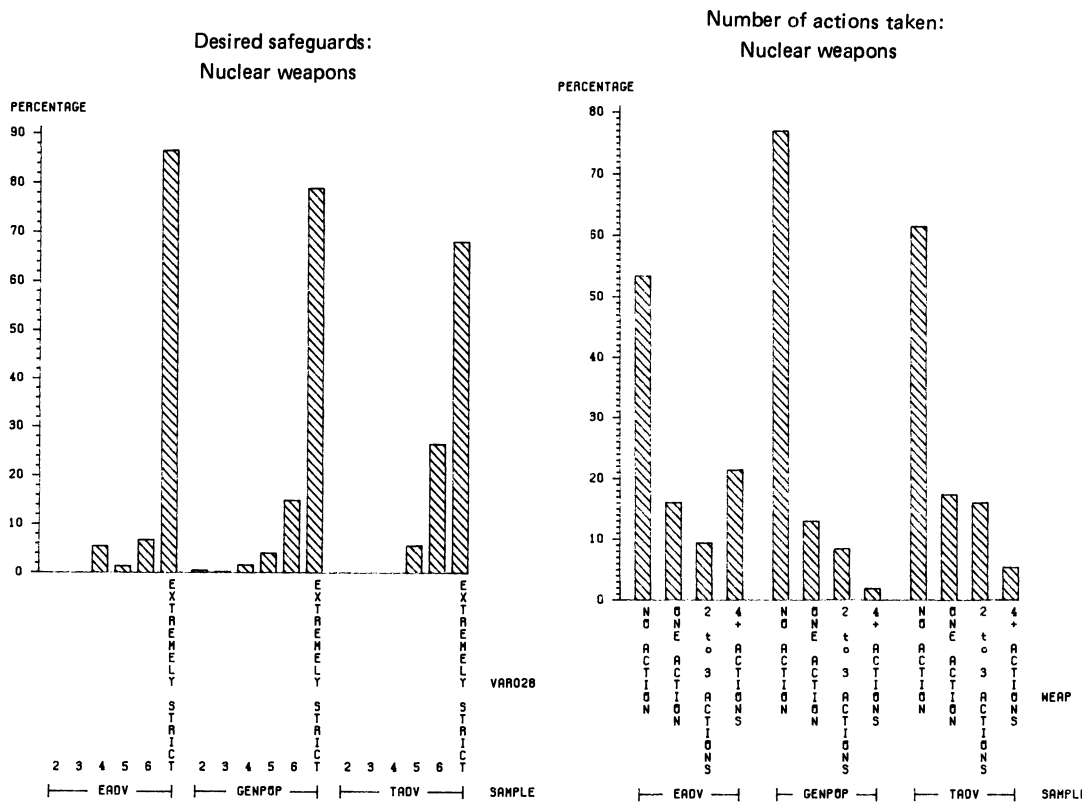

Figure 5b. Frequency distributions of perceptions of desired safeguards and the number of actions taken associated with nuclear weapons, as reported by enviromental advocates (EADV, left, $n=75$), the general population (GENPOP, center, $n=542$), and technology advocates (TADV, right, $n=75$).

Actions. "No action" taken was the most frequent response to questions on personal involvement in nuclear weapons matters: more than one-half of the environmentalists, three-fourths of the general population, and almost two-thirds of the protechnologists had not participated in any of the 10 activities asked about. Nearly one-half of the environmental sample, over one-third of the technology advocates, and about one-quarter of the general population have engaged in at least one action pertaining to the safeguards associated with maintaining nuclear weapons as part of the national defense. The most common activity of the 10 measured for both advocate groups was to "write a letter, telephone, or send a telegram." The general population, on the other hand, was most likely to recall having "voted for or against a candidate for public office, in part, because of his or her position on nuclear weapons." The general population was found to be passive, even in the case of this relatively controversial technology.

Handguns

Risks. Handguns were perceived as posing great risks, although to a lesser extent than nuclear weapons. Responses displayed in the histograms for each sample are highly clustered toward the "very great risks" end of the scale. 40% of the environmental advocates, half of

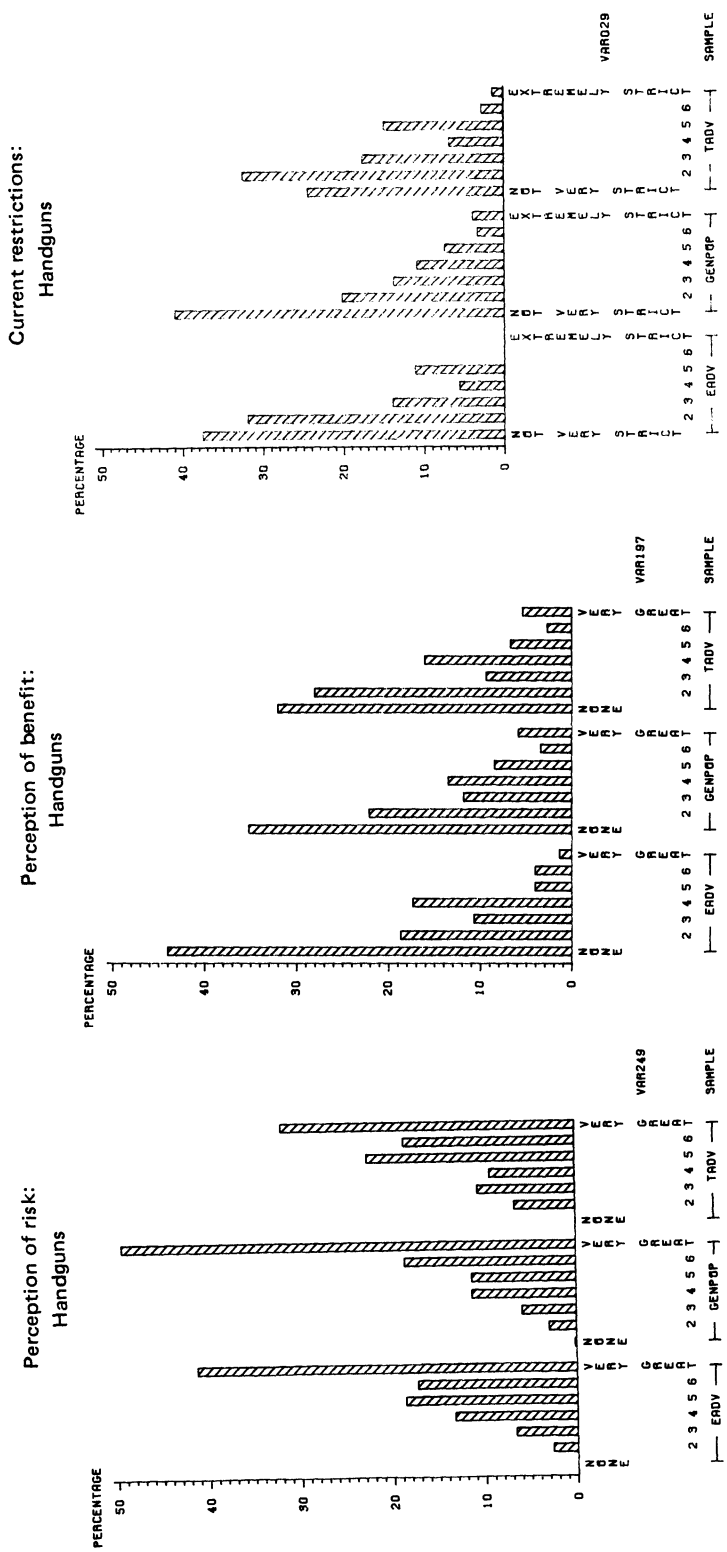

Figure 6a. Frequency distributions of perceptions of risks, benefits, and current restrictions associated with handguns, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

the general population, and one-third of the technology advocates selcted the highest risk point on the scale. Overall, however, members of the general population perceived the risks of handguns to be greater than did either of the advocate samples (Figure 6a).

Benefits. The frequency distributors for the benefits of handuns show a pattern of widespread agreement—virtually no one perceived handguns to be particularly beneficial. Each of the three histograms is highly skewed in the same direction. For each sample, the largest proportion of respondents fall at the "no benefits" scale point (44% of the environmentalists and one-third of both the general population and the technology advocates), while only 5% of the composite group peceived the overall benefits of handguns to be "very great."

Current Restrictions and Standards. There is general agreement among the three samples that *current* restrictions on handguns are "not very strict." However, the pattern for the technology advocate sample is less extreme in this regard than the other two groups; 15% of the former sample placed the current handgun restrictions toward the "extremely strict" end of the scale (points 5, 6, or 7).

Desired Restrictions and Standards. The three histograms pertaining to the desired restrictions on handguns are also consisent between samples in the opposite direction (Figure 6b). These distributions are very skewed toward the "extremely strict" end of the scale for

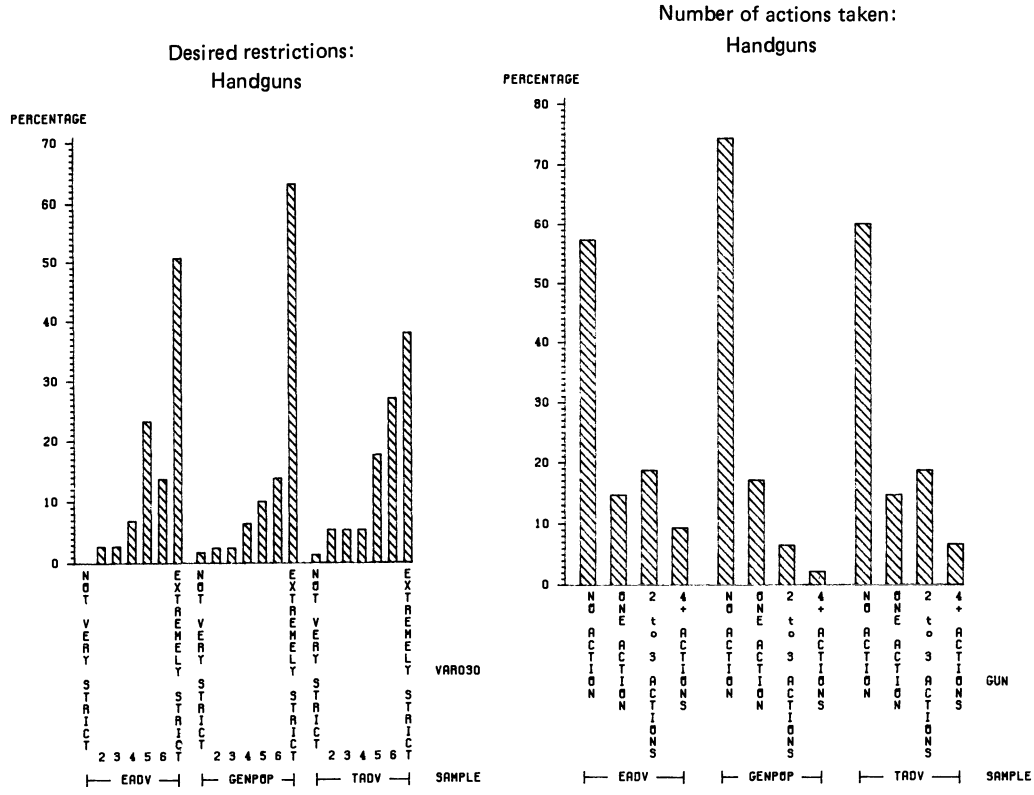

Figure 6b. Frequency distributions of perceptions of desired restrictions and the number of actions taken associated with handguns as reported by environmental advocates (EADV, left, $n=75$), the general population (GENPOP, center, $n=542$), and technology advocates (TADV, right, $n=75$).

each of the three samples. The proportion of general population respondents (nearly two-thirds) who desired "extremely strict" handgun restrictions exceeds the one-half of the environmental advocates who chose that point on the scale. None of the environmentalists and few respondents of the general population (1.7%) or technology advocates (1.4%) desire handgun restrictions which are "not very strict." By contrast, over one-third of the environmental group, 41% of the general population, and one-quarter of the technology sample felt that the current handgun restrictions were "not very strict." Handgun regulation is clearly supported by a large majority of people in Connecticut.

Actions. The general population has been involved in more activity pertaining to handguns than any other technology examined in this study. One-quarter of this group have participated in at least 1 of the 10 actions, as compared with 43% of the environmental advocates and 40% of the technology sample. Both advocate groups have been more active with regard to nuclear electric power and industrial chemicals than handguns; the environmentalists also have been more involved in actions relating to nuclear weapons. When the environmental group participated in actions pertaining to handguns, they were most likely to have written letters, signed petitions, or have their votes influenced. The technology advocates most often signed petitions, and the general population most frequently reported voting for or against a candidate for public office, partly because of his or her position on handguns.

Industrial Chemicals

Risks. Both the environmental advocates and, to a lesser extent, the general population, perceive the overall risks of industrial chemicals to be very great, as evidenced by the highly skewed frequency distributions (Figure 7a). On the other hand, of the three groups, the technology advocates perceive industrial chemicals to be "less risky," with the largest proportion of respondents falling on the middle points of the scale.

Benefits. The technology advocates displayed more agreement regarding perceptions of the benefits of industrial chemicals than did either of the other samples. Two-thirds of the respondents in the technology sample, just over half of the environmentalists, and only one-third of the general population selected one of the two highest benefit scale points.

Current Restrictions and Standards. The responses to the question about the current restrictions and standards on industrial chemicals show considerable differences in perception between samples. While less than one-tenth of the technology advocates chose the minimum point on the scale ("not very strict"), nearly one-third of the general population and over one-quarter of the environmental advocates felt current restrictions and standards were so characterized. Members of the technology sample were much more likely to place current restrictions on the high end of the scale. On the other hand, the highly skewed distributions for the general population and the environmental advocates (toward the "not very strict" end of the scale) indicate perceptions of the current restrictions as being much more lenient.

Desired Restrictions and Standards. The histograms pertaining to the desired restrictions and standards on industrial chemicals are fairly similar for each of the three groups (Figure 7b). For each sample, although to a lesser extent for the technology advocates, the distribution is highly skewed toward the "extremely strict" end of the scale. For each

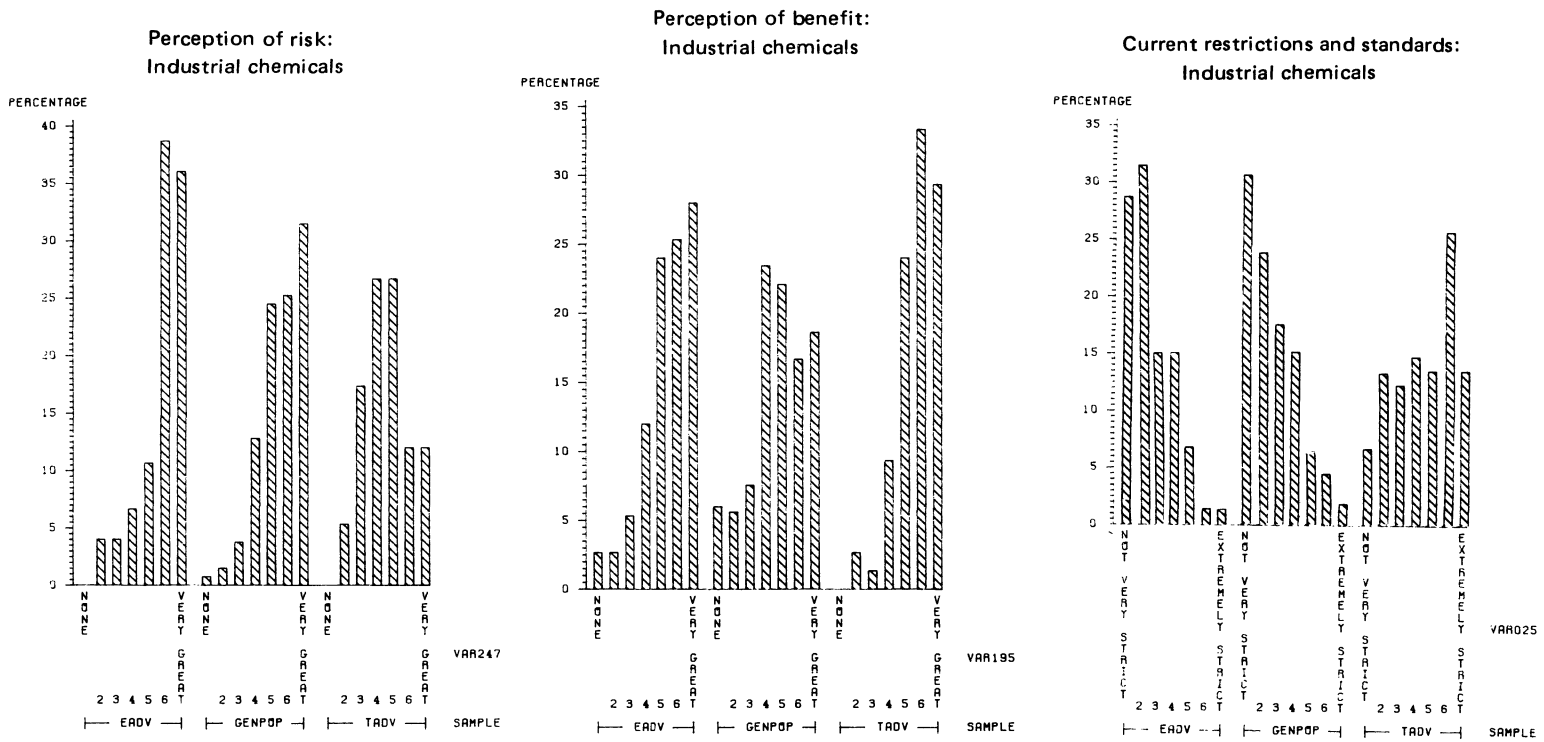

Figure 7a. Frequency distributions of perceptions of risks, benefits, and current restrictions and standards associated with industrial chemicals, as reported by environmental advocates (EADV, left, $n = 75$), the general population (GENPOP, center, $n = 542$), and technology advocates (TADV, right, $n = 75$).

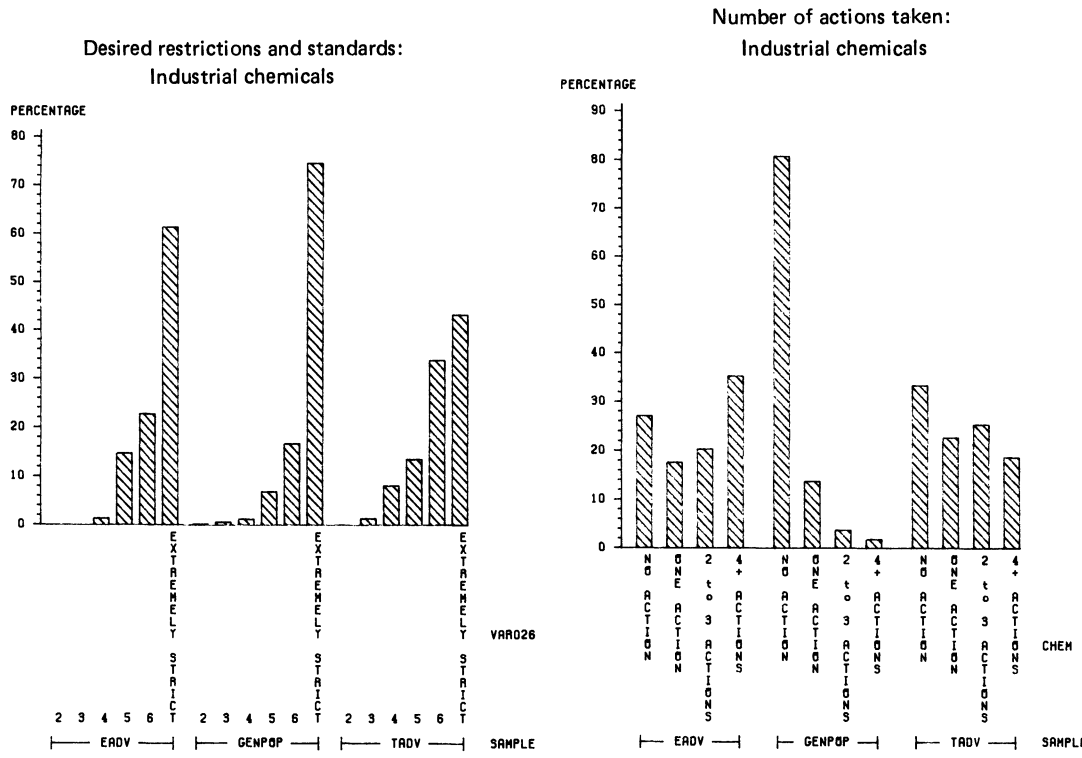

Figure 7b. Frequency distributions of perceptions of desired restrictions and standards and the number of actions taken associated with industrial chemicals, as reported by environmental advocates (EADV, left, $n=75$), the general population (GENPOP, center, $n=542$), and technology advocates (TADV, right, $n=75$).

of the three samples, "extremely strict" was the scale point most frequently selected. Of the three samples combined, virtually no one felt that these standards should be "not very strict." Compared to other groups, the general population as a whole felt the standards on industrial chemicals should be more restrictive: three-quarters of the general population desired restrictions that are "extremely strict," while this was the case for only two-thirds of the environmental advocates. Although more than 40% of the technology sample felt that these restrictions and standards should be "extremely strict," only about 13% perceived this to be currently the case.

Actions. As expected, the most frequent response of all samples across all technologies is "no action." One exception, however, is the environmental advocates with regard to industrial chemicals—the majority of the respondents have been involved in four or more actions to express their views on restrictions and standards for transporting and disposing industrial chemicals. By definition, the general population is consistently more passive than either of the advocate groups with respect to each of the six technologies examined. The environmental advocates, on the other hand, have the lowest proportion of "no action" responses for each of the six technologies.

There is a much larger difference between the general population and the advocates in proclivity for action for industrial chemicals than for any of the other technologies. As compared with less than 20% of the general population, nearly three-fourths of the envi-

ronmental group and two-thirds of the technology advocates were involved in actions pertaining to the safety of industrial chemicals. Both advocate samples were about twice as likely to have taken action on industrial chemicals as compared to automobile travel. The general population, by contrast, was equally likely to have participated in activities involving either technology. Over one-third of the environmental advocates reported having done more than three actions. The action histogram for the technology sample is nearly flat.

CONCLUSIONS

In the absence of completed analyses for either the Northeast or the Southwest, and without the descriptive statistics for the Southwest, it is impossible to draw conclusions at this time on the models and hypotheses presented earlier.

There are, however, some interesting general points to be noted from the data as presented here. It is clear that the purposive samples of advocates were more similar to each other than to the general population—especially with respect to gender, income, and educational level. In several instances members of the general population were quite extreme in their risk perception ratings: their responses sometimes showed risk magnitude estimates that were as high as (or even higher than) those reported by the environmental advocates.

For some technologies there may be a time lag in the perception of current restrictions and standards. For example, the technology advocates generally reported current standards to be more strict than did the general population. Some analysts would argue that the advocates are more knowledgeable about current standards, and that the general public thinks more of the consequences of past standards, which were perhaps less restrictive. Other analysts might argue that the differences are a matter of personal value orientations. The extent to which this reflects differences in values and attitudes, as opposed to differential access to more complete and current information, can be partially determined when the analytical models are examined.

In the aggregate, the relative number and level of actions reported by the general population are clearly lower than those reported by the advocates. Nevertheless, actions of the general population occurred at fairly high levels. Activists were heavily represented in the random sample, and when weighted by the total numbers in the region, it would appear that the total action input provided by individuals who intervened in the technology management process is substantial.

A better understanding of the perceptions underlying this high degree of active participation by the public in risk management decision making would clearly be beneficial to the overall risk management process.

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Appendix A. Questionnaire Items Measuring Personal Actions and Actions in Regard to Specific Technologies

9. Some people do different things to make their feelings known on issues that concern them.

HAND CARD C

Here is a list of actions people have taken in order to express their views.

READ EACH ITEM.

Have you done any of these things to express your views on the restrictions and standards that apply to **the safety of automobile travel?**

Yes 1
No ..... (GO to Q. 10) 2
Don't know or can't remember 8

	YES	NO	DON'T KNOW
A. Written a **letter, telephoned**, or sent a **telegram** to an editor, public official or company.	1	2	8
B. **Signed** a petition.	1	2	8
C. **Circulated** a petition.	1	2	8
D. **Voted** for or against a candidate for public office in part because of his or her position on this issue.	1	2	8
E. Attended a **public hearing** or a meeting of a **special interest organization.**	1	2	8
F. **Spoken** at a public hearing or forum.	1	2	8
G. **Boycotted** a company.	1	2	8
H. **Joined** or **contributed** money to an organization.	1	2	8
I. Attended a **public demonstration.**	1	2	8
J. Participated in a **lawsuit.**	1	2	8
K. Other: Specify: _____			

Also asked for:

10. Have you done any of these things to express your views on the restrictions that apply to **handguns.**

11. Have you done any of these things to express your views on the restrictions and standards that apply to **the safety of nuclear electric power?**

12. Have you done any of these things to express your views on the restrictions and standards that apply to **the safety of commercial air travel?**

13. Have you done any of these things to express your views on the safeguards associated with maintaining **nuclear weapons** as part of our national defense?

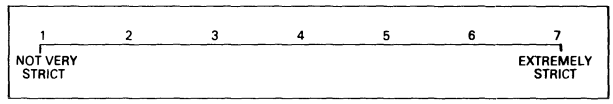
14. Have you done any of these things to express your views on the restrictions and standards that apply to **transporting and disposing of industrial chemicals?**

Appendix B. Questionnaire Items Measuring Perception of Safety Standards

3. Now, I am going to ask you two questions about several technologies or industries. The first asks your opinion about current conditions—as they are **NOW**. The second question asks for your opinion on what the conditions **SHOULD BE**.

   Some people believe that the current restrictions and standards that deal with **the safety of automobile travel** are not very strict—point number 1 on this scale.

HAND CARD B



4. Some people believe that the current restrictions and standards that deal with **transporting and disposing of industrial chemicals** are not very strict—point number 1.

5. Next, think about the safeguards associated with maintaining **nuclear weapons** as a part of our national defense.

6. Next, think about the restrictions that deal with buying, selling, and owning **handguns**.

7. Next, consider the restrictions and standards that deal with the safety of **nuclear electric power**.

8. Finally on this question, think about the restrictions and standards that deal with the **safety of commercial air travel**.

Appendix B. (continued)

30. Do you **favor** further increasing the safety of auto travel through such things as improved auto design and added safety features **or** do you **oppose** such measures because they would be too expensive?

Favor 1
Oppose 2
Not sure 8

---

31. Which **one** of the following positions comes closest to expressing your views on industrial chemicals?

HAND CARD E

READ TWO POSITIONS.

Position (1) Industrial chemicals have contributed so much to our standard of living that we should do all we can to encourage the development and distribution of new industrial chemicals.

Position (2) Industrial chemicals have been such a mixed blessing for our society (country) that we should be much more careful before allowing new industrial chemicals to be developed and distributed.

INDICATE POSITION TAKEN.

Favors Position (1) 1
Favors Position (2) 2
Not sure 8

---

32. Do you **favor** further increasing the safety of commercial air travel through improved airplane design and added safety features at airports **or** do you **oppose** such measures because they would be too expensive?

Favor 1
Oppose 2
Not sure 8

33. I am going to read to you three statements, each of which represents how some people feel about nuclear electric power generation. Please listen carefully and tell me which **one** view you favor the most.

HAND CARD F

READ THE THREE POSITIONS.

Position (1) All currently operating nuclear electric power plants should continue operating, with careful safety monitoring. If more electricity is needed, more nuclear power plants should be built.

Position (2) All currently operating nuclear electric power plants should continue operating, with careful safety monitoring, but **no more** new nuclear power plants should be built until more is known about the safety risks involved. If more electricity is **needed**, some other form of power generation should be used.

Position (3) All nuclear electric power plants should be shut down permanently and no more should be allowed to be built. If more electricity is needed, some other form of power generation should be used.

INDICATE POSITION TAKEN.

Favor Position (1) "continue operating" 1
Favor Position (2) "continued, but no new ones" .. 2
Favor Position (3) "shut down permanently" 3
Not sure 8

(continued)

Appendix B. (continued)

34. Which **one** of the following three positions comes closest to expressing your views on handgun restrictions?

HAND CARD G

READ THREE POSITIONS.

Position (1) The use, sale, and ownership of handguns should be banned.

Position (2) The use, sale, and ownership of handguns should be allowed, but should be restricted by licensing handgun dealers and owners.

Position (3) The use, sale, and ownership of handguns for lawful purposes should not be restricted by government.

INDICATE POSITION TAKEN.

Favors Position (1) "ban" 1
Favors Position (2) "licensing" 2
Favors Position (3) "no restrictions" 3
Not sure 8

---

35. In order to maintain our national defense, which **one** of these three views do you favor most?

HAND CARD H

READ THREE POSITIONS.

Position (1) We should strive to maintain nuclear superiority over the Soviet Union by continuing to manufacture nuclear weapons.

Position (2) We should increase our arsenal of nuclear weapons to achieve equality with the Soviet Union.

Position (3) Our current nuclear arsenal is more than sufficient to deter any potential aggressor; we need manufacture no more nuclear weapons.

INDICATE POSITION TAKEN.

Favors Position (1) 1
Favors Position (2) 2
Favors Position (3) 3
Not sure 8

37. Suppose two friends were having a discussion about how to deal with industrial chemical waste disposal. Both agree that there is the need to regulate the transportation and disposal of industrial chemical wastes and that current dumps should be cleaned up. However, each has a different opinion on paying victims who have been harmed:

HAND CARD J

Person (1): feels the matter of compensating (paying) victims who have been harmed **should be settled on a case by case basis in the courts.** This means the victims would have to sue the company involved. Payment would result if the court found the company responsible for the harm.

Person (2): feels the compensating (paying) of victims who have been harmed **should be regulated and paid for by the government.** This means the victims would file a claim with a government agency which, on finding harm done, could award payment from a fund contributed to by all the companies in the business. No single company would have to be proven responsible.

With which person do you most agree?

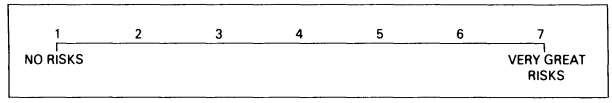
Person (1) ..... "courts" 1
Person (2) ..... "government fund" 2
Don't know 8

Appendix C. Questionnaire Items Measuring Perception of Risks Associated with Technologies

46. All activities involve some risks. Accidents can occur no matter what measures are taken to avoid them. Think about the hazards and risks related to industries and their products: for example, risks of illness, injury or death to those who use the products, as well as those who make them; air, water, land pollution or other environmental damage; community disorder; national disaster. Consider **only** risks, not benefits. Think of hazards or risks to you and your family, as well as risks to the rest of the people in the country.

HAND CARD V

A. Here is a scale, where "1" means **no risks overall** and "7" means **very great risks overall**. How would you rate each industry or product?



B. The risks of some industries and their products are **well** known and understood by scientists and technical people. The risks of other industries and products are **not** well known and understood by scientists and technical people. How would you rate each industry or product on this scale?

C. One of the risks of industries and their products is the risk of death. On this scale where "1" means **few** and "7" means **many**, how many deaths are likely to occur in this country in the next year, as a result of each of the following?

D. The risks of death from some industries and their products affect people only one at a time. The risks of death from other industries and their products can affect large numbers of people in a single event. How would you rate the risk of death from each industry or product on this scale?

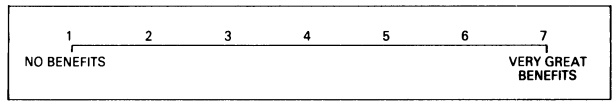
E. Some industries and their products produce risks that people have learned to live with and can think about reasonably calmly. Other industries and products produce risks for which people have very great dread. How do you feel about each industry or product on this scale?

Appendix D. Questionnaire Items Measuring Perceptions of Benefits from Technology

44. Next, I would like you to think about the benefits people get from some industries and their products. One way to think about these benefits is to imagine what it would be like if the products, or services these technologies provide, were not easily available, or even did not exist at all. When making your ratings think **only** of benefits; we will deal with hazards or risks later. Think of benefits to you and your family, as well as benefits to the rest of the people of the country.

HAND CARD P

A. Using a scale, where "1" means **no benefits** and "7" means **very great benefits**, how would you rate the **overall** benefits for each of the following:



B. Now consider just the **economic** benefits, such as, jobs, income, and increased productivity for each of the following.

C. Next consider benefits related to **basic human needs**, such as, health, food, shelter, and clothing.

D. Now think about **safety** and **security** benefits, such as protection from enemies, criminals, fire, natural hazards, insect and animal pests, and so on.

E. Now think about your **personal pleasure** or **satisfaction**. On this scale "1" means **no personal pleasure or satisfaction** and "7" means **very great personal pleasure or satisfaction**. Where would you place yourself on this scale for each of the following?

Appendix E. Questionnaire Items Measuring Attitudes toward Risk Management, Other Institutions and Actors, and the Environment

2. I am going to name some institutions in this country. As far as the **people running** these institutions are concerned, would you say you have a great deal of confidence, only some confidence, or hardly any confidence at all in them?

READ EACH ITEM. CODE ONE FOR EACH. REPEAT THE QUESTION, OR CATEGORIES, IF NECESSARY.

HAND CARD A

	A great deal of confidence	Only some confidence	Hardly any confidence at all	Don't know
A. Organized religion	1	2	3	8
B. Education	1	2	3	8
C. Medicine	1	2	3	8
D. The Press	1	2	3	8
E. TV	1	2	3	8
F. Organized labor	1	2	3	8
G. Major companies	1	2	3	8
H. Banks and financial institutions	1	2	3	8
I. Executive branch of the federal government	1	2	3	8
J. U.S. Supreme Court	1	2	3	8
K. Congress	1	2	3	8
L. U.S. Environmental Protection Agency	1	2	3	8
M. U.S. Consumer Product Safety Commission	1	2	3	8
N. Military	1	2	3	8
O. Scientific community	1	2	3	8
P. Consumer interest groups	1	2	3	8
Q. Environmental groups	1	2	3	8

(*continued*)

Appendix E. (continued)

45. The next section is designed to help us understand your attitudes toward the environment. It contains a series of statements on various subjects. As I read each statement, tell me how much you agree or disagree with it. Again, there are no right or wrong answers. Try to answer each question, even if you must guess, using one of the five categories on this card.

READ EACH ITEM. CODE ONE FOR EACH. REPEAT QUESTIONS OR CATEGORIES, IF NECESSARY.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
A. I like amusement parks.	5	4	3	2	1	8
B. Machines increase people's freedom.	5	4	3	2	1	8
C. The idea of walking into the forest and "living off the land" for a week appeals to me.	5	4	3	2	1	8
D. Life in the city is more interesting than life on a farm.	5	4	3	2	1	8
E. It is exciting to go shopping in a large city.	5	4	3	2	1	8
F. When buying clothes, I usually look more for comfort than for style.	5	4	3	2	1	8
G. Suburbs should replace the city as the center of cultural life.	5	4	3	2	1	8
H. Cities are too noisy and crowded for me.	5	4	3	2	1	8
I. I often feel uneasy in a large crowd of people.	5	4	3	2	1	8
J. I can identify many of the local flowers and trees.	5	4	3	2	1	8

Appendix E. (continued)

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
K. Our **national forests** should be preserved in their natural state, with roads and buildings prohibited.	5	4	3	2	1	8
L. Small town life is too boring for me.	5	4	3	2	1	8
M. I enjoy a change in the weather, even when it turns bad.	5	4	3	2	1	8
N. Hiking is boring.	5	4	3	2	1	8
O. Jet air travel is one of the great advances of our society.	5	4	3	2	1	8
P. The wilderness is cruel and harsh.	5	4	3	2	1	8
Q. I often wish for the seclusion of a weekend retreat.	5	4	3	2	1	8
R. Modern communities are plastic and ugly.	5	4	3	2	1	8
S. Science does as much harm as good.	5	4	3	2	1	8
T. The cultural life of a big city is very important to me.	5	4	3	2	1	8
U. It's fun to walk in the rain even if you get wet.	5	4	3	2	1	8
V. Mental problems are more common in the city than in the country.	5	4	3	2	1	8
W. Given enough time, science will solve most human problems.	5	4	3	2	1	8

Appendix F. Questionnaire Items Regarding Receipt of Information about Technology

24. In general, which of the following do you rely on **most** for information you trust on public issues such as the topics we have been discussing—television, newspapers, books and magazines, or radio?

Television 1
Newspapers 2
Books and magazines 3
Radio 4
None 5
Don't Know 8

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25. How often do you watch television news or documentary programs—every evening, 3 or 4 times a week, once or twice a week, or less often?

Every evening ..... (Ask A) 1
Three or four times a week ..... (Ask A) 2
Once or twice a week ..... (Ask A) 3
Less often ..... (Ask A) 4
Never (VOLUNTEERED ONLY) ... (Go to Q. 26) .. 5
Don't know 8

ASK ONLY IF WATCH TV NEWS OR DOCUMENTARIES

A. When you watch TV news and documentary shows do you pay a **great deal of attention** to issues such as the ones on technology we have been discussing; do you **pay some attention**; or **don't you pay much attention** to these issues?

Don't pay much attention 1
Pay some attention 2
Pay a great deal of attention 3
Don't know 8

Also asked for:

1. Magazines that report on issues dealing with technology.
2. Daily newspapers.
3. Radio news and public information programs dealing with technology issues.

29. In general, do you rely much on each of the following to provide information you trust on issues related to technology, industry, or products? (Answer Yes or No).

READ EACH ITEM.

	YES	NO	DON'T KNOW
A. Family members	1	2	8
B. Friends or neighbors	1	2	8
C. Co-workers	1	2	8
D. Talks with experts	1	2	8

Appendix G. Questionnaire Items on Beliefs about Self and Nonself

43. Now I am going to read you a series of statements that will help us understand how you feel about a number of things. For each, please tell me how much you agree or disagree with it. There are no right or wrong answers. Try to answer each question, even if you must guess how you feel, using one of the five categories on this card.

HAND CARD O

READ EACH ITEM. CODE ONE FOR EACH. REPEAT QUESTIONS OR CATEGORIES, IF NECESSARY.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
A. People should budget their personal expenses and then always live within their budgets.	5	4	3	2	1	8
B. Life is too short; I shall never be able to do everything I would like to.	5	4	3	2	1	8
C. It is great to be living in these exciting times.	5	4	3	2	1	8
D. I think I worry too much.	5	4	3	2	1	8
E. People should be self-controlled and self-disciplined.	5	4	3	2	1	8
F. The less one owns, the fewer troubles one has.	5	4	3	2	1	8
G. Success is more dependent on luck than on ability.	5	4	3	2	1	8
H. Most people can be trusted.	5	4	3	2	1	8
I. In general, I like to take risks.	5	4	3	2	1	8

(*continued*)

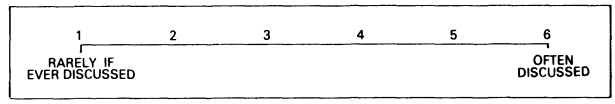
Appendix G. (continued)

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree	Don't Know
J. Feelings are just as important for decisions as figures and facts.	5	4	3	2	1	8
K. The government should pay for promising projects which, however, may possibly fail.	5	4	3	2	1	8
L. It is better to have life go along smoothly than to be surprised, even when the surprises are pleasant.	5	4	3	2	1	8
M. It is more important to have a rich emotional life than success in life.	5	4	3	2	1	8
N. I am like those people who enjoy hang-gliding, mountain climbing, downhill skiing, or some other exciting and risky sport.	5	4	3	2	1	8
O. I like to bet on long shots.	5	4	3	2	1	8
P. Usually reason is a better guide to action than feelings.	5	4	3	2	1	8
Q. Sometimes I feel I don't have enough control over the direction my life is taking.	5	4	3	2	1	8
R. I hope for new experiences almost every day.	5	4	3	2	1	8
S. People should strive to attain their important goals even when uncertain of success.	5	4	3	2	1	8
T. It is important for me to have an exciting life.	5	4	3	2	1	8

Appendix H. Questionnaire Items on the Importance of Policy Alternatives

39. On a scale of 1 to 6, where "1" means that you and your friends and family **rarely, if ever,** discuss the following issues and "6" means that you and your friends and family discuss it relatively **often**, where would you place yourself?

HAND CARD K



40. On a scale of 1 to 6, where "1" means you could change your mind **very easily** on the following issues, and "6" means that you are likely to **stick with your position** no matter what, where would you place yourself?

41. On a scale of 1 to 6, where "1" means that the following issues affect you personally **very little** and "6" means that you really feel **deeply involved** in these issues, where would you place yourself?

42. On a scale of 1 to 6, where "1" means that you feel you **definitely need** more information on the following issues and "6" means that you **do not** feel you need to have any more information on them, where would you place yourself?

REFERENCES

Analysis Manual. 1982. Research Project on "Public Perceptions of Technological Risks: A Methodological Study," New Haven, Connecticut: The Roper Center, Yale University, unpublished manuscript.

Bachrach, Peter and Morton S. Baratz. 1970. *Power and Poverty*. Oxford: Oxford University Press.

Baram , Michael S. 1982. *Alternatives to Regulation*. Lexington, Massachusetts: Lexington Books.

Bonjean, Charles M., Terry N. Clark, and Robert L. Lineberry, eds. 1971. *Community Politics*. New York: The Free Press.

Buss, David M. and Kenneth H. Craik. 1982. "Contemporary Worldviews: Personal and Policy Implications," Berkeley, California: University of California, unpublished manuscript.

Buss, David M., Kenneth H. Craik, and Karl M. Dake. 1982. "Perceptions of Technological Risks and Their Management," Berkeley, California: University of California, unpublished manuscript. Paper presented at Symposium on Environmental Health and People at Risk, 20th International Congress of Applied Psychology, Edinburgh.

Cox, Fred M., John L. Erlich, Jack Rothman, and John E. Tropman, eds. 1974. *Strategies of Community Organization,* second edition. Itasca, Illinois: F.E. Peacock Publishers, Inc.

Douglas, Mary and Aaron Wildavsky. 1982. *Risk and Culture*. Berkeley, California: University of California Press.

Farhar, Barbara, Patricia Weis, Charles Unseld, and Barbara Burns. 1979. "Public Opinion about Energy: A Literature Review," Golden, Colorado: Solar Energy Research Institute Report No. SERI/TR-53-155.

Finsterbusch, Kurt and C. P. Wolf, eds. 1981. *Methodology of Social Impact Assessment,* second edition. Stroudsburg, Pennsylvania: Hutchinson Ross Publishing Co.

Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, and B. Combs. 1978. "How Safe is Safe Enough? A Psychometric Study of Attitudes Towards Technological Risks and Benefits," *Policy Sciences,* 8: 127–152.

Fischhoff, B., S. Lichtenstein, P. Slovic, S. Derby, and R. Keeney. 1981. *Acceptable Risk*. New York: Cambridge University Press.

Fishbein, M. 1975. *Belief, Attitude, Intention, and Behavior*. Reading: Addison-Wesley.

Fishbein, M. and I. Ajzen. 1974. "Attitudes Toward Objects as Predictors of Single and Multiple Behavioral Criteria," *Psychological Review,* 81: 59–74.

Gamson, William A. 1968. *Power and Discontent*. Homewood, Illinois: The Dorsey Press.

Gardner, G., A. Tiemann, L. Gould, D. DeLuca, L. Doob, and J. Stolwijk. 1982. "Risk and Benefit Perceptions, Acceptability Judgments, and Self-Reported Actions Toward Nuclear Power," *Journal of Social Psychology,* 116: 179–197.

Green, C. 1980. "Not Quite Dr. Strangelove." Paper presented at the Conference on Energy and Planning, Craigie College, Ayr, May 27–29.

Hohenemser, Christoph and Jeanne Kasperson, eds. 1982. *Risk in the Technological Society*. Boulder, Colorado: Westview Press, Inc.

Humphrey, Craig R. and Frederick H. Buttel. 1982. *Environment, Energy, and Society*. Belmont, California: Wadsworth Publishing Co.

Kahneman, E. and A. Tversky. 1979. "Prospect Theory: An Analysis of Decisions Under Risk," *Econometrica,* 47: 262–291.

Kahneman, E., P. Slovic, and A. Tversky, eds. 1982. *Judgment Under Uncertainty: Heuristics and Biases*. New York: Cambridge University Press.

Kates, R. W. and Christoph Hohenemser, eds. 1981. *Technological Hazard Management*. Cambridge, Massachusetts: Oelgeschlager, Gunn, and Hain.

Keene, Karlyn H. and Victoria A. Sackett. 1981. "An Editors' Report on the Yankelovich, Skelly and White Mushiness Index," *Public Opinion* (April/May).

Kreitler, Hans and Shulamith Kreitler. 1976. *Cognitive Orientation and Behavior*. New York: Springer.

Kreitler, Hans and Shulamith Kreitler. 1980. "The Theory of Cognitive Orientation: Widening the Scope of Behavior Prediction." Tel Aviv, Israel: Tel Aviv University, unpublished manuscript.

Lenski, Gerhard E. 1966. *Power and Privilege*. New York: McGraw-Hill.

Lobel, T. E. 1982. "The Prediction of Behavior from Different Types of Beliefs," *Journal of Social Psychology,* 118: 213–223.

McKechnie, George E. 1974. *Environmental Response Inventory Manual*. Palo Alto, California: Consulting Psychologists Press.

Melber, Barbara D., Stanley M. Nealey, Joy Hammersla, and William L. Rankin. 1977. "Nuclear Power and the Public: Analysis of Collected Survey Research," Seattle, Washington: Battell Memorial Institute, Human Affairs Research Center.

Nelkin, D. 1979. *Controversy: Politics of Technical Decisions*. Beverly Hills: Sage Publications.

Otway, H. 1980. "Perspective on Risk Perception: Confessions of a Disillusioned Analyst." Paper submitted to the Oregon Risk Perception Conference, Eugene, Oregon, December 11–13.

Otway, H. and J. Cohen. 1975. "Revealed Preferences: Comments on the Starr Benefit–Risk Relationships." Research Memorandum 75-5. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Otway, H. and M. Fishbein. 1977. "Public Attitudes and Decision Making." Research Memorandum 77–54. Laxenburg, Austria: International Institute of Applied Systems Analysis.

Renn, O. 1981. *Man, Technology and Risk: A Study on Intuitive Risk Assessment and Attitudes Toward Nuclear Energy*. Julich, Germany: Kernforschungsanlage Julich GmbH.

Schuman, H. and M. Johnson. 1976. "Attitudes and Behavior," *Annual Review of Sociology*, 2: 161–207.

Schwartz, S. H. 1968. "Words, Deeds, and the Perception of Consequences and Responsibility in Action Situations," *Journal of Personality and Social Psychology*, 10: 232–242.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1977. "Behavioral Decision Theory," *Annual Review of Psychology*, 28: 1–39.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1979. "Rating the Risks," *Environment*, 21: 14ff.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1980. "Facts and Fears: Understanding Perceived Risk." In R. Schwing and W. Albers, Jr., eds., *Societal Risk Assessment: How Safe is Safe Enough?* New York: Plenum Press.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1981. "Characterizing Perceived Risk." In R.W. Kates and C. Hohenemser, eds., *Technological Hazard Management*. Cambridge, Massachusetts: Oelgeshlager, Gunn, and Hain.

Slovic, P., B. Fischhoff, and S. Lichtenstein. 1982. "Regulation of Risk: A Psychological Perspective." Paper submitted to the conference on Social Science and Regulatory Policy, Reston, Virginia, January 22–23; also: Decision Research Report 82-11. Decision Research, Eugene, Oregon.

Starr, C. 1969. "Social Benefit Versus Technological Risk," *Science*, 165: 1232–1238.

Starr, C. and C. Whipple. 1980. "Risks of Risk Decisions," *Science*, 208: 1114–1119.

Stolwijk, Jan, Donald R. DeLuca, Leroy C. Gould, Leonard W. Doob, Gerald T. Gardner, and Adrian Tiemann. 1981. "Final Report to Northeast Utilities," New Haven, Connecticut, Yale University.

Vlek, C., and P. Stallen. 1979. "Persoonlijke Beoordeling van Risico's," University of Groningen, Institute for Experimental Psychology.

Weigel, R., and L. Newman. 1976. "Increasing Attitude-Behavior Correspondence by Broadening the Scope of the Behavioral Measure," *Journal of Personality and Social Psychology*, 33: 793–802.

Zetterberg, Hans L. 1980. "The Swedish Public and Nuclear Energy: The Referendum 1980," Stockholm, Sweden, unpublished manuscript. Madrid, Spain.

3

Public Disputes about Risky Technologies

Stakeholders and Arenas

Ward Edwards and Detlof von Winterfeldt

INTRODUCTION

On their way to social acceptance, many technologies experience periods of public concern, controversy, and social opposition. Sometimes these responses to technologies are short episodes, motivated by naive fears or esoteric values of a small segment of the public. As in the case of religious opposition to the implementation of lightning rods (see Mazur, 1981), these episodes may be little more than amusing footnotes in the history of an ultimately successful technology. In other cases, the public responses may swell to a strong social movement against the technology, leading to its disruption, halting, or eventual abandonment. Water fluoridation, nuclear power, and the SST are recent examples of technologies suffering this fate (see Lawless, 1977; Mazur, 1981; Nelkin, 1978).

The reasons for social opposition to technologies have usually been complex, including worries about employment and livelihood, moral and religious objections, as well as concerns with industrial growth and pollution (see Otway and von Winterfeldt, 1982). However, in today's debates, one theme seems to dominate—risks to human health, safety, and the environment. Even in controversies with strong political and ideological undertones, such as the debates about the SST or nuclear power, risk is often a major theme, creating headlines in the newspapers and keeping regulatory agencies busy.

Why has risk become such a dominant factor in technology debates? Four different explanations have been offered. First, as the scale of technologies has grown, some risks may have indeed increased. Some new technologies can produce or have produced unprecedented catastrophes and others have produced subtle but long term health effects.

Second, the modern awareness of risks may simply be a consequence of changed perceptions of risks. Scientific studies have identified technological risks earlier, and media exposure has made them more visible, creating dramatic images of disaster and providing

Ward Edwards and Detlof von Winterfeldt • Social Science Research Institute, University of Southern California, Los Angeles, California 90089.

nationwide coverage of scientific estimates of morbidity and mortality rates. Exposure to these publications may have exaggerated public perception of the actual risks. Whether the changed perception is appropriate or not is debatable, but surely depends on the hazard.

The third explanation is that social values and preferences have changed to emphasize risks, not benefits. Perhaps the benefits of technologies are questioned because of satiation effects, diffusion of benefits, and changing public trade-offs. A radical version of this hypothesis can be found in the "value change" thesis by Inglehart (1977), who claims that modern industrial societies are moving toward adopting "post-materialistic" values.

According to the fourth explanation, institutional changes have caused increased attention to risks. The institutions that plan, promote, regulate, and oppose technologies may be better suited to address risk issues than other concerns, thus shifting the focus of the debate from whatever the "real" issues might be.

These four explanations are neither exclusive nor exhaustive. Beyond the institutional interpretation, one can conceive of cultural explanations for the emergence of the risk debate, as Douglas and Wildavsky (1982) have recently done in a most stimulating book. And most risk researchers would acknowledge that risk debates are probably created by a mixture of reasons, including changes in the production, perception, evaluation, and management of risk, as well as in the cultural context in which the debate takes place.

The four explanations are nevertheless competing, as they generate different interpretations of current risk debates and different expectations about how these debates evolve. Only the "production" and "perception" explanations acknowledge risk as the "real" issue of the debate. Concern about risk leads to creation of risk-regulating institutions as arenas for technology debates. The rules of these arenas focus attention on risk because they are designed to deal with risk and not with other issues. According to the production and perception explanations, similar risks or similarly perceived risks should create similar controversies, while the value change hypothesis would suggest that technological controversies occur to the extent to which they are appropriate targets and symbols for the expression of changing values and attitudes. The institutional explanation implies that the nature of a risk debate can take radically different turns, depending on which institutions become involved.

In order to assess the four explanations and to understand better the reasons for technology debates, we have studied 10 past, recent, and ongoing technological controversies. By comparing the historic opposition to steamboats, cars, and zeppelins with the recent opposition to the SST, LNG terminal siting, and bullet trains, we attempted to identify historic changes in technology debates. By comparing the controversy about nuclear power with that about genetic engineering we tried to assess the factors that determine the nature of the debate about technically similar risks.

*TECHNOLOGICAL CONTROVERSIES IN THE PAST**

Early Opposition to the Steamboat

It is difficult today to realize the importance of the steamboat, as it has largely disappeared from our lives. But for a long time steam was the only mechanical power that was

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capable of moving vessels. The steamboat was, of course, ultimately successful, but its river to success was full of snags and sandbars.

As usual, the early opponents of steamboats were those whose livelihood was threatened: sailboat owners, sailors, and stagecoach drivers. In France, Denis Papin designed the first steamboat in which an engine pumped water onto a waterwheel that drove two paddlewheels on the same shaft (Dayton, 1925). Other boatmen thought that the boat worked by witchcraft and destroyed it. Jonathan Hulls patented a steamboat in England in 1736 and was severely ridiculed by fellow boatmen.

The first American steamboat designer, Robert Fulton, also experienced opposition from the sailboat business, and reportedly had to guard his boat against sabotage by sailors. Financiers' and friends' attitudes ranged from skepticism to indifference (Hill, 1953). At the launching of his first boat, the *Clermont,* most people thought it would be a failure; in fact, Fulton had to promise embarrassed friends and investors that their names would not receive publicity in the venture. Passengers were frightened by the unfamiliar noises and the steam.

In spite of all this apprehension, the *Clermont* was a success; steamboats soon overcame the opposition by sailors and their economic prospects convinced investors. But simultaneously with the gradual acceptance of the technical and economic feasibility of the steamboat, public fears of its dangers arose. Nicholas Roosevelt constructed the *New Orleans,* which was to run from Pittsburg to New Orleans. Despite advertisements, no passengers appeared for its first trip, but Roosevelt and his pregnant wife made the trip together with a crew of 14. The public was outraged that Roosevelt would subject his wife to such danger. Women, fearful for Mrs. Roosevelt's safety, wept and condemned her "headstrong" husband (Drago, 1967).

The *New Orleans* made its trip safely, but steamboat accidents soon became common. An official government estimate of 1848 listed a total of 233 steamboat explosions between 1816 and 1848, producing 2563 fatalities and over 2000 injuries (Burke, 1965).

The technological responses to these disasters were slow and largely inadequate. They included wrought iron construction, lower steam pressure, and safety valves. A curious technological response to the growing public concerns about the safety of steamboats was safety barges, which were towed behind steamboats and advertised widely:

> Passengers on board the safety barges will not be in the least exposed to any accident by reason of the fire or steam on board the steamboats. The noise of the machinery, the trembling of the boat, the heat from the furnace, boilers and kitchen, and everything which may be considered unpleasant on board a steamboat are entirely eliminated. (Dayton, 1925, p. 38)

The novelty gradually wore off, and the barges were eventually used for cargo only. The need for the use of such devices demonstrates, however, the fears that steamboats had produced.

The frequent disasters, the media attention they received, and the obvious public concerns produced a climate in the U.S. Congress that favored regulation of steamboat construction and operation. But Congress acted slowly, taking over 30 years to decide on regulations, partly because there were no precedents for regulating a privately developed technology, partly because opposition from the private sector was strong (Burke, 1965). An initial bill that provided for hydraulic testing of all boilers, inspections, and liabilities in case of explosions was finally passed in 1838. This bill was the first regulation of a technological risk in the United States. Because of its lax formulations, it did not, however, change matters much. Steamboat accidents continued and so did the public concern and media outcry against disasters. The debate continued, now focusing on the ideological

differences concerning the regulation of steamboats. A proponent of a tougher bill argued in Congress:

> I consider that the only question involved in this bill is this: whether we shall permit a legalized, unquestioned, and peculiar class in the community to go on committing murder at will, or whether we shall make such enactments as will compel them to pay some attention to the value of life. (cited after Burke, p. 21)

An opponent replied:

> What will be left of human liberty if we progress on this course much further? What will be, by and by, the difference between citizens of this far famed Republic and the serfs of Russia? Can a man's property be said to be his own, when you take out his control and put it into the hands of another, though he may be a Federal officer? (cited after Burke, p. 21)

After much debate in Congress, the proponents of stricter regulation won in 1858. A law was passed that specified tough engineering safety criteria, giving inspectors authority to examine boats and refuse licenses, and creating a regulatory agency, the Board of Directors of Inspectors, supervised by presidential appointees.

Subsequently, steamboat explosions did, indeed, become less frequent events. Public concerns about steamboats decreased, and steamboats remained the main mode of transportation until the end of the century, when they were replaced by railroads.

Early Opposition to the Automobile

In general, the automobile and the mobility it brought elicited much enthusiasm from most public groups. It was thought to promote health by doing away with unsanitary and noisy horses, ending isolation, aiding education, and bringing families together. The scattered opposition occurred for four reasons: threats to the livelihood of special interest groups (farmers, horse breeders, horse carriage associations); safety and risks (publicists and public officials); economic reasons (bankers); moral and cultural reasons (religious groups).

At the start of the automobile age, those who stood to lose their jobs opposed them most strongly. Horse breeders, livery stable owners, and horse drawn drivers associations demonstrated opposition and frequently presented petitions to ban automobiles from public roads. Motorcars, they said, were only a passing fad for the wealthy. Automobile touring was very popular in the early 20th century, but generated substantial rural opposition by damaging crops and endangering livestock. In Rochester, Minnesota, farmers plowed roads, making it impossible for motor vehicles to travel but allowing horses to trot through. But this opposition subsided by 1908, when it became apparent that automobiles would help farmers. With the advent of the tractor and other farm vehicles, the last organized opposition to the motorcar disappeared.

Automotive safety was already recognized as a major problem by the mid-1920s: 5900 fatalities in 1915; 9825 in 1919; 10,100 in 1920; 15,000 in 1921 (*The Nation,* 1922). According to a 1926 article in *The New Republic,* titled "The Murderous Motor," 22,500 deaths were caused by automobile accidents during the preceding year. *The Nation* (1922, p. 79) asked, "How shall we control the modern Juggernaut?" It went on to lament the many accidents caused by motorcars and noted that "in Elmira one woman was killed by a car driven by a man 90 years of age!" But these complaints were more against the drivers than against the technology of the motorcars themselves.

According to Flink (1975), concerns that the car would encourage financial extravagance and economic frivolity started in the 1920s when time payments became common. The Chicago Central Automobile Credit Association wrote on March 20, 1922:

> Widespread conviction on the part of the bankers that the financing of automobile purchases was a more or less hazardous business . . . a tendency to encourage extravagance was contrary to the thrift ideas which the bankers were so anxious to establish in the minds of the public. (Flink, 1975, p. 148)

Moral attitudes toward the automobile were positive in the beginning, but later turned into suspicions that the vehicle, by permitting individual mobility, threatened the family unit and the moral standards of society. It undercut parental authority and promoted promiscuity. People often found the Sunday drive preferable to going to church (Flink, 1975). In addition, the automobile threatened to tear apart traditional family and friendship units:

> The trend towards decentralization of workers' dwellings means that instead of a family's activities in getting a living, making a home, play, church going, and so on largely overlapping and bolstering each other, one's neighbors may work at shops at the other end of the city, while those with whom one works may have their homes and other interests anywhere from one to two miles distant. (Flink, 1975, p. 161)

The opposition to the car was neither vehement nor massive, and with the exception of the early opposition by horse-related businesses it was hardly organized. Most opponents knew that the automobile was highly popular, that it was here to stay, and that there was little one could do to stop its expansion.

Opposition to the Zeppelin

The zeppelin had an illustrious and short-lived history. Most of its promoters had military and economic interests. Opponents came from competing industries (mainly the emerging airplane industry), military strategists who did not believe in the zeppelin's ability to attack and defend itself, and journalists and members of the public who stressed its risks.

In 1900, Count von Zeppelin carried out the first successful zeppelin flight. The German government soon recognized the military potential of the zeppelin and promoted a zeppelin program prior to World War I. The program almost came to a halt when a zeppelin was completely destroyed during its first flight, killing its crew. Interestingly, the public response in Germany was in favor of continuing the program in spite of this disaster. Count von Zeppelin received large private contributions to continue his work, and the government followed suit (Eckener, 1958).

But the risks and dangers of the zeppelin would soon attract public attention and generate criticism and opposition. In 1922, the French airship *Dixmude* burned in a thunderstorm off the coast of Sicily, killing its crew. This accident received wide media coverage, and prompted one French journalist to ask: "When will they stop people from flying these criminally dangerous ships?" (Hearnes, 1916). In 1934, the American airship *Akron* collapsed and sank off the shore of New Jersey, killing 73 people. The English zeppelin *R.101* crashed into a French hillside in 1930, killing 48 of the 54 people aboard. Finally, the tragedy of the *Hindenburg* in 1937 in New Jersey killed 50 people and highlighted the problems of airships that used hydrogen instead of helium. According to Abbott, this series of accidents was the main reason for the abandonment of zeppelin development: "A tragic series of avoidable accidents caused the entire concept of passenger carrying airships to be abandoned with impatient haste" (Abbott, 1973, p. 152).

There are, of course, other important reasons for the demise of the zeppelin, but they varied from country to country. In Germany, a main reason was the lack of helium, which would have made travel by zeppelin cheaper and safer. The United States had a virtual monopoly on helium, but since World War I helium export was forbidden by law. German lobbyists worked until 1937, when that law was repealed. After a very brief period of helium

export, tension grew in Europe, and soon after Hitler's annexation of Austria, helium export to Germany was again halted.

In the United States, the development of the zeppelin was boosted by the economic interests of rubber manufacturers, and supported initially by the Navy and the Federal Aviation Commission. In 1940, the United States had a substantial network of zeppelin transport, but this expansion was short-lived. The risks, combined with improvements in airplanes and the lesser cost effectiveness of the zeppelin, brought about the decline of the zeppelin in the United States (Hearnes, 1916; Eckener, 1958).

The Supersonic Transport (SST)

The SST had a rocky but quiet beginning under the Kennedy administration. In May 1960, the head of the Federal Aviation Agency announced that the government would be willing to pay for half of the costs of developing the SST, but business response was lukewarm at best (Levy, 1973). Nevertheless, for nine years Congress voted funds for SST research and development. It was in the late sixties that widespread opposition began. The opposition was based on two concerns: environmental and economic. In 1967, William Schurcliff founded the Citizens League Against the Sonic Boom, drawing attention to the noise problem of the SST. On April 1, 1970, the Coalition Against the SST was formed, backed by 16 national and 15 state and local groups. Its only goal was to stop funding of the SST. The newly founded environmentalists' lobby group, Friends of the Earth (FOE), also chose stopping the SST as one of its goals (Levy, 1973). As a major step against the SST, FOE published William Schurcliff's *The SST and Sonic Boom Handbook,* which described the possible dangers of the SST to the environment.

The growing concerns about environmental damage were summarized in a recent *Los Angeles Times:*

> A "greenhouse effect" would raise temperatures around the globe, they said. Radio communications would be disrupted. More people would get skin cancer as jet exhausts depleted the stratosphere's ozone layer and allowed more ultraviolet rays from the sun to penetrate the atmosphere. More species would become extinct as, for example, sonic booms cracked the delicate eggs of the whooping cranes (*Los Angeles Times,* 1982).

There was concern that "all animals living out of doors during the day would be blinded (by ultraviolet radiation) unless they wore protective goggles" (*Chemistry,* 1973). And the sonic boom would "break windows, crack walls, and stampede cattle" (*U.S. News and World Report,* 1970a). These arguments were frequently supported by scientific studies commissioned by the environmentalist groups and by regulatory agencies.

The lobbying activities of environmental groups against the SST produced political action. On May 12, 1970, Senator William Proxmire, a long-standing critic of the SST, held hearings. Russell Train, chairman of the Council of Economic Affairs, testified that a fleet of SSTs could warm the atmosphere enough to affect the polar ice caps. Richard Wegman, an assistant for Proxmire said, "It was the first time any responsible official had suggested that such a far-out scare could be true" (Levy, 1973, p. 34).

The defenders of the SST argued that it was necessary for the United States to develop the plane if it were to remain the leading nation in aircraft technology. The Concorde was being developed by France and the Russians had their supersonic TU-144. Cancellation of the project could result in high unemployment as technicians and workers were laid off. Proponents also argued that a favorable net balance of payments would be reached through sales of the SST to foreign airlines. Finally, the Department of Transportation said that the

SST would not cause sonic booms because it would be forbidden to fly faster than sound when it was flying over the nation (*U.S. News and World Report,* 1970b).

However, the anti-SST coalition came up with some interesting responses to these arguments. In 1970, they polled 16 of the nation's top economists, ranging from the very liberal to the very conservative. The economists were asked if the SST would make a profit, and if the government should continue funding the development of the plane. Fifteen economists opposed federal funding of the SST, and did not think it would make a profit. Only one economist supported it, arguing that U.S. technology must keep up with Russia. Milton Friedman expressed the views of many in his reply: "If the SST is worth building, the market will make it in Boeing's interest to build without a subsidy; if a subsidy is needed, the SST should not be built" (Levy, 1973).

Media opposition to the plane was growing as well. Both the *New York Times* and the *Washington Post* wrote strong editorials against the SST. One popular argument was that the money for the SST was needed elsewhere. The SST had required $864 million over a nine-year period. In 1970, President Nixon, a supporter of the SST, asked for $290 million for two prototypes of the SST (*U.S. News and World Report,* 1970a). *Life* magazine replied: "The Nixon administration's openhandedness with the SST stands in stark contrast to its penny-pinching approach to the neglected parts of the country's transportation system" (*Life,* 1971). And Representative Sidney Yates of Illinois said: "The SST, which looked like a supersonic marvel on paper, looks more and more like a supersonic white elephant as the time approaches to begin prototype construction" (*U.S. News and World Report,* 1970b).

By the end of 1970, the assault against the SST had succeeded. The opposition from economists, environmentalists, politicians, and publicists, the numerous bills against the SST pending in state and local legislatures, and the loss of political support in the Senate and House made the final decision to terminate the project merely a matter of time. On December 3, 1980, the Senate voted to stop government funding of the SST. After a brief compromise, and a last-ditch effort by Boeing to revive the project (which included the creation of American Industry and Labor for the SST), both the House and Senate voted to cut off future funds. Soon thereafter Boeing announced its cancellation of the SST project.

*Opposition to Liquefied Natural Gas (LNG) Terminals**

The origin of the following controversy was a proposal by the Pacific Lighting Corporation of California to purchase LNG from Indonesia, and to land and distribute it in California, whose demand for natural gas was predicted (by Pacific Lighting) to outgrow its supply. In 1973, Western LNG Terminal Corporation, a subsidiary of Pacific Lighting Corporation and of El Paso Natural Gas Company, suggested two possible terminal sites: Los Angeles and Oxnard. The Oxnard terminal was to be located at Point Conception (Cojo Bay).

A ten-year period of political and legal battles and regulatory investigations over the terminals followed, concentrating on the Point Conception site (Linnerooth, 1980). Advocates of the plan stressed the need for fuel and the benefits of the project in producing economic growth and employment. Opponents were environmentalists, landowners, local residents who feared the risks of explosions and fires, and American Indians, who considered the Cojo Bay area sacred.

* This section draws heavily on summaries by Linnerooth (1980) and information provided by L. Philipson.

The debate took place in the media and in licensing and regulatory proceedings. From the beginning, LNG safety was a major issue. The Sierra Club and a group called Ventura County Concerned Citizens Committee argued that the entire system of storing and transporting LNG was unsafe (Raimundo, 1978). A 1944 LNG disaster in Cleveland, Ohio, which killed 128 people and injured over 300, was widely cited. The environmental and safety concerns were addressed in a series of studies issued by both opponents and proponents of the plan. The studies agreed that the probabilities of disasters were extremely small, but the potential consequences could be extremely severe. But the stakeholders drew conflicting conclusions: opponents stressed the maximum consequences, while proponents pointed to the small probabilities.

The situation was complicated by ill-defined and often diffuse regulatory responsibilities and a lack of clear safety goals. Part of the process therefore consisted of creating regulatory responsibility and safety guidelines. The 1977 California LNG Terminal Siting Act removed licensing and permit authority from a number of local agencies and gave the California Public Utility Commission (PUC) the main responsibility for regulation (Linnerooth, 1980), with the California Coastal Commission (CCC) in charge of ranking potential sites. Soon after, the Federal Energy Regulatory Commission defined new safety criteria and regulations for LNG storage and transportation. Based on these regulations the PUC chose the Point Conception site from four sites submitted by the CCC.

But the safety debate did not stop. During the decision process by the PUC an earthquake fault, discovered near the proposed site, jeopardized what appeared to be the solution to the siting problem. New studies were needed to examine the safety problem in light of the earthquake fault. In late 1981, the PUC finally accepted the wind/wave seismic studies for Point Conception and concluded that, with appropriate engineering fixes, the risk to the population was acceptable.

While safety was a major issue in the debate about the LNG site, it was by no means the only one. The Sierra Club and other public interest groups had expressed both economic and safety concerns. They questioned the need for LNG, pointing out that it created another source of energy dependence and that it would be too expensive for the consumer. They also argued that if an LNG terminal turned out to be unavoidable, it should be sited in a remote area. Thus, need, economics, and safety were intimately coupled in the environmentalists' arguments.

The opposition by local landowners was based largely on their economic interests in the land on which the LNG terminal was to be built. The Bixby and Hollister Ranch Associations lobbied strongly against the site, because the terminal would reduce land value and interfere with development plans (Linnerooth, 1980).

Strong objections also came from American Indians, to whom Point Conception is a sacred place. In May 1978, 25 Indians invaded Point Conception in a protest against the development (*The Nation,* 1979). One Indian woman said, " . . . that is our sacred ground and if they put that liquified gas stuff there, something bad is going to happen, you can feel it" (*The Nation,* p. 138, 1979). Partly because of such strong opposition, partly because of the slackening demand for natural gas, and partly because of the general uncertainty surrounding technological regulation in this area, Pacific Lighting decided in October 1982, to postpone the development of the LNG plant at Point Conception indefinitely.

Opposition to the Bullet Trains

A number of recent proposals have been made in the United States to develop a high speed train, similar to those built by the Japanese and the French to connect large metropolitan

areas. Some of the proposals have reached the specific planning stage: the proposed train to link Los Angeles and San Diego is an example. It is therefore of considerable interest to examine the recent opposition to that train in Japan. Opposition in the United States is likely to take similar forms, since the issues are the same, and since the Japanese legal and regulatory mechanisms for coping with risks and environmental hazards are similar to those in the United States. Following is a brief account of the battle Japanese residents fought against the Shinkansen high speed trains. (See also the more extensive treatments in Ikeda and von Winterfeldt, 1982; Hashimoto, 1975; Straszak and Tuch, 1981.)

In the early days of its development, the Shinkansen was a source of national pride to most Japanese, hailed as a technological breakthrough and as a symbol of Japanese ability to innovate rather than to imitate. The Shinkansen built up an immaculate safety and economic record. With speeds over 200 kilometers per hour, it was by far the fastest commercial train in the world. And, unlike other railway systems in Japan, it actually produced profits. Thus, when the Tokaido line was opened in 1964, connecting Osaka and Tokyo, the few residents who complained about the noise, vibration, and TV interference were hardly heard.

There is no doubt that the Shinkansens are noisy. At present trains run at intervals of five minutes along the Osaka–Tokyo line from 6:00 a.m. to 11:35 p.m. Noise levels of 85–90 decibels (dB) are not uncommon, and noise can reach over 100 dB on steel girder bridges. Residents at distances of up to 200 meters from the tracks can be substantially disturbed; they frequently complain or even stage protests.

In 1975, the Japanese Environment Agency set noise standards well above the residents' requirements (70–75 dB). The noise standards were set on the basis of noise–complaint relationships and consistency requirements with standards for car and airplane noise. Their adequacy is at present a matter of dispute in court, but it seems likely that they will be upheld.

Meanwhile, the battlefronts have widened. Extensions of the Shinkansen system are under heavy attack from environmentalists and local residents. Radical activists have added economic and political objections to the original complaints about noise. The Shinkansen, they say, serves the rich and provides revenue only to the few cities that have stations; the residents along the line and the cities without stations do not reap any benefits, but carry the burden of noise and displacement. With the Narita airport controversy and a recent defeat in a legal case about Osaka airport noise still fresh in their minds, government officials and representatives of JNR are cautious about further expansion plans. A sweeping development plan that was to double the Shinkansen system has already been abandoned and even a small new stretch connecting Tokyo with the new Narita airport is in jeopardy. It appears that, at least for the moment, the Japanese bullet train has lost some of its glamour and prestige.

Comparison of Present and Past Controversies

Having set out to find dramatic differences between the technology debates of the past and the present, we were struck by the surprising similarities in the topics of the debate, in the nature of the arguments, even in some of the rhetoric. The topic of risk, especially to human health and safety, was an important factor in all three historic cases. The worries about steamboat explosions and the fear of zeppelin disasters are reminiscent of today's concerns with LNG and nuclear power safety. And the public outcry against too many automobile-produced deaths that began in the early 20th century has never really stopped.

Just as risk was an important issue in the past, nonrisk arguments strongly shaped the more recent debates. Economics ultimately brought down the SST. Political and religious concerns were a large part of the LNG siting controversy. Issues of growth and inequities

of risks and benefits became focal concerns in the later stages of the expanding conflict over bullet trains. In addition, from the days of the steamboat controversy to today, the arrival of each new technology has stimulated discussions about the necessity and appropriateness of additional governmental regulation.

Changes in topics occurred, of course, reflecting changes in public perceptions and attitudes. The environment was hardly a concern of the past, and little evidence exists of worries about endangered species or about subtle disturbances of the ecological balance, themes that are now familiar. Environmental concerns were usually coupled to people's well-being and not considered as values in themselves. Another novel topic of recent years is concern about long-term impacts on future generations. This is probably motivated by the scale and nature of some new risks, e.g., the risks of genetic research, of nuclear waste disposal, and of fossil fuel burning ("greenhouse effect").

We think that the similarities in topics and arguments far outweigh the differences, and it would be rather difficult to make a case that today's debates are fundamentally different from those of the past. Yet there is little doubt that technologies have fallen on harder times. Our case studies suggest four related reasons: (1) increased scale: technologies have become larger, more expensive; their complex and time-consuming planning processes offer ample opportunities for public intervention; (2) new institutions: two new types of organizations have emerged that play important parts in technology debates—special-purpose regulatory agencies and powerful, single issue organizations that can selectively fight technologies; (3) changing arenas: the battles over technologies are fought increasingly in regulatory arenas and in the courts, rather than in political bodies; (4) adversary procedures and expert disagreement: the new arenas have turned technology debates into adversary procedures in which experts take the sides of the technology proponents or opponents.

The scale of past technologies was smaller, they could be developed with private funds, and their success depended crucially on individual entrepreneurship. The early histories of the steamboat, the car, and the zeppelin are examples of both the advantages and the difficulties of small-scale private efforts. Recent controversies that we described were, in contrast, about much larger-scale technologies, involving complex corporate arrangements, and frequently requiring substantial government subsidies. The 10-year planning phase of the SST and of the LNG terminal clearly demonstrate the problems that can result from this process. The necessity of government support and incentives, in turn, leads to a larger public stake in the technologies and a request for public inputs into planning and decision making. Planning has become a long, arduous process. Many public hearings and discussions make the technology visible and vulnerable in its early stages of development. Debate about the steamboat was mostly after the fact; debate about the SST was not.

The case history of the steamboat dramatizes the second factor contributing to the vulnerability of new technologies: the emergence of laws and agencies that monitor, inspect, and license them. If risk regulation was a hotly debated novelty then, as discomforting to the technology sponsors as it was beneficial in reducing the physical risks, it is commonplace today. Depending on their legislative mandate, regulatory agencies emerged that ranged from being critical of new technologies (e.g., Occupational Safety and Health Administration) to relatively supportive (e.g., Nuclear Regulatory Commission). Whether supportively or antagonistically administered, however, the new rules and regulations provided more hurdles and obstacles for emerging technologies. Another institutional novelty is public special interest groups, usually focusing on a single issue like environment or individual freedom. Because these issues cut across technologies, representatives of these organizations can pick a fight in regulatory or legal arenas in an attempt to use their resources to their best political advantage.

Regulatory processes provide both the opportunities and the arenas for such fights. Many of the newer regulatory processes and bodies emerged from, and are responsive to, environmentalist and public interest groups. The direction of political pressure within such groups and processes has significantly changed. Procedural phenomena reflect such changes. Regulatory processes are usually open to intervenors and to opponents of the technology in question—by design. Senator C. P. Anderson argued during a Senate discussion of the Atomic Energy Act: "I feel so strongly that nuclear energy is possibly the most important thing we are dealing with in our industrial life today, I wish to be sure that the Commission has to do business out of doors, so to speak, where everyone can see them" (Del Sesto, 1979, p. 118). The National Environmental Protection Act and similar acts provided for public hearings concerning licensing and impact assessment. Public financing and strong government involvement in developing large-scale technologies made both regulation and its openness legitimate and necessary.

The legal or quasi-legal nature of planning, licensing, and regulation has turned the stakeholders into adversaries and amplified their differences and disagreements. Experts have begun to play a partisan role in these adversary processes. In the past, experts normally worked for and sided with the technology sponsor, but today this picture has changed. Regulators must have the expertise to control and supervise technological developments. Single-issue opponents of technologies frequently employ a full-time staff of experts. Experts therefore have a career path that is not directly linked to the success of the technology itself. The fact that experts take sides would, of course, be of little consequence if sufficient data and experience could be accumulated to force expert opinions to converge. Unfortunately, the novelty and scale of many technologies have reduced the role of trial and error and frequently made it impossible to replace expertise with "hard facts." As a consequence, many answers to technological questions have become educated opinions rather than scientific truths (Otway and von Winterfeldt, 1982). Using the same data and different assumptions, experts can arrive at wildly different estimates. The resulting display of expert disagreement has contributed to a growing mistrust of expertise and of the institutions promoting and regulating technologies. As Renn (1982) points out, an expert is more likely to be asked "Who paid for your study?" than "What is the scientific basis for your conclusions?"

*NUCLEAR ENERGY AND GENE SPLICING: DO SIMILAR RISKS PRODUCE SIMILAR CONTROVERSIES?**

Several observers of the nuclear power controversy have pointed out that DNA research and gene splicing technologies may encounter public opposition similar to that of nuclear power, because the risks are similar (Starr and Whipple, 1980; Slovic et al., 1981). Gene splicing and nuclear power both may have delayed effects, are relatively unknown and new risks, have large catastrophic potential, and are severe and dreaded (Slovic et al., 1981). If the debates were purely about risks, therefore, one would expect substantial similarities in their evolution and disposition.

To examine this hypothesis, we compared the debates about nuclear power and gene splicing at comparable stages of development (mid-1950s to mid-1960s for nuclear power, 1970s for gene splicing). Fortunately, the development of nuclear power has been well documented both by proponents and opponents (Del Sesto, 1979; Gyorgy, 1979; Duncan,

* We gratefully acknowledge Rosa Vasquez's help in collecting the material for this section.

1978; Lombardo, 1979). Wade (1977) thoroughly covers the DNA debate up to 1977. In addition, we conducted our own review of all *Science* articles between 1977 and 1982 on the subject. We created a timeline of major events, listing the main stakeholders (proponents, opponents, and regulators) and analyzing their conflicts.

Early Opposition to Nuclear Power

Most reviews credit the beginning of opposition to nuclear power to the environmentalist movements of the late 1960s and early 1970s, but nuclear power encountered opposition virtually from its very conception as a realistic idea. According to Del Sesto (1979), the AFL-CIO raised concerns about radiation and occupational safety as early as 1949. Only a few short years after Eisenhower's famous "Atoms for Peace" speech and the enactment of the Atomic Energy Act, the AFL-CIO fought a legal battle against the Atomic Energy Commission (AEC) over the safety of the Enrico Fermi experimental fast breeder reactor near Detroit. Unions also brought to the public attention early nuclear reactor accidents at the Nuclear Reactor Testing Station in Idaho in 1961, which killed three workers (Del Sesto, 1979). Throughout the 1950s, unions raised accusations that the AEC had suppressed studies and whitewashed reports about incidents (see also Mazur, 1981).

In 1957, the AEC carried out its first reactor safety study, an assessment of the consequences of a major accident. While the report stressed the theoretical nature of the accident, the size of the consequences was staggering (thousands of fatalities, up to $7 billion in property damage). Worse, the liability issues raised by this study became a major obstacle to the economic viability of nuclear power. The Price Anderson Act of 1957 solved that problem by imposing a ceiling on private liabilities in the event of a serious accident.

The liability issue was, of course, only one of the many economic problems that early nuclear power development had to overcome. Many utilities were reluctant to replace their cheap and reliable coal- and oil-fired plants with an economically uncertain, and still not fully proven, technology. The AEC's nuclear power development program had to provide substantial financial incentives to construction firms and utilities.

As the interest in nuclear power increased in the private sector, public concern arose. Various citizens' groups began to fight legal battles against specific plants, usually through the public licensing process. Opposition at that time was, however, still focused on residential and local interests, and did not have a broad political base.

Complaints by unions and local residents broadened during the 1960s to include national and international issues such as plutonium diversion and low dose radiation. In the late 1960s, the Gofman and Tamplin affair stirred up additional controversy. In 1969, Sternglass (1969) published a paper "Infant mortality and nuclear tests" in the *Bulletin of the Atomic Scientists,* in which he estimated that about 400,000 excess cancer fatalities could be expected from low-dose radiation produced by nuclear fallout. The AEC, attempting to prove that cancer mortality caused by excess radiation from nuclear weapons and nuclear power plants is nonexistent or at least negligibly low, issued studies by Lawrence Livermore scientists Gofman and Tamplin, to refute the Sternglass estimates. But, in the process of refuting Sternglass's controversial and staggering numbers, Gofman and Tamplin produced an uncomfortable set of estimates themselves. According to one of their studies, additional cancer fatalities from exposure to radiation could be over 12,000. The AEC and many other scientists quickly contradicted Gofman and Tamplin. In one such study, Bond (1970) estimated merely 0.02 additional cancers per year produced by low dose radiation (see e.g., Mazur, 1981). The public was suddenly confronted with extremely divergent expert assessments of the

risks, which, coupled with the often vicious tone of the debate, helped undermine public trust in experts and regulators. Meanwhile, many successful suits by local residents and environmental groups produced costly delays and disruptions in the construction of new nuclear plants.

Thus, even before 1970, nuclear power faced some stiff opposition, starting with union concern about occupational safety. The 1970s, of course, saw an enormous escalation of the conflict, produced by a coalition of environmentalist groups, residents, unions, and political groups. This broad alliance, escalating costs, an uncertain regulatory climate, and reduced energy consumption are the main reasons for the ongoing decline of nuclear power in the United States.

Early Opposition to Gene-Splicing Experiments

Criticism of gene-splicing experiments began as soon as the technology was invented in 1973. Early warnings came from the scientific community itself. The concerns focused on inadvertent increases of virulence and the potential for epidemics. In June 1973, a group of scientists gathered at the Gordon conference and proposed an examination of the safety issues. The group published a letter in *Science,* suggesting that the National Academy of Sciences (NAS) set up a committee to investigate genetic engineering risks. In April 1974, the NAS convened an initial meeting, which had two outcomes. The first was a proposal for an international conference on the subject and the second a request for a voluntary partial moratorium on gene-splicing experiments. The proposal was apparently widely acted on, not only in the United States, but also in foreign countries as scientists all over the world became aware of the potential risks of gene-splicing experiments.

The next important event was an international conference at Asilomar, California, at which risks of genetic engineering were discussed and guidelines for containment procedures were developed. The conference apparently favored strict initial regulations, which could later be relaxed. The most critical participants wanted to ban all experiments with *E. coli,* seen as a particular danger because it colonizes the human colon. Use of *E. coli* was not banned, but proposals to use "crippled" *E. coli* strains for experimental purposes were approved (Wade, 1977).

The National Institutes of Health (NIH) set up a committee to produce guidelines for gene-splicing experiments based on the Asilomar ideas. The final NIH guidelines required two grades of physical and biological containment, depending on the danger of the experiment. These guidelines were somewhat less stringent than those proposed at Asilomar.

In mid-1976, scientists mounted a new attack against genetic engineering and the NIH guidelines. Two prominent researchers, Chargoff and Sinsheimer, added to the initial list of biological risks the risks of "meddling with evolution" and the deeper ethical problems of genetic engineering. The issue of self-serving regulations was also raised frequently, since most members of the NIH committee had a stake in genetic engineering research (Wade, 1977).

Public involvement was also on the rise. In June 1976, the Cambridge City Council began investigating the risks of genetic engineering experiments that were to be carried out at Harvard. A public review board examined the issue in 72 hours of hearings, and finally came to the conclusion that the experiments could go on under guidelines somewhat stricter than those of NIH.

Throughout 1977, various environmental and religious groups took positions on genetic engineering, but most of them were surprisingly mild. The Environmental Defense Fund

asked for public hearings. The Sierra Club opposed genetic engineering except for small laboratory experiments. Friends of the Earth asked for a moratorium pending risk research. Religious groups were neutral or cautiously supportive. Simultaneously, many local citizens' groups and local regulators entered the debate, since the NIH guidelines applied only to experiments supported by federal grants. Since 1977, Congress has been trying to pass mandatory gene-splicing regulations, which would apply to all types of experiments. However, today no such guidelines have yet been passed; the responsibility still belongs to local governments.

In 1978 and 1979, a number of events occurred. An NIH study indicated that the risk of genetic engineering had been exaggerated in the early days. The founding of Genentech and other firms made gene splicing a business. Environmentalists were still split or uncertain about the issues.

Meanwhile, the NIH acted as a strict regulator in two separate incidents. The first occurred after a researcher at the University of California, Los Angeles, violated the NIH rules by inserting genetic material into humans. The researcher was asked to resign a number of positions and was stripped of several federal grants in early 1980. In the second incident, a researcher who miscloned a virus at the University of California, San Diego, was eventually forced to resign his position.

There still has been no congressional action on gene-splicing experiments. A September 1981 *Science* article noted that the NIH may soon relax its guidelines, since it found only four minor violations in five years and studies indicated that the containment procedures are effective. The media are still quite attentive, but frequently focus on the dramatic benefits of what are now called "designer genes."

Comparison of Gene Splicing and Nuclear Power

The early oppositions to gene splicing and to nuclear power were similar in content, but different in the processes of their evolution and disposition. Some of the similarities in content are a result of the similarities in the risks. Catastrophic potential, impacts on future generations, and the mysteriousness and unpredictability of the hazards were issues in both cases. The scale and novelty of the risks led to discussions of deeper ethical and moral issues. Scientists were among the most outspoken critics in the early stages, and Sternglass played a role that was not too dissimilar to that of Chargoff and Sinsheimer. Even the rhetoric sounded the same.

The evolution of public concerns about risk was also similar. The nuclear controversy began with union concerns about occupational health and safety. In the DNA case, scientists themselves voiced concern. Issues were low dose effects (e.g., risks of inadvertent infections, cancer from low dose radiation), disaster (e.g., epidemics, meltdowns, and massive radiation), war and war-related uses (e.g., biological warfare, proliferation of plutonium), and ethical concerns (e.g., meddling with evolution, genetic impacts on future generations).

But some pronounced differences also exist in the topics and issues discussed in the two cases. The genetic engineering issues were usually confined to the risks, with an occasional sprinkling of moral and ethical objections, and a recent concern with the commercialization of genetic research. As early as the 1960s, the nuclear debate included economic concerns about the sustainability of nuclear power, decentralization, growth, and conservation. Furthermore, the benefit side was viewed quite differently in the two cases. The benefits of genetic research (for example, the production of insulin and interferon) appear to be tangible and novel contributions to the individual's health and well-being. The link between nuclear energy and electricity benefits was, in contrast, much more indirect.

Even with the threats of oil embargoes and blackouts, the benefit of a steady provision of electricity appears merely as a continuation of a *status quo* that many take for granted.

More important than these differences in the content of the debate are several fundamental differences in institutions and regulatory processes. One difference was the close alliance between nuclear researchers, regulators, and utility companies. The public suspicions of collusion that grew out of this close alliance were amplified by the dual role of the AEC as promoter and regulator of nuclear energy. One commentator on the nuclear debate created an argument against nuclear energy mainly on the basis of this entangled institutional arrangement (Metzger, 1982). And, it did not help matters much that most researchers associated with the promotion of peaceful nuclear energy had previously been involved in nuclear weapons development.

The gene splicing case is quite different. Proponents of genetic research were molecular biologists, chemists, epidemiologists, and physicians who were interested in exploring the potential of DNA research for biological and medical purposes. The commercial interests came at a later stage when it became technically feasible to use gene splicing for cheap production of drugs and vaccines. The media and some opponents therefore did not identify proponents with big business and big government, but rather with disciplines like medicine and biology.

In addition, the regulator was not an obvious proponent of gene splicing experiments. While some charged the NIH committee with "self-servingness," the conflict of interest was not as clear as in the case of the AEC. Regulatory action supported these different images. The AEC was frequently on the defensive, being accused of "whitewashing" and "cover-ups," and having to tighten standards and regulations after they were reexamined (Mazur, 1981). The scientists and members on the NIH committee, on the other hand, were seen as relatively strict and trustworthy. Their strategy was to set stringent standards initially, which could later be relaxed if the risks were better understood and adequate containment procedures were developed. Trust in the regulation was also aided by the fact that the Cambridge citizens' committee essentially endorsed it after an independent review.

We conclude that the risks for gene splicing and nuclear power were similar and that the nature of the debate about risks was similar. The opposition to nuclear power, however, largely through faulty institutional arrangements and inadequate responses to publicly expressed fears, partly through successful expansion of the issues to environmental and political ones, developed into a much stronger opposition. The conflict about genetic engineering, on the other hand, by creating a more trustworthy regulator and by confining the issues to risk, may today be in a state of de-escalation.

PRELIMINARY CONCLUSIONS

Issues in Disputes about Risky Technologies

In the introduction, we suggested four reasons for the emergence of risk as a major theme of today's technological controversies: (1) the risks have increased (risk production); (2) the risks are perceived as being larger (risk perception); (3) the values have changed (risk evaluation); and (4) institutions have changed (risk management). Having reviewed past, recent, and ongoing technological controversies we come to the not-so-surprising conclusion that changes have taken place in all four areas. But our case studies suggest that institutional changes may be a much more important factor than we initially anticipated.

If we had anticipated this conclusion when we started our review, we would have focused more intensively on the detailed institutional structure of the controversies we

examined—in particular, on the arenas in which they were resolved, for those that were resolved. We would have done an auxiliary study of the development of regulatory agencies, not only for issues of risk, but also for other forms of government regulation of business. We would have kept an eye out for attempts on the part of the participants in controversy to control the arenas in which they fought. And, in consequence, we would have needed to give a much more detailed account of the cut-and-thrust of the processes by which the controversy was resolved. Perhaps it is fortunate that we did not; our goal was to write a paper, not a book. Still, what follows is severely limited by our ignorance and by those omissions.

Institutional Changes and Arenas

The major institutional change has been the development of regulatory agencies as arenas for risk controversies. This development can only partially be explained by changes in the risks themselves or in the perception or evaluation of them. Our case studies indicate that risk has always been a major public concern. But in spite of continued public concern with technological risks, Congress only created one major agency before World War II whose primary concern was risk, the Food and Drug Administration. The real growth of federal regulation began in the 1950s and accelerated in the 1960s because the other two arenas for risk regulation, the legislative bodies and the courts, were inadequate to the task.

Legislative bodies are the most obvious and important arenas. They, on the whole, do not deal with specific risks, but rather (when functioning wisely) define rules and mechanisms by which risk-related issues will be dealt with, in the process specifying objectives that those rules and mechanisms are intended to attain. Recourse to legislatures about specific instances of risk is difficult, expensive, and inconsistent with societal views about how they should perform.

Recourse to the courts is both natural and frequent, but the courts are limited. In principle, they can only enforce laws, not make them. That same principle implies that they can only punish lawbreakers. Any such assertion is a caricature. Injunctions, consent decrees, and similar mechanisms permit courts to demand or forbid particular acts. But such devices are awkward for permanent resolution of a controversy and rarely have served that purpose with respect to risks.

Courts and legislatures share two other severe limitations: they are busy and inexpert. The latter problem is at least partly soluble; the former seems not to be.

Our society long ago recognized that a quasi-judicial body capable of reaching binding resolutions of complex technical disputes has many advantages. The three key ones are (1) they can invent, order, and supervise execution of positive solutions, and thus provide specificity and meaning for vaguely worded legislative intents; (2) they can function much more informally than can the courts; and (3) they can combine a quasi-judicial function with in-house expertise continuously on tap, to provide not only advice but also monitoring of problems and supervision of solutions. On the whole, the regulatory agencies can do all this with minimal damage to Constitutional or legal rights, since someone who feels wronged can, at least in principle, appeal to the courts—or even to the relevant legislature—to change the law. They are, then, a creative combination of executive branch and judicial branch functions.

Regulatory organizations at state and local levels, some called commissions, came into existence during the early 19th century as local and state legislative solutions to public outcries concerning the misuse of increasing business power. The key stimulus to their development was the railroads. The federal government gave them enormous land grants to

encourage westward expansion. Their superiority to other forms of transportation then available enabled them, by controlling fares, freight rates, schedules, and other business practices, to exercise extraordinary power over the economic development of the Midwest and West. The steamboat boiler inspectorate, a minor organization, was created in 1838 and strengthened in 1852, but its functions were technical and it was not politically important. The critical date in the development of federal commissions as a means for controlling U.S. businesses was 1877.

> The Act to Regulate Commerce was . . . of broadest significance . . . for it departed from the idea of limited governmental authority that reached private action only to punish wrongful acts after they were committed. . . . substituted . . . a permanent, continuing, day-to-day surveillance of the private conduct of the railroads. Its central purpose was not to punish . . . but to regulate . . . for the future. To practice this type of preventive medicine on the railroads, the acts created a new agency of government, the Interstate Commerce Commission (ICC). . . . Thus was the form of the regulatory commissions established as independent, expert, nonpartisan agencies wherein the worlds of politics and industrial economics would be reconciled. (Kohlmeier, 1960, pp. 12–13).

In fact, the ICC mainly controlled fares and freight rates, with some attention to safety issues.

The next major regulatory agency was the Federal Trade Commission, which came into existence in 1914 to enforce its own act and the Clayton Act. These acts, along with the earlier Sherman Antitrust Act, define U.S. antitrust policy.

The decade of the 1920s, dominated by business interests and business-oriented governments, saw only one new regulatory agency emerge: the Food and Drug Administration (FDA), which started as the Food, Drug and Insecticide Administration in 1928, and became the FDA in 1931. This was the first major federal agency whose main agenda was health and safety rather than economics.

The combination of an activist Democratic administration, eager to innovate, and severe economic conditions, which dampened American enthusiasm for laissez-faire economics, produced an alphabet-straining rush of regulatory agencies in the 1930s. Examples include the Federal Deposit Insurance Corporation (1933), the Federal Communications Commission (1934), the Securities and Exchange Commission (1934), the National Labor Relations Board (1935), the Federal Maritime Commission (1936), and the Civil Aeronautics Board (1938). (The Federal Communications Commission took over the functions of a 1920s predecessor, the Federal Radio Commission.) All of these organizations survive to this day. So by the beginning of World War II, the regulatory commission was well established as a federal device of choice for regulating the conduct of major businesses—and also, at that time, for promoting the development of businesses. With the exception of FDA, none of these organizations (not even the Civil Aeronautics Board) had risk as a primary concern.

When the end of World War II brought us into the Nuclear Age, the Atomic Energy Commission (1946) was the natural response to interrelating the three tasks of transferring control of nuclear energy for peaceful purposes into civilian hands, regulating its safety, and facilitating its private development. These functions were separated in 1975, in response to the obvious conflict between promoting an industry and regulating its safety, when the safety issues are so anxiety-provoking as in that case. The Nuclear Regulatory Commission was charged with regulating the safety (and other aspects) of nuclear power, and the Energy Research and Development Agency (ERDA) with promoting it. Later the ERDA was merged into the Department of Energy, when the latter was created during the Carter administration.

Upwellings of public concern about specific risk topics have quite naturally produced the invention of new regulations and regulatory agencies to enforce them, as an adequate legislative response. Examples include the Environmental Protection Agency, the Occupa-

tional Safety and Health Administration, the National Highway Traffic Safety Administration, and the Federal Aviation Administration. The same phenomenon occurs at state levels; an example is the California Coastal Commission, which regulates development along California's coastline.

Sometimes agencies created for another purpose become the arena for the risk technology debate. For example, the Federal Power Commission (now the Federal Energy Regulatory Commission) was created as an economic regulator rather than as a safety regulator. As an economic regulator, it was granted jurisdiction over natural gas imports and exports. Because of its tradition of public notice and hearings, safety fears about LNG imports had a readily available arena. On the other hand, liquid petroleum gas (LPG) imports and exports are not subject to economic regulation, and as a result, no similar arenas exist for LPG.

Thus, we now have three major classes of arenas in which risk-related controversies are fought out: the legislative bodies, the regulatory agencies, and the courts. The deficiencies of the others have made the roles of regulatory agencies even more prominent. Still, if the issue is important enough, Congress can and sometimes does preempt the regulatory agencies; it resolved the SST debate, and may well resolve the nuclear power debate. And, if the disputants are sufficiently combative, the fight ends up in the courts—but after the activities of the regulatory agencies have transformed it in major ways.

Values and Strategies

We have identified three classes of stakeholders in technological risk controversies: proponents, opponents, and regulators. Note that regulators are stakeholders and also manage an arena—a frequent source of complaint.

The values that developers of a technology bring to its introduction and use combine simple desire for profit with genuine concern for wider development and use of the technology about which they are expert. Boeing's development of the SST illustrates the interplay of these motives. Developers frequently have fellow-traveler proponents: the labor unions may support a technology because it will produce employment, and local business and government interests may relish the prospect of local economic growth. These values are best served if the process of introduction is orderly, predictable, and easy to manage. The existence of (surmountable) hurdles matters little, if they do not cost so much to deal with that they change the economics of the technology, and if they do not take so long to deal with that they compel modification of its natural schedule. Any incremental costs resulting from regulation can simply be added to the price for which the end result is sold. Promoters are therefore less concerned with escaping from regulation than with its predictability, cost, and ability to produce delays. Such interests are well served by a regulatory agency. They are less well served by the legislative arena and are miserably served by the courts. The difference between legislatures and courts arises because technology sponsors typically have much more day-to-day ability to influence legislative action than do technology opponents. This may also be true in the courts, since lawyers' fees are high, but the effect is much less dramatic.

Regulators can tread on the toes of technology promoters in various ways. Worst is unpredictability—but we suspect (in spite of the public statements of technology promoters) that this is a rare event. Technology promoters can afford the time and expertise required to keep detailed track of how regulatory agencies behave in response to various combinations of facts and pressures, and the nature of the specific facts and pressures in the current conflict. Delays are more common, since they are easy for technology opponents to produce. Similarly, though the cost of dealing with any one regulatory agency is manageable, the cost of multiple

hurdles may be so great as to change significantly the economic advantages of the technological advance.

The values of technology opponents range from tangible self-interests to broad public concerns. Examples of the former are residents' concerns with the noise from bullet trains and landowners' worries that an LNG terminal nearby will reduce the value of their land. Examples of more general public concerns are environmental objections to the SST by the Friends of the Earth and the Sierra Club's concern with radiation from nuclear power plants. We mentioned earlier that special-interest groups with public values of this kind are a relatively recent phenomenon in technological controversies. They usually draw on a (potentially) broad constituency, yet they define their values narrowly, but in a way that cuts across many technological topics.

Such values can be served in either of two ways. One is to set limits on the technology that prevent it from affecting the relevant value adversely (e.g., preservation of the environment). Since this is what regulatory agencies are set up to do, such technology opponents are well served if they do it well. But the definition of "well" is specified by statute and interpreted by the regulatory process. The participants in a controversy may disagree about what the limits should be. In that case, the technology opponents have another option: they can multiply hurdles and seek to increase the cost and time a developer needs to get over each. This approach exploits two facts. One is that the multiplicity of governments, which characterizes the United States, encourages a similar multiplicity of arenas, since each government can, if it chooses, create one. (Or, occasionally, more than one.) The other is that the developer must win in every arena, get over every hurdle. This means that the developer must fight in every battle, while the technology opponent can choose when and when not to fight. This asymmetry goes a long way toward countering the natural opposing asymmetry produced by the developer's longer purse and typically greater technological and legal expertise; we are not wise enough to know on which side the balance comes out, and far too wise to guess.

The values that govern the behavior of a regulating agency are quite a bit more complex than those that govern the behavior of a technology proponent or opponent. Unlike the opponents, and unlike some proponents, the regulator has an explicit, externally defined mission, specified by statute. The responsibility of a regulating agency is to interpret and implement the intentions, often stated very vaguely, of the legislation that created it. This task, of course, must be done with due attention both to changing technological realities and to the current political pressures. Thus, regulators are coherent but responsive; not much pressure exists on them to be consistent from one case to another.

Regulatory agencies may be relatively supportive of new technologies, like the Nuclear Regulatory Commission, or less so, like the Environmental Protection Agency. We cannot find a convincing example of a regulatory agency that is highly critical of the technology it regulates. Without evidence, we speculate that a key determiner of the degree of supportiveness of the regulator is the security of the agency. Agencies derive security both from age and history and from being in control of many kinds of business, not just one. If the United States should eliminate nuclear power from its future, the NRC would wither. So long as people eat, we can think of no scenario that would cause the FDA to wither.

Far more than opponents or proponents, regulators must tend their images. As adjudicatory agencies, they must be seen as fair by the parties of the disputes and by numerous publics. They must convince experts about the technology that they are expert. In addition, they must be successful. A regulatory agency whose rulings are consistently reversed on appeal to the courts would lose both credibility and all usefulness.

An issue in image-tending for regulatory agencies is the origins of staff members. The

NRC is often seen as proindustry because it is staffed with nuclear engineers, many of whom are AEC veterans. The EPA and OSHA are often seen as antiindustry; they initially attracted many nonindustry experts who were sympathetic to environmental and occupational protection.

Implementing these values under such constraints is tough. Formally, any regulatory agency has an "easy out": statutory mandate for procedures and preferences. This "out" cannot solve the problem of fairness for any agency which is required to promote the technology it regulates; that is why the AEC no longer exists. Insiders in most regulatory agencies say that safety lies in playing it straight. The amount of oversight a regulatory agency receives from Congress, the press, and the courts pretty much requires that if the agency acts at all, it must play by the book. Though the NRC is seen as the most favorably inclined of all regulatory agencies to the technology it regulates, the nuclear industry does not regard the NRC as a friendly party.

But the wide discretion that regulatory agencies typically have makes the formal solution incomplete. It must be supplemented with wisely selected policies initiated by the agency itself. The task of balancing statutory mandate, legislative intent, the need to be perceived as fair, direct business and interest group pressure, indirect pressure applied by political mechanisms, and the requirements of the problem as understood by the regulating agency's technical people is one of the most interesting wire-walking acts American politics has to exhibit.

The fact that the balancing act is so delicate means that the regulatory agencies have little maneuvering room, and, consequently, little use for broad strategies of the kind we sketched for technology proponents and opponents. When the political issues are ticklish, the major tool available to the regulatory agency is delay. This serves the opponents well and the developers ill, but it is easy to justify (often in the form of a request for additional information) and it postpones the day when the agency has to take a stand—thereby incurring the wrath of at least some of the contending forces.

The other natural tool available to the regulatory agency is to say "no." The legislation leading to the existence of a regulatory agency was invariably the result of concern over hazard. It is very difficult to attack a regulator who identifies a hazard and prohibits it for not having carried out the intent of the legislation, while such attacks are routine when a regulator says "yes." But this tool must be used with great discretion; a regulatory agency that consistently says "no" has no political future.

Issues are substantially less dramatic if the choice confronting the regulator is not "yes" or "no," but rather "how much." "How much" is always a technical question, and arguments can always be made for various values. Whenever possible, therefore, regulators try to avoid phrasing what they do in "yes–no" terms, and instead try to address "how-much" versions of the problem. Moreover, "how-much" questions keep the regulator's technical staff happy and employed.

Rules

Arenas specify rules of procedure and also define audiences; these specifications determine in a relatively detailed way how each class of stakeholder can best implement values fought out in conflicts. We have already mentioned that this fact is more useful to opponents than proponents, since opponents can choose the arena whose rules are most favorable. Strictly worded laws, like the Endangered Species Act, provide opponents with an opportunity to use a very narrow argument (e.g., that a project endangers the survival of the snail darter fish) to halt a project for which the stakes are, for most, much higher.

The legal and quasi-legal rules in regulatory proceedings invite fact finding, examination of procedures, and arguments about what the law says or means. Seldom is that a good context in which to explore or negotiate about issues of fundamental conflicts over values. The greater latitude of regulatory proceedings makes such issues easier to examine there than in courts. The courts differ from the regulatory arenas in being more procedural, more powerful, and less expert. If a regulatory arena exists, the law usually provides that it must be used first.

City councils and legislative procedures at state and national levels follow quite different rules, which shift the emphasis from fact finding to evaluations and from single-issue debates to the task of identifying and packaging options, and then winning acceptance for them from conflicting stakeholders. Negotiating and trading are explicitly required. This of course encourages stakeholders to be persuasive, i.e., to lobby. Technology sponsors can offer tangibles like local economic benefits and jobs. Technology opponents cannot; they must get their clout from voting power, plus as much persuasive skill as they can muster. Regulatory agencies enter the legislative arena also, but not ordinarily as advocates. They may simply motivate action and provide expertise. If they have any substantive stake, it is to be given an orderly, straightforward set of rules to enforce—preferably ones that focus on factual issues rather than value conflicts. This latter statement is predicated on the notion that the regulatory agency is already in place; if not, the first issue is whether the risk should be regulated. If a regulator is absent, it means some other government body is dealing with the issue, hampered by a set of rules ill-suited to the task and pressured by the stakeholders to "do something."

NEEDS FOR FUTURE RESEARCH

Our comparative developmental study of old and new risks yielded a conclusion that was new to us: the biggest change from previous to present risk controversies is that present ones fall under the control of regulatory agencies, while most early ones did not. Much of our discussion has focused on the development and characteristics of these agencies. Our ideas about future research also focuses on them.

We would like to understand, better than we do now, the dramatic increase in the number of such agencies and the development of conflict-reduction tools within each.

We suppose that the enhanced awareness of risks provided by the media leads to both a more rapid and a better informed development of public concern about them. Obviously, this reasoning helps explain the increase in regulatory agencies, but it also raises some interesting developmental questions. Initial concern about steamboats was economic, but was rapidly supplemented by public fears of their danger. This led to two simultaneous events: development of a rudimentary set of regulatory procedures, and technological development that enhanced safety. The enhanced safety led to decreased public concern, and eventually the regulatory agencies just about vanished.

Is that the normal developmental pattern for the relations among risk production, risk perception, and risk regulation? It seems possible, but unlikely. The disappearance of the steamboat regulatory agencies has few parallels; it seems more likely that such organizations will remain in vestigial form long after they outgrow their usefulness. More important, however, is the cycle of risk perception leading to risk regulation, the combination of risk regulation and natural technical development leading to risk reduction, and risk reduction leading to reduced public concern about risks. That pattern clearly has occurred in the aviation industry; commercial flight was regarded as dangerous in the 1930s, but is considered

very safe today, in part because of technical development and in part because of regulation. There does not seem to be any reduction of regulation within the United States. But U.S. technical progress has clearly served to make unnecessary the development of similarly complex regulation in many other parts of the world (Europe being the exception). A better understanding of this kind of developmental link among production, perception, and regulation would be very helpful.

Finally, we are especially interested in developing procedures for eliciting, measuring, and using risk-related values. Such values produce laws and thus define arenas (courts, hearings) and regulatory procedures. But the arenas and the regulatory procedures alike tend to be formal and confrontational. We believe that more explicit knowledge of values and better ways for stakeholders to communicate about their value conflicts would permit the stakeholders themselves to find more constructive compromises, and might permit the development of new kinds of arenas (e.g., mediation) in which more adaptive and flexible compromises could be worked out. It should be easier than it is at present to find solutions to public conflicts about technologies that are acceptable to many stakeholders; after all, so far this has been a game in which just about everyone has been a winner, and we know of no reason to believe that the facts about human inventiveness and flexibility that make that true have changed. We feel that improved ability to elicit and work with stakeholders' values should inevitably lead to better risk management.

SUMMARY

Why is risk such an important topic in contemporary debates about new technologies? Four answers have been proposed: (1) risk may have increased; (2) risk perceptions may have been enhanced; (3) social values and preferences emphasize risks, not benefits; and (4) institutional changes may have caused increased attention to risks. The purpose of the paper is to examine these explanations by reviewing past and present technological controversies.

An early case was the steamboat. Although original opposition, as usual, came from those whose livelihoods were threatened, accidents soon aroused public concern. This led to Congress's passage of the first bill regulating a risk in 1838. After being toughened in 1858, the regulation was effective and public concern declined.

Opposition to the automobile because it was risky began in the mid-1920s and continues to this day. But only the unfortunates whom the new technology made jobless ever wanted to prevent its use.

Opposition to the zeppelin in the 1920s and 1930s, triggered by several disastrous accidents, peaked after the 1937 *Hindenburg* disaster and eventually caused abandonment of the concept.

Opposition on environmental grounds to the planned SST grew steadily from 1967 to 1970. Finally, its development in the United States was terminated for both economic and environmental reasons.

A major public debate over a LNG terminal in California began in 1973; the issues were economic advantage versus environmental risks. The initial issue was where the import site should be located. As demand for natural gas decreased, Pacific Lighting decided to postpone indefinitely development of a terminal at the site chosen in Point Conception.

The Japanese bullet train is fast but noisy. Protests about the noise led the Japanese Environment Agency to set noise standards in 1975. That action and other opposition has caused abandonment of sweeping development plans.

The comparison between past and present technology debates makes clear that the debates are suprisingly similar; the involvement of risk and other issues in such arguments has changed little, although specific concerns about the environment, ecology, and endangered species are new. Technologies have fallen on harder times because of increased scale, the emergence of regulatory agencies and single-issue organizations that can fight them, changes in arenas to emphasize regulatory organizations and courts rather than political bodies, and the transformation of technology debates into adversary procedures in which experts take sides. The scale of technologies involved in controversies is now larger; decisions take longer. New laws and regulatory agencies, which enforce them, delay or prevent introduction of new technologies and create new arenas in which to fight. Partisan experts work for developers, opponents, and regulators, and disagree in public.

A comparison of the controversies involving DNA research and nuclear energy shows the opposition to these technologies was similar in content, but different in the processes of resolution. Public concerns about risks evolved similarly in the two cases. But the debates were about different issues, and the institutions and regulatory processes differed. Partly as a result of public mistrust of the regulation of nuclear power, the opposition to nuclear energy was stronger than that to genetic engineering.

Of the four reasons for the importance of risk, all four have changed from past to present. But changes in institutions seem especially important, particularly those involving the development of regulatory agencies as arenas. Regulatory organizations came into existence during the early 19th century, stimulated by the expansion of the railroads. Economic regulatory agencies like the Federal Trade Commission followed. Many new regulatory agencies were created during the 1930s, and the Atomic Energy Commission was created in 1946 to regulate the development and safety of nuclear energy. Other risk-regulating agencies emerged later. Regulatory agencies, legislative bodies, and the courts provide the arenas for risk controversies.

Technology developers want to promote their technologies and to make a profit. Regulators can tread on their toes by being unpredictable, causing delays, and increasing cost.

Technology opponents want to set limits on technologies to prevent them from adversely affecting relevant values, such as preservation of the environment. Their values range from self-interest to broad public concerns.

Regulatory agencies have complex values. They must carry out their missions, tend their images, appear fair, be convincingly expert, and be successful. Implementing these values is tough. Safety lies in playing it straight, because of various forms of oversight. Regulators have two main tools: delay and denial. If a regulatory agency does not say "no," it can say "how much"—a technical question.

Arenas specify rules and audiences, and thus help stakeholders decide how to implement values in conflicts. Legal rules in regulatory proceedings invite fact finding, examination of procedures, and arguments. The latter environment is not a good context in which to negotiate about conflicts. Future research should examine the dramatic increase in the number of regulators, help them develop conflict-reduction tools, and examine the developmental pattern linking risk production, risk perception, and risk regulation. It is important to develop procedures for eliciting, measuring, and using risk-related values (see Edwards and von Winterfeldt, 1986).

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REFERENCES

Abbott, P. *Airship,* New York: Charles Scribner's Sons, 1973.

Bond, V. Radiation standards, particularly as related to nuclear power plants. Raleigh, N.C.: Council for the Advancement of Science Writing, 1970.

Burke, T. G. Bursting boilers and the Federal power. *Technology and Culture,* 1965, 1–23.

Chemistry, "Ozone and the SST," April, 1973.

Dayton, F. E. *Steamboat days.* New York: Frederick Stokes Company, 1925.

Del Sesto, S. L. *Science, politics and controversy: Civilian nuclear power in the United States, 1946–1967.* Boulder, Col.: Westview Press, 1979.

Douglas, M. and Wildavsky, A. *Risk and culture.* Berkeley: University of California, 1982.

Drago, H. S. *The steamboaters.* New York: Dodd, Mead and Co., 1967.

Duncan, O. D. Sociologists should reconsider nuclear energy. *Social Forces,* 1978, *51,* 1–22.

Eckener, H. *My zeppelin.* London: Putnam, 1958.

Edwards, W. and von Winterfeldt, D. Public values in risk controversies. *Risk Analysis,* 1986 (in press).

Flink, J. J. *America adopts the automobile, 1895–1910.* Cambridge, Mass.: The MIT Press, 1975.

Gyorgy, A. *No nukes.* Boston: South End Press, 1979.

Hashimoto, M. Present status of noise regulation and control in Japan. *Inter-Noise,* 1975, 719–724.

Hearnes, R. P. *Zeppelins and super-zeppelins.* New York: Lane, 1916.

Hill, R. N. *Sidewheeler Saga.* New York: Rinehart and Co., 1953.

Ikeda, S. and von Winterfeldt, D. Standards against noise pollution: The case of the Shinkansen trains in Japan. *Journal of Environmental Management,* 1982, *14,* 3–16.

Inglehart, R. Values, objective needs, and subjective satisfaction among western publics. *Comparative Political Studies,* 1977, *4,* 428–458.

Kohlmeier, L. M. *The regulators.* New York: Harper & Row, 1960.

Lawless, E. W. *Technology and social shock.* New Brunswick, N.J.: Rutgers University Press, 1977.

Levy, E. *The people's lobby.* New York: Delacorte Press, 1973.

Life, "Let's ground the SST," March 19, 1971.

Linnerooth, J. A short history of the California LNG terminal. Laxenburg, Austria: International Institute for Applied Systems Analysis, October, 1980.

Lombardo, T. G. The decision makers: A cacophony of voices. *IEEE Spectrum,* 1979, *18,* 81–91.

The Los Angeles Times, January 26, 1982, p. A1.

Mazur, A. *The dynamics of technical controversy.* Washington, D.C.: Communications Press, Inc., 1981.

Metzger, H. P. *The atomic establishment.* New York: Simon & Schuster, 1982.

The Nation, "The automobile's death toll," March 8, 1922, pp. 279–281.

The Nation, "Last stand at the western gate," August 25, 1979, pp. 136–138.

Nelkin, D. (ed.) *Controversy: politics of technical decisions.* Beverly Hills: Sage, 1978.

The New Republic, "The murderous motor," July 7, 1926, pp. 186–280.

Otway, H. J. and von Winterfeldt, D. Beyond acceptable risk: On the social acceptability of technologies. *Policy Sciences,* 1982, *14,* 247–256.

Raimundo, J. LNG: Where, when, and why? *Sierra,* June 1, 1978, pp. 35–38.

Renn, O. Analyse der Sozialverträglichkeit von Energiesystemen. Technical Report, KFA Julich, Julich 1982.

Slovic, P., Fischhoff, B., and Lichtenstein, S. Characterizing perceived risk. In R. W. Kates and C. Hohenemser (eds.) *Technological hazard management.* Cambridge, Mass.: Oelgeschlager, Gunn, and Hain, 1981.

Starr, C. and Whipple, C. Risks of risk decisions. *Science,* 1980, *208,* 1114–1119.

Sternglass, D.K. Infant mortality and nuclear tests. *Bulletin of the Atomic Scientists,* 1969.

Straszak, A. and Tuch, R. *The Shinkansen high speed rail network of Japan.* New York: Pergamon Press, 1977.

Time, "A fast fix for a scarce fuel," March 13, 1978.

U.S. News and World Report, "SST: Is it worth the price?" May 25, 1970, p. 70.(a)

U.S. News and World Report, "Major blowout for the supersonic plan," February 12, 1970.(b)

Wade, N. *The ultimate experiment.* New York: Walker and Co., 1977.

4

Contemporary Worldviews and Perception of the Technological System

David M. Buss, Kenneth H. Craik, and Karl M. Dake

INTRODUCTION

Perhaps one of the most central public policy issues in the past two decades has been focused on explorations of the ways in which appropriate relations may be fostered between modern industrial societies and their environments. Two general strategies may be followed in this exploration, one tightly focused, the other wider-ranging. The narrow-gauge strategy typically examines in depth the details of a specific environmental variable. In contrast, the broad-gauge strategy seeks to identify the major systems and to examine the interplay and linkages among them. Our investigation of the perception and management of technological hazards has been guided by the broader strategy, involving a conceptual framework that examines the interplay among personal, societal, and environmental systems (Figure 1)(Craik, 1972).

The personal system refers to the skills, cognitive capacities, values, dispositions, and psychodynamics of the individual. The societal system encompasses the institutional structures, regulatory principles, technological capacities, and adjustment mechanisms of a society. The environmental system may be viewed as a dynamic linked network of physical, chemical, and biological subsystems. Within this model, each of the three entities in Figure 1 represents a class or set of conceptual scientific constructions (that is, there exists a variety of formulations of personality and psychological functioning, several theories of society, and an array of sciences dealing with the environmental system).

Cross-disciplinary fields of inquiry have focused upon aspects of these intersystemic relations. Thus, examination of the interplay of personal and societal systems are undertaken within the research traditions of personality and social structure (Smelser & Smelser, 1970), political psychology (Knutson, 1973), and personality and culture (Hsu, 1961). Relations between societal and environmental systems are studied by the ecological approach in cultural

David M. Buss • Department of Psychology, University of Michigan, Ann Arbor, Michigan 48109. *Kenneth H. Craik and Karl M. Dake* • Institute of Personality Assessment and Research, University of California—Berkeley, Berkeley, California 94720.

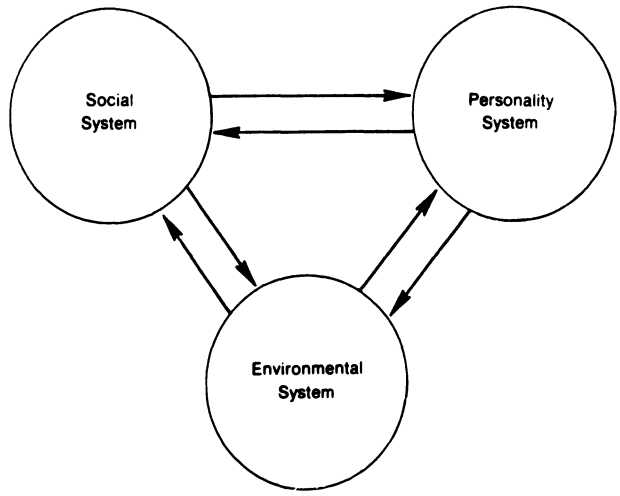

Figure 1. Personal, societal, and environmental systems.

anthropology (Vayda, 1969) and the new field of environmental sociology (Dunlap & Catton, 1979). Interrelations between the personal and environmental systems are the province of the new field of environmental psychology (Craik, 1973; Stokols, 1978; Russell & Ward, 1982).

Within our own research program, the personal system can be viewed from two perspectives. The first entails an examination of the modal group perceptions of technology hazards and their management. Is fossil electric power, for example, generally perceived as more hazardous than the alternative technologies of hydroelectric power or solar collectors? Analysis of modal group perceptions addresses questions at this level. The second perspective on the personal system involves examining differences among individuals in their perceptions and preferences. This mode of analysis is central to our research program. For example, do some individuals characteristically perceive more risk to be associated with an array of technologies than do other individuals? Thus, the personal system, within our research program, is represented by complementary analysis at the levels of modal group perceptions and systematic individual variations in perceptions of technology.

IMPORTANT PREVIOUS RESEARCH

Our formulation of the interplay among personal, societal, and environmental systems is guided by two research approaches to issues in environmental psychology: the environmental perception paradigm and the personality research paradigm (Craik, 1977).

Environmental Perception and the Perception of Technological Hazard and Its Management

The study of environmental perception examines individuals' experiences of their everyday physical environment and deals with the processes and factors influencing their varied impressions of environments. Within this strategy, the term *perception* has been used broadly, encompassing not only immediate visual perception but other forms of environmental awareness as well, and pertaining to both descriptive and evaluative responses. A wide-ranging research agenda has been pursued in the study of environmental perception, including per-

ception of landscapes (Elsner & Smardon, 1979), perception of urban and rural settings (Rapoport, 1977; Feimer, 1983), and perception of natural hazards (Burton, Kates, & White, 1978). The findings of this research approach have been seen as pertinent to a number of contexts in environmental planning and management (Craik & Zube, 1976; Rowe & Chestnut, 1983; Saarinen, 1976).

The perception of the environment as hazard (Kates, 1976) has not been neglected in this research field. Indeed, certain studies of the perception of flood hazards constitute classic contributions to our understanding of environmental perception (Burton & Kates, 1964; Kates, 1963; White, 1961). This analysis of perception and choice has been extended to other natural hazards (e.g., avalanches, blizzards, earthquakes, hurricanes, volcanic eruptions) in a cross-national research program (Burton, Kates, & White, 1978; White, 1974).

Analysis of the perception of technological hazards and their management to some extent grew out of these earlier studies of the perception of natural hazards (Kates, 1977). Technology and its perception occupies an interesting place in the relations between societal and environmental systems. In the broadest sense, the technologies of a society represent its means of adjusting to its environment to meet the functional prerequisites of a society (Aberle, et al., 1950). At the same time, the exercise of a society's technologies constitutes the source of its distinctive impact upon the form and potential of its environment. Thus, technology can be viewed both as societal process and as a set of environmental components and consequences. The perception of technology also incorporates these facets (Craik, 1985).

From the perspective of our conceptual framework, we have assumed that the individual agent not only forms impressions of the attributes of specific technologies but also forms impressions of the societal institutions that manage the technologies and the societal processes for reaching decisions about them. These impressions may range from vague and relatively unarticulated views to well formulated belief systems.

Perceptions of Technologies. Studies of the perception of technologies have thus far been relatively restricted in scope. Researchers have attempted to explore the full range of cognitive representations of the perception of landscapes, urban and rural settings, and specific living and work environments; the variety of descriptive terms used in depicting them; and the breadth of affective reactions to them (Craik, 1971, 1981; Ward & Russell, 1981; Russell & Pratt, 1980).

In contrast, current research in the perception of technologies has been influenced by an initial purpose of bringing a psychological viewpoint to bear upon safety analyses and the quantification of risks from technologically based activities (Otway & Thomas, 1982). Thus, the most important pioneering study in this tradition (Fischhoff et al., 1978) analyzed judgments of the perceived risk, perceived benefit, and acceptable risk of specific technologies. In addition, nine descriptive attributes of perceived risk (e.g., voluntariness, catastrophic potential, number of persons exposed) were studied.

In our research program, we have continued the exploration of the perceived risk and perceived benefit of specific technologies. Slovic et al. (1982) convincingly argue that the issue of risk acceptability is more incisively framed as the acceptability of technologies. Thus, we have obtained attitude judgments (favorable-unfavorable) toward specific technologies.

Perceptions of Societal Decision Processes. A society can reach decisions about how to adjust and react to droughts, earthquakes, and other natural hazards whose occurrence is largely unpredictable and uncontrollable. But it can also decide whether or not it will even develop and thus ever encounter certain technologies, with their attendant hazards.

Thus, the societal decision processes concerning technologies and the perceptions of these processes take on special importance.

Within the expert realm of technological risk assessment, a number of alternative approaches to societal decisions have been advanced and are being considered (Fischhoff et al, 1981). The use of certain approaches such as cost–benefit analysis appear to be controversial within expert circles (Williams, 1972) and may yet emerge as significant political issues (Shabecoff, 1981). In our research program, we have begun to examine individuals' perceptions of societal decision approaches (e.g., cost–benefit analysis, implied preferences, professional judgment). We are also studying the perceived desirability of a set of attributes of decision approaches (e.g., fair, aids clear thinking, economically oriented, logically sound).

In certain ways, an issue prior to the decision approach or process concerns the locus of decision making: Who shall decide? (Slovic et al., 1980). Should decisions about technology, for example, be made by appointed regulatory agencies, by elected officials, or by the general public? In addition to examining perceptions of societal decision approaches, we have added a scrutiny of perceptions and preferences concerning the locus of decision making, or deciding who shall decide.

Personality and the Sociotechnological Environment

Imagine an ordinary citizen, Samuel Mendon. Because Mr. Mendon resides in a modern technological society, he may encounter motor vehicles, computers, Polaroid cameras, nuclear power plants, photocopy machines, and a wide variety of other technologies. And in the mass media and everyday conversations, he is offered an ongoing discourse regarding public policy toward technology, agency performance, emergencies and triumphs, and prospects for the future that are grim or rosy. Let us suppose that Mr. Mendon is unusually fortunate and during a one-month period participates in six separate studies: (1) he judges the perceived benefits and risks of an array of alternative energy technologies; (2) he gives his views on the possible siting of a hazardous waste treatment facility in his area; (3) he reports his behavior and attitudes concerning auto seat belts; (4) he is polled on his confidence in the Nuclear Regulatory Commission; (5) he appraises the impact of alternative electric power transmission tower designs upon the scenic quality of undeveloped countryside in his region; and (6) he cites any respiratory symptoms he has noted since moving to his new workplace.

Each independent research team would use the data from Mr. Mendon's responses for its own scientific purposes. The findings of the studies would be used to meet the discrete and urgent needs of each sponsoring agency (which in this case might be the Department of Energy, the Environmental Protection Agency, the Federal Highway Administration, the Nuclear Regulatory Commission, the Bureau of Land Management, and the Occupational Safety and Health Administration, respectively). This example highlights the fact that each citizen serves as a constituent for a wide array of governmental agencies and programs having varied responsibilities for society's actions within the realm of the sociotechnological environment.

The rare sequence of events encountered by Mr. Mendon, however, would also usefully turn the focus of attention upon himself, not as an occasional agent within the sociotechnological environment, but as a single enduring organism, a distinctive personological entity, a system with its own structure, dynamics, and behavioral order (Craik, 1976). Without coordinated research efforts, the order that may exist among an individual's diverse technologically relevant attitudes and behaviors would remain unexamined.

Over the past five decades, the personality research tradition (Pervin, 1975; Wiggins, 1973) has advanced our knowledge of the personal system through the development of a comprehensive array of techniques for describing the diversity of individual differences among persons (Buss & Craik, 1983a; Goldberg, 1971; Kleinmuntz, 1982; Sundberg, 1977). These attributes of personality encompass intrapsychic dynamics, interpersonal traits, personal values, cognitive capacities and styles, vocational interest patterns, attitude orientations, and psychopathological propensities. Some of these dimensions of interindividual variations refer to the way a person relates to himself (e.g., self-accepting), some to his characteristic manner of relating to others (e.g., nurturant), and some to his style of relating to the everyday physical environment (e.g., stimulus seeking).

Our research program has been guided by five major assumptions that link the personality of citizens to their orientation toward the sociotechnological environment: (1) specific technologies are not perceived in isolation but as part of a broader sociotechnological environment; (2) the sociotechnological environment does not consist merely of technological processes and their artifacts but also includes the decision-making structure for their development, deployment, and risk management; (3) even the perception of the sociotechnological environment takes place within a broader framework of the person's understanding and satisfaction with society and its functioning, its social evolution, and its potential fate; (4) individuals take a stance toward this complex matrix of technology and society in more or less organized and coherent fashion guided by wide-ranging contemporary worldviews; and (5) these contemporary worldviews are linked in one direction with present-day and often controversial public policy issues about technology and its management and in another direction with other important personality characteristics (Buss, Craik, & Dake, 1982).

From our perspective, the bridging elements between the person and the sociotechnological environment are contemporary worldviews. Within the United States and other industrial nations, discourse among experts and public leaders over the past two decades has generated an evolving and expanding issues complex in which policies regarding resources, population, environment, technology, economics, energy, and broad societal purposes are increasingly recognized as interrelated (Buss & Craik, 1983b). The cognitive and attitudinal response of ordinary citizens to this issue domain constitutes their contemporary worldviews. The identification of systematic individual differences among persons in their contemporary worldviews is a task for personality research that we have undertaken.

Our approach also has been guided by previous analyses of expert discourse and interpretations of public opinion findings. Within the arena of expert discourse, certain broad themes and orientations have emerged. For example, in the area of energy policy analysis, commentators have discerned a tripartite structure with one orientation calling for continued growth in energy supplies, a second calling for conservation and changes in demand, and a third calling for radical cultural and social transformations (Thompson, 1981).

Other observers have formulated a bipartite structure to expert discourse. Dunlap (1983a, 1983b) notes a paradigmatic chasm separating two fundamentally opposing worldviews: (1) the exemptional worldview, which stresses the ingenuity of humans in using science and technology to create resources, control pollution, provide food sources, and so on, thereby exempting humans from the ecological limits which constrain other species; and (2) the ecological worldview, which does not view the unique characteristics of humans as exempting them from ecological constraints and which sees efforts to extend limits via technology as creating more problems than they solve.

Within the broader arena of public opinion, Cotgrove (1982) refers to two patterns of beliefs and attitudes: (1) the cornucopian position, entailing core values of material economic growth, worth of the natural environment as a resource, dominion over nature, and confidence

in a bountiful future; and (2) the catastrophic position entailing core values of nonmaterial self-actualization, the intrinsic worth of the natural environment, harmony with nature, and alarm about the prospects of a dreadful future if present trends continue. In a parallel formulation, Milbrath (in press) has reviewed evidence for a culturally dominant, nonenvironmentalist system of beliefs and values as well as a newer environmentalist system of beliefs and values.

From the vantage point of the personal system (Figure 1), an individual's contemporary worldview represents a more or less integrative way of sizing up and responding to the complex ramifications of the sociotechnological environment. The organization of a given person's contemporary worldview is likely to derive in part from individual cognitive effort and in part from formulations encountered by the individual in public forums and the mass media. This process of personal insight and cultural selection is also likely to be compatible with and in some sense express broader aspects of personality, such as personal values and lifestyle commitments (Smith, Bruner, & White, 1956). This expectation is supported by the intensity with which even experts have debated these issues and advanced their positions. Controversies have been linked to deeply held attitudes and beliefs (Cumming, 1981; Holdren, 1981; Inhaber, 1981) and to competing paradigms that are not, in the last analysis, scientifically testable but whose implications are seen as having great significance (Dunlap, 1983b; Ehrlich, 1982; Simon, 1982).

In summary, our research program pursues three aims: we are assessing individual differences among persons in their contemporary worldviews; exploring the relation of these contemporary worldviews to the perception of technologies and to the perception of societal decision processes regarding technology; and examining the relations of contemporary worldviews to other facets of personality.

CURRENT RESEARCH

In the following pages, the development and nature of our procedures for assessing contemporary worldviews will be described briefly. The focus will then shift to our findings from general public samples regarding the perception of a selected set of technologies and the perception of options regarding societal decision procedures. Modal results for our samples will be supplemented by correlational findings on the relation of the contemporary worldviews to the perceptions of technologies and social decision processes.

Assessment of Contemporary Worldviews

The assessment of contemporary worldviews was guided by a tripartite formulation of expert discourse on issues of technology and society (Reuyl et al., 1977) and a pilot study of university undergraduates (Buss & Craik, 1983b). The analysis offered by Reuyl and his associates points to three broad stances or "perceptions": (1) perception A embodies the notion of a high-growth, high-technology, centralized free enterprise society, with a probusiness stance on regulation, materialistic goals, and rational, quantified decision- making processes; (2) perception B stresses leveling off of material and technological growth, concern about social and environmental impacts of growth, redistribution of resources from richer to poorer nations, lower levels of consumption, decentralization of both control and population, goals of human self-actualization, and participative decision making guided by nonmaterialistic values; and (3) perception C calls for a fundamental transformation of industrial society, a new rationale for planetary stewardship of the earth's finite resources, fulfilling

modes of work, and forms of decision making and societal goals drawn from the spiritual aspects of human nature. Due to the lack of terms in ordinary language to capture fully these wide-ranging orientations, we have continued the original designations of A, B, and C, respectively, but refer to them as contemporary worldviews rather than as "perceptions."

A set of 16 statements was used to represent the facets of each worldview.* Our findings from a sample of the general public indicates that the measures of contemporary worldviews B and C are largely redundant, showing a correlation of (+0.77) in one sample. This failure to distinguish between the two contemporary worldviews may reflect (1) the absence of a worldview that is conceptually distinct from contemporary worldview B, (2) inadequacy in the content of the measure of contemporary worldview C, or (3) lack of an adequate representation of that viewpoint within a sample drawn from the general public. Thus, we have directed our study primarily to the role of contemporary worldviews A and B in the perception of technologies and their societal management.

Table 1 presents the set of statements that compose the measures of contemporary worldviews A and B. A research participant indicates on a rating form the extent of agreement—disagreement with each assertion, and the rating values are tallied in computing a total scale score. Thus, with a 5-point rating (ranging from 1 = strongly disagree through 5 = strongly agree) a person's contemporary worldview score can range from 16 (a rating

Table 1. Contemporary Worldviews

Worldview A

1. A high-growth, high-technology society provides the best hope for raising the poor to a high state of material and social well-being.
2. The ability to achieve humane goals has been and will continue to be made possible through economic growth and technological progress.
3. Hard-headed rationality should be the basis of decision making in society.
4. The benefits of a high-growth, high-technology society, as compared with any feasible alternative, are obvious.
5. The social costs of abruptly slowing economic growth rates (such as unemployment and dooming the poor to hopelessness) are too high to accept.
6. Regulation is necessary in a highly complex modern society but it should be applied with moderation; we must not kill the goose that lays the golden eggs.
7. Some of the decentralization talk heard nowadays is romantic nonsense; we can never go back to the family farm.
8. Quantification of data and the development of the conceptual frameworks of economics have contributed greatly to the quality of decision making in our society.
9. The United States has a responsibility to use its technological and economic leadership in aiding the poorer nations to industrialize and modernize.
10. On the whole, centralization promotes efficiency and effective management.
11. Those pessimists who see crippling shortages in the near future are ignoring our demonstrated ability to cope with such problems by technological innovations, substitution, exploiting lower-grade ores, etc.
12. The federal government should regulate with the *primary aim* of providing business with a stable climate needed to maintain a healthy economy and risk new technological ventures.
13. Material accomplishment and economic growth are the best means to achieve humane goals in this society.
14. Although centralization may cause some problems, it is needed in our society for efficient production and management.
15. Economic, material, and technological growth should be continued at least for the present.
16. Logic and rationality are our best guides to making decisions that affect our society.

(*continued*)

*Eighteen items were initially written for each scale. Psychometric considerations led to elimination of two items per scale.

Table 1. (continued)

Worldview B

1. Decentralization of technology and of population is necessary if we are to have a just and free society.
2. The only way to avoid regulation that will ultimately infringe on our rights and liberties is through reduced demands on resources and the decentralization of society.
3. The "new scarcity" (of physical resources, waste-absorbing capacity of the environment, resilience of planetary life-support systems) is *qualitatively different* from the scarcity problems "solved" by modern industrial production.
4. The social and environmental costs of continued technological growth and rising per capita energy consumption are intolerably high.
5. Humane ends can be attained only through more emphasis upon human growth and development and less emphasis on material accomplishment and consumption.
6. Decision making in our society should be made as participative as possible and guided more by humane criteria.
7. Social choices should be made, not on the narrow base of profit and productivity, but on the broader basis of social efficiency—does it pollute the environment, squander resources, bring about unemployment, frustrate workers, misguide consumers?
8. The answer to our energy and resource problems is voluntary simplicity and frugality in lifestyle and abandonment of the consumption ethic.
9. Richer nations like the United States must consume less, support the redistribution of resources, and recognize the validity of societal choices other than Western-style industrialization and agribusiness.
10. The rich nations of the world consume far more than their fair share of the Earth's limited resources and contribute far more than their share of environmental damage.
11. Our society should move away from the goals of material consumption and toward the goals of human growth and development.
12. The best way to avoid the regulations that necessarily go along with high consumption of resources is found in the idea that "small is beautiful."
13. A just society is best achieved by strengthening individual communities and giving local power to them.
14. Small, frugal and decentralized technologies are needed to maintain a humane and free society.
15. Reducing our current consumption of resources is the best way to avoid future harsh regulations that will infringe on our rights.
16. The United States should stop consuming more than its fair share of world resources.

of 1 on every statement) to 80 (a rating of 5 on every statement). A person who strongly endorses the array of statements exemplifying one of the contemporary worldviews can be described in a summary fashion as affirming that perspective on the evolving public issues complex dealing with resources, economic development, population, the environment, technology, rationality in decision making, broad societal values, and so forth. Each measure yields a continuous variable, locating persons according to the extent of their overall endorsement of each perspective.

Each person is assigned scale scores for both contemporary worldviews A and B. In two samples of the general public, the research scales displayed adequate reliability, showing alpha coefficients of $+0.80$ and $+0.82$ for contemporary worldview A and $+0.82$ and $+0.88$ for contemporary worldview B. Analysis of interindividual differences between the two measures shows correlations of -0.17 and -0.34 for the two samples, respectively. Thus, the two perspectives may not be bipolar in nature: one can endorse both or neither, although the trend is for stronger affirmation of one to be negatively related to affirmation of the other.

The characteristics of the two general public samples that will be the main focus of this review of findings warrant brief description. The samples were drawn from cities in the East Bay area of the San Francisco region: Richmond, Oakland, Piedmont, and Alameda. Participants were recruited via telephone directory sampling, letter of invitation, and telephone follow-up. Participants took part in a day-long session held at local public schools, in groups of about 25, during which they completed a wide range of procedures recording

their perceptions of technologies and social decision processes and assessing their contemporary worldviews, political and social orientations, personal values, and backgrounds. The primary aim of the sampling was to secure a wide-ranging cross section of the general public that would permit analysis of interindividual variations among the psychological measures of interest. The descriptive findings on the obtained samples presented in Table 2 suggest that this goal was obtained.

Perception of Technologies

A set of technologies was selected to represent prototypical examples of technology per se and to represent technologies reflecting a broad range on the dimensions of perceived risk and perceived benefit. Participants recorded their perceptions of the technologies following procedures similar to those used in previous research by Fischhoff et al. (1978). One

Table 2. Sample Descriptions[a]

	Percent sample 1	Percent sample 2	
Sex			
Male	49	46	
Female	51	54	
Age			
18–24 years	6	10	
25–34 years	28	34	
35–44 years	18	18	
45–54 years	15	12	
55–64 years	17	13	
65–74 years	14	10	
75+	2	3	
Range	21–88 years	19–89 years	
Mean	45.4 years	42.05 years	
Self-rated social class			
Lower	5	6	
Working	13	19	
Lower middle	21	20	
Middle	45	42	
Upper middle	15	12	
Upper	1	1	
Family income			1980 census
5,000 and under	7	10	6
5,000–9,999	12	11	13
10,000–14,999	9	19	14
15,000–19,999	13	14	14
20,000–24,999	17	9	14
25,000–34,999	21	20	20
35,000–49,999	12	7	13
50,000 and over	10	10	7
Education			
8th grade or less	3	1	
9th through 11th grade	4	2	
Completed high school	11	7	
Some college or technical school	40	43	
College graduate	19	17	
Some graduate work	8	14	
M.A. or equivalent	12	11	
Ph.D., M.D., LL.B.	3	5	

[a]Sample 1: 1981 Richmond–Oakland–Piedmont–Alameda (N = 166). Sample 2: 1982 Oakland–Piedmont–Alameda (N = 134).

Table 3. List of Technologies

1. Refrigerators[a]
2. Tape recorders
3. Weather modification (e.g., cloud seeding)
4. Photocopy machines (e.g., Xerox)[a]
5. Stimulants (e.g., amphetamines)
6. Pocket calculators
7. Strip mining
8. Fluorescent lights[b]
9. Contraceptives[a,b]
10. Microfilming
11. Suspension bridges[a]
12. Electric typewriters
13. Sedatives (barbiturates, Quaaludes)
14. Electron microscopes
15. Nuclear power[a,b]
16. Radar
17. Orbiting satellites[b]
18. Transcontinental oil pipelines
19. Stereo equipment
20. Electronic games[a]
21. Microwave ovens[b]
22. DNA research[b]
23. Hydroelectric power[b]
24. Diagnostic X rays[a,b]
25. Bicycles[b]
26. Nuclear weapons[a,b]
27. Power lawn mowers[b]
28. Computers[a]
29. Vaccinations[a,b]
30. Chemical fertilizers[b]
31. Anesthetics[b]
32. Water fluoridation[a,b]
33. Television
34. Rooftop solar collectors[a]
35. Radiation therapy
36. Lasers[a,b]
37. Tranquilizers[a]
38. Polaroid photographs[a]
39. Fossil electric power[a,b]
40. DDT[b]
41. Motor vehicles[a,b]
42. Private aviation[b]
43. Home appliances[b]
44. Movie special effects[a]
45. Pesticides[a,b]
46. Opiates (e.g., morphine, heroin)[a]
47. Food preservatives[a,b]
48. Open-heart surgery[a,b]
49. Commercial aviation [a,b]
50. Liquid natural gas[b]

[a] Judged by both samples.
[b] Studied also by Slovic et al. (1980).

Table 4. Risk Judgments

	Sample 1		Sample 2		CWV A		CWV B	
					Sample 1	Sample 2	Sample 1	Sample 2
Technologies	Mean	SD	Mean	SD	*r*	*r*	*r*	*r*
Computers	2.23[a]	1.77	2.02[b]	1.38	−0.10	−0.31[e]	0.18[c]	0.18[c]
Pesticides	5.26	2.23	5.05	1.60	−0.03	−0.26[e]	0.18[c]	0.29[e]
Commercial aviation	4.32	2.22	3.58	1.43	−0.05	−0.14	0.07	0.08
Diagnostic X rays	3.93	2.16	3.56	1.38	−0.18[c]	−0.16[c]	0.20[d]	0.19[c]
Nuclear power	6.85	2.40	5.67	1.88	−0.26[e]	−0.26[e]	0.31[e]	0.38[e]
Polaroid photographs	1.72	1.52	1.49	1.00	−0.05	−0.12	0.18[c]	0.03
Lasers	4.25	2.64	3.31	1.78	−0.12	−0.04	0.03	0.16[c]
Electronic games	2.08	1.76	1.87	1.29	−0.06	−0.16[c]	0.15[c]	−0.08
Open-heart surgery	5.45	2.63	4.16	1.92	0.03	0.14	0.07	−0.07
Contraceptives	4.21	2.37	3.12	1.68	0.04	−0.22[d]	0.11	0.27[e]
Fossil electric power	3.34	2.08	3.25	1.64	−0.16[c]	−0.19[c]	0.23[d]	0.11
Photocopy machines	2.17	1.77	1.76	1.18	−0.03	−0.29[e]	0.20[c]	0.11
Nuclear weapons	8.19	1.73	6.55	1.20	−0.23[d]	−0.13	0.29[e]	0.40[e]
Refrigerators	1.72	1.22	1.53	0.89	−0.12	−0.19[c]	0.16[c]	0.05
Vaccinations	2.71	1.69	2.33	1.23	−0.08	−0.26[e]	0.01	0.03
Food preservatives	4.30	2.19	3.48	1.60	−0.05	−0.23[d]	0.30[e]	0.35[e]
Rooftop solar collectors	1.87	1.40	1.44	0.91	0.10	0.03	0.01	−0.10
Movie special effects	2.43	2.00	2.05	1.41	0.02	−0.00	−0.05	−0.09
Water fluoridation	3.07	2.18	2.47	1.35	−0.13	−0.17[c]	0.25[d]	0.10
Motor vehicles	5.78	2.14	5.20	1.48	−0.07	−0.18[c]	0.19[c]	0.28[e]
Opiates	7.36	2.02	5.58	1.57	0.07	0.08	0.07	−0.01
Tranquilizers	5.84	2.25	4.92	1.58	−0.05	−0.13	0.13	0.22[d]
Suspension bridges	3.19	2.20	2.71	1.61	0.07	−0.08	0.03	0.10

[a] 1–9 rating scale. [b] 1–7 rating scale.
[c] $p < 0.05$. [d] $p < 0.01$. [e] $p < 0.001$.

of the general public samples rated 50 technologies; the second rated 25 technologies. Table 3 presents the technologies rated by the samples, identifying the 23 technologies rated by both samples and a set of technologies that were also studied by Slovic et al. (1980).

Judgments of Risk. Participants rated how risky they judged each technology to be for U.S. society as a whole at present. They were asked to take risk to mean the risk of dying as a consequence of the technology and to consider the total risk to society during the next 12-month period (Fischhoff et al., 1978).

Table 4 presents the mean ratings of risk for the 23 technologies rated by both samples. Although a different rating scale was used by each sample, the correlation between the two sets of mean judgments is +0.98, indicating that these aggregate judgments are reliable across samples. According to these public perceptions, the three most risky technologies in our set are nuclear weapons, opiates, and nuclear power; the three least risky technologies are Polaroid photographs, refrigerators, and rooftop solar collectors.

Judgments of Benefits. Participants judged how beneficial each technology is at present to U.S. society as a whole. They were asked to judge total benefits (not net benefits) and, in their overall ratings, to consider such forms of benefits as economic, health/physiological, security, pleasure, and personal freedom. With these points in mind, they were to judge the total value to society derived from each technology during the next 12 months (Fischhoff et al., 1978).

Table 5 presents the mean ratings of benefits for the 23 technologies rated by both

Table 5. Benefit Judgments

	Sample 1		Sample 2		CWV A		CWV B	
					Sample 1	Sample 2	Sample 1	Sample 2
Technologies	Mean	SD	Mean	SD	*r*	*r*	*r*	*r*
Computers	7.45[a]	1.69	6.16[b]	1.18	0.12	0.46[e]	−0.06	−0.24[d]
Pesticides	5.65	2.14	4.71	1.56	0.33[e]	0.41[e]	−0.10	−0.29[e]
Commercial aviation	7.35	1.90	5.82	1.22	0.24[d]	0.39[e]	0.07	0.07
Diagnostic X rays	7.11	1.94	5.69	1.27	0.23[d]	0.40[e]	−0.02	−0.12
Nuclear power	5.76	2.49	4.14	1.97	0.27[e]	0.36[e]	−0.19[c]	−0.34[e]
Polaroid photographs	4.92	2.44	4.38	1.77	0.17[c]	0.21[d]	0.08	−0.06
Lasers	5.65	2.38	4.97	1.59	0.14	0.36[e]	−0.05	−0.21[d]
Electronic games	4.52	2.36	3.75	1.81	0.08	0.19[c]	0.22[d]	0.09
Open-heart surgery	6.43	2.42	5.35	1.49	0.08	0.17[c]	0.04	0.04
Contraceptives	6.37	2.30	5.53	1.62	−0.07	0.05	0.27[e]	0.05
Fossil electric power	6.42	2.17	5.19	1.42	0.18[c]	0.14	−0.09	−0.05
Photocopy machines	6.60	1.89	5.29	1.62	0.26[e]	0.32[e]	−0.13	0.00
Nuclear weapons	3.98	2.87	2.73	1.97	0.27[e]	0.25[d]	−0.15[c]	−0.33[e]
Refrigerators	8.51	1.37	6.23	1.13	0.32[e]	0.32[e]	−0.01	−0.04
Vaccinations	7.78	1.60	6.09	1.17	0.11	0.32[e]	0.07	0.06
Food preservatives	5.58	2.33	4.62	1.54	0.17[c]	0.26[d]	−0.03	−0.07
Rooftop solar collectors	6.15	2.39	5.28	1.66	−0.15[c]	−0.09	0.15[c]	0.15[c]
Movie special effects	4.33	2.46	3.59	1.89	0.25[d]	0.04	0.05	0.07
Water fluoridation	5.55	2.26	4.63	1.62	0.26[e]	0.36[e]	0.04	−0.27[e]
Motor vehicles	8.08	1.22	6.16	1.09	0.30[e]	0.43[e]	−0.07	−0.11
Opiates	3.17	2.01	3.39	1.77	0.13	0.12	0.09	0.05
Tranquilizers	4.17	2.07	3.16	1.50	0.03	0.16[c]	0.03	0.04
Suspension bridges	6.21	2.17	5.31	1.59	−0.04	0.07	0.10	−0.02

[a] 1–9 rating scale. [b] 1–7 rating scale.
[c] $p < 0.05$. [d] $p < 0.01$. [e] $p < 0.001$.

samples. Again, despite a different rating scale used by each sample, the correlation between the two sets of mean judgments is +0.95, showing a reliable aggregate ordering across the samples. The four most beneficial technologies perceived by the respondents are refrigerators, motor vehicles, computers, and vaccinations; the three least beneficial are nuclear weapons, opiates, and tranquilizers.

Attitudes toward Technologies and Self-Reported Knowledge of Technologies. The public acceptance of technologies is a central policy issue. Aggregations of individual attitudes toward technologies may not fully or directly account for eventual societal acceptance or rejection, but they are germane. Perceived risks and benefits may be related to attitudes toward technologies, but other factors may also be involved. Our participants rated their general attitude toward each technology on a continuum from very favorable to very unfavorable. The most favorably judged technologies are refrigerators, vaccinations, and photocopy machines, while the least favorably judged are nuclear weapons, opiates, and tranquilizers (Table 6). The mean ratings are reliable across the two samples (+0.97).

Self-rated knowledge of technologies may bear upon attitudes in two ways. First, the seeking out of information, familiarity, and favorable attitudes may be reciprocally intertwined. Second, a perceived lack of knowledge may evoke an aura of mystery, which promotes an unfavorable attitude as well as an elevated level of perceived risk. Our participants rated their knowledge of each technology, from a great deal to very little. Those technologies considered to be best known are motor vehicles, contraceptives, and refrig-

Table 6. Attitudes toward Technologies

	Sample 1		Sample 2		CWV A		CWV B	
Technologies	Mean	SD	Mean	SD	Sample 1 *r*	Sample 2 *r*	Sample 1 *r*	Sample 2 *r*
Computers	4.31[a]	0.82	6.01[b]	1.42	0.38[e]	0.41[e]	−0.14	−0.20[d]
Pesticides	2.99	1.09	3.62	1.99	0.38[e]	0.44[e]	−0.28[e]	−0.45[e]
Commercial aviation	4.23	0.79	5.95	1.31	0.26[e]	0.41[e]	−0.04	−0.17[c]
Diagnostic X rays	3.99	0.91	5.27	1.73	0.45[e]	0.39[e]	−0.12	−0.21[d]
Nuclear power	2.91	1.32	3.27	2.15	0.40[e]	0.41[e]	−0.35[e]	−0.48[e]
Polaroid photographs	3.95	0.93	5.53	1.50	0.22[d]	0.25[d]	−0.01	−0.15[c]
Lasers	3.73	0.97	5.51	1.73	0.32[e]	0.37[e]	−0.16[c]	−0.20[c]
Electronic games	3.45	1.04	4.47	1.96	0.13	0.25[d]	−0.03	−0.08
Open-heart surgery	4.30	0.75	6.05	1.26	0.24[d]	0.33[e]	0.00	−0.16[c]
Contraceptives	3.91	1.11	5.71	1.83	−0.14	0.00	0.00	−0.03
Fossil electric power	3.43	0.97	4.74	1.73	0.11	0.31[e]	−0.14[c]	−0.25[d]
Photocopy machines	4.36	0.79	6.25	1.18	0.25[d]	0.41[e]	−0.12	−0.27[e]
Nuclear weapons	2.01	1.19	1.99	1.79	0.27[e]	0.30[e]	−0.40[e]	−0.40[e]
Refrigerators	4.67	0.71	6.57	1.09	0.21[d]	0.28[e]	−0.10	−0.02
Vaccinations	4.52	0.73	6.37	1.20	0.19[c]	0.39[e]	−0.00	−0.05
Food preservatives	2.95	1.13	3.94	2.04	0.26[e]	0.23[d]	−0.24[d]	−0.33[e]
Rooftop solar collectors	4.25	0.80	6.21	1.39	−0.23[d]	−0.20[c]	0.06	0.30[e]
Movie special effects	3.65	0.94	5.28	1.55	0.17[c]	0.17[c]	0.17[c]	−0.05
Water fluoridation	3.44	1.08	4.80	1.89	0.19[c]	0.25[d]	−0.19[c]	−0.30[e]
Motor vehicles	4.15	0.90	5.92	1.40	0.31[e]	0.44[e]	−0.16[c]	−0.34[e]
Opiates	2.01	1.13	3.00	2.03	−0.09	0.01	0.05	0.08
Tranquilizers	2.75	1.00	3.05	1.69	−0.02	0.15[c]	−0.15[c]	−0.09
Suspension bridges	3.81	0.86	5.68	1.47	0.05	0.17[c]	−0.07	−0.15[c]

[a] 1–5 rating scale. [b] 1–7 rating scale.
[c] $p < 0.05$. [d] $p < 0.01$. [e] $p < 0.001$.

Table 7. Self-Rated Knowledge of Technologies

Technologies	Sample 1 Mean	Sample 1 SD	Sample 2 Mean	Sample 2 SD	CWV A Sample 1 *r*	CWV A Sample 2 *r*	CWV B Sample 1 *r*	CWV B Sample 2 *r*
Computers	3.87[a]	1.70	3.89[b]	1.71	0.08	0.28[e]	−0.13	−0.12
Pesticides	3.62	1.55	3.87	1.46	−0.10	0.09	0.08	−0.06
Commercial aviation	3.68	1.70	3.86	1.55	0.14	0.28[e]	0.05	−0.19[c]
Diagnostic X rays	3.58	1.60	3.77	1.49	0.10	0.05	0.15[c]	−0.02
Nuclear power	3.34	1.73	3.84	1.63	−0.14	−0.04	0.15[c]	0.08
Polaroid photographs	3.68	1.63	3.86	1.66	0.20[d]	0.21[d]	0.04	−0.24[d]
Lasers	2.62	1.61	2.99	1.72	0.23[d]	0.20[c]	−0.05	−0.21[d]
Electronic games	3.56	1.71	3.84	1.59	−0.08	−0.16[c]	0.13	−0.07
Open-heart surgery	3.44	1.74	3.46	1.65	0.08	0.12	0.13	−0.20[c]
Contraceptives	4.79	1.66	4.99	1.67	−0.18[c]	−0.04	0.17[c]	−0.01
Fossil electric power	2.98	1.83	3.11	1.90	0.02	0.09	−0.03	−0.12
Photocopy machines	3.85	1.54	4.45	1.61	0.18[c]	0.34[e]	0.03	−0.18[c]
Nuclear weapons	3.30	1.77	3.86	1.67	−0.04	−0.10	0.29[e]	0.11
Refrigerators	4.45	1.49	5.01	1.47	0.16[c]	0.26[e]	−0.12	−0.19[c]
Vaccinations	4.35	1.45	4.79	1.55	0.08	0.20[c]	0.10	−0.17[c]
Food preservatives	3.87	1.60	4.29	1.51	−0.01	0.06	0.26[e]	−0.02
Rooftop solar collectors	3.78	1.82	3.86	1.77	−0.09	−0.05	0.04	0.04
Movie special effects	3.27	1.78	3.55	1.62	0.05	0.07	0.16[c]	−0.01
Water fluoridation	3.78	1.63	3.92	1.39	−0.02	0.19[c]	0.19[c]	−0.14
Motor vehicles	5.31	1.37	5.28	1.24	0.13	0.21[d]	−0.13	−0.12
Opiates	3.33	1.82	3.79	1.72	−0.05	−0.06	0.10	0.05
Tranquilizers	3.67	1.69	3.84	1.60	0.13	−0.08	0.08	0.05
Suspension bridges	3.17	1.71	3.43	1.71	0.09	0.06	0.02	−0.23[d]

[a] 1–7 rating scale. [b] 1–7 rating scale.
[c] $p < 0.05$. [d] $p < 0.01$. [e] $p < 0.001$.

erators, while the least known include lasers, fossil electric power, and suspension bridges (Table 7). The low rating of fossil electric power may reflect an unfortunate choice of too technical a term for coal- and oil-generated electric power. This problem indicates one limitation of the use of brief verbal presentations of the technological entities being studied. The mean ratings for the technologies, however, are reliable across the two samples (+0.95).

Comparisons among Aspects of Technological Perception. For this set of 23 technologies, the mean judgments are located on the high end of the scales by more than 2 to 1 on favorable attitude and benefit, while they are located by more than 2 to 1 at the lower end of the scales for self-rated knowledge and risk. These trends appear in the results for the full set of 50 technologies as well. Whether they can be generalized to all technologies is not readily determined. Specifying the complete domain of technologies and sampling representatively from it are tasks that present interesting but formidable difficulties.

Another way to compare aspects of technological perception is to examine the interrelations among judgments of attitude, benefit, risk, and self-rated knowledge. These relations can be analyzed at the level of technologies as units or at the level of individual judges. Table 8 presents the intercorrelations using technologies as units of analysis. Note the correlation between perceived benefit and perceived risk is −0.48 for sample 1 (N = 50 technologies) and −0.40 for sample 2 (N = 25 technologies). These results are similar to the most comparable study reported by Slovic et al. (1980), which found a correlation of −0.42, based on a sample of 175 college students using a somewhat different rating scale

Table 8. Correlations across Technologies between Mean Ratings

	Attitudes	Benefits	Perceived risks	Self-related knowledge
Attitudes	—	0.82[b,c]	−0.75[b,c]	0.29[b]
Benefits	0.80[a,c]	—	−0.40[b,e]	0.43[b,e]
Perceived risk	−0.77[a,c]	−0.48[a,c]	—	−0.07[b]
Self-rated knowledge	0.38[a,d]	0.42[a,d]	−0.23[a]	—

[a] Based on Sample 1 with 50 technologies.
[b] Based on Sample 2 with 25 technologies.
[c] $p < 0.001$.
[d] $p < 0.01$.
[e] $p < 0.05$.

for a different but overlapping set of 90 technologies and activities. Earlier, Fischhoff et al. (1978) reported a correlation of −0.20 between perceived benefit and perceived risk, based on a sample of female and male members of the League of Women Voters ($N = 76$), in which two subsamples separately rated either benefit or risk on a more complex judgment scale for 30 technologies and activities. Thus, a moderate inverse relation between the perceived benefit and perceived risk of technologies has been generally found.

The attitude index obtained in our research can serve as an indicator of a favorable inclination to (and perhaps closely related to acceptability of) a technology. Table 8 shows that perceived benefit is positively related to favorable attitudes in both of our samples (+0.80, +0.82), perceived risk is negatively related (−0.77, −0.75), and self-rated knowledge is less positively related (+0.38, +0.29)-significant only in sample 1. For the larger set of technologies rated ($N = 50$), a multiple regression equation predicting mean attitudes toward technologies from mean perceived benefit and perceived risk yields an R of +0.92. Application to the set of 25 technologies rated by sample 2 yields an R of +0.94. Inclusion of self-rated knowledge does not add significantly to the prediction.

Our participants in sample 1 also rated the 50 technologies on six qualitative characteristics of perceived risk, previously studied by Fischhoff et al. (1978) and Slovic et al. (1980). These characteristics are control over risk, global catastrophic potential, common dread, immediacy of effect, observability, and number of persons exposed. Sample 2 rated 25 technologies on three of the qualitative characteristics of perceived risk: controllability, observability, and number of persons exposed. When technologies are taken as the unit of analysis, Fischhoff et al. (1978) and Slovic et al. (1980) have reported two principal components in the domain of these qualitative characteristics: dread risk (e.g., uncontrollable, catastrophic, dreaded) and unknown risk (e.g., not observable, not known to science, effect delayed). A third component, dominated by a single characteristic (number of persons exposed) is reported by Slovic et al. (1980) for one study. Our principal components analysis (with varimax rotation) with smaller sets of characteristics yields a two-component solution (dread risk, unknown risk) with the characteristic "number of persons exposed" neither loading consistently on these components nor forming a third component. The precise nature of the component structure is somewhat dependent upon the analysis of qualitative characteristics, technologies, and judges. Nonetheless, the two components of dread risk and unknown risk appear to warrant attention.

Within our data set for sample 1, the two components of dread risk and unknown risk

can be measured for each technology by mean ratings on the relevant qualitative characteristics (e.g., for dread risk: severity of effects can't be controlled versus can be controlled, global catastrophic potential very high or very low, and dread versus common; for unknown risk: effect delayed versus immediate, and not observable versus observable). Using the same method employed by Fischhoff et al. (1978), the 50 technologies rated by sample 1 were plotted in a two-dimensional space (see Slovic et al., 1980, Figure 5). The technologies that overlap with previous analyses (Fischhoff et al., 1978, Figure 7; Slovic et al., 1980, Figure 5) show generally comparable locations in our plot. For example, the technologies of nuclear power, pesticides, DDT, and chemical fertilizers appear in the high dread-high unknown quadrant in both studies; nuclear weapons, opiates, and open-heart surgery appear in the high dread-known quadrant; food preservatives, diagnostic X rays, microwave ovens, contraceptives, and fluorescent lights are located in the high unknown-low dread quadrant; and bicycles, home appliances, and lawn mowers appear in the low dread-known quadrant. Examination of the subset of technologies that show noticeable shift in location indicates a drift toward the central, less differentiating area in the case of one of the studies.

When the set of 23 technologies overlapping in our analysis with the Slovic et al. (1980) set are ranked on the dread risk component for the two studies, the rank order correlation is $+0.76$; when they are rank-ordered on the unknown risk component, the rank order correlation is $+0.55$. For our sample 2, only a single rating is available for each of these two components; thus measurement of technologies on them is less reliable. Examination shows somewhat less comparability in the location of technologies when plotted, probably for this reason. Overall, however, technologies do display generally reliable locations of the two-dimensional space formed by the dread risk and unknown risk components of qualitative characteristics of perceived risk.

Contemporary Worldviews and Perceptions of Technologies

The sample mean judgments provide one kind of information about the perception of technologies but do not deal with the considerable interindividual variation around the mean values. Analysis of the correlations of these judgments of technologies with contemporary worldviews A and B provides one strategy for attending to and giving psychological interpretation for these interindividual variations.

Examination of Tables 4–7 reveals pervasive relations between contemporary worldviews and perceptions of technologies. Table 6 shows 17 replicated significant associations between contemporary worldview A and attitudes toward specific technologies, and 8 such associations for contemporary worldview B. With only one exception, contemporary worldview A is positively related to favorable attitudes and contemporary worldview B is negatively related. Interestingly, the exception, rooftop solar collectors, shows the only significant and replicated negative correlation of attitude to contemporary worldview A, and is positively related to contemporary worldview B. These correlations may reflect the advocacy of solar collectors as a soft energy technology (Lovins, 1979); that is, a source of energy that is more compatible with contemporary worldview B. If the attitude ratings of each participant are averaged across all technologies, an overall index of attitude toward technologies can be derived. This index correlates $+0.49$ and $+0.52$ with contemporary worldview A, and -0.29 and -0.37 with contemporary worldview B in the two samples, respectively.

Table 5 shows 12 replicated significant relationships, with 11 indicating a positive relation between contemporary worldview A and perceived benefits and 1 indicating a negative relation for contemporary worldview B. The generally positive association between contemporary worldview A and perceived benefits is supported by correlations of $+0.35$

and +0.38 between the overall index of perceived benefits and contemporary worldview A, while small and nonsignificant correlations (−0.03 and −0.09) are found for contemporary worldview B.

Table 4 identifies 10 replicated significant correlations between perceived risk and the contemporary worldviews: 7 positive correlations for contemporary worldview B and 3 negative correlations for contemporary worldview A are indicated. The directions of the signs are generally positive for contemporary worldview B and negative for contemporary worldview A. Correlations between the overall index of perceived risk and contemporary worldview B are +0.28 and +0.25, but measure −0.10 and −0.21 for contemporary worldview A.

Table 7 provides little support for a general relation between the contemporary worldviews and self-rated knowledge of technologies. The replicated significant correlations and tendency of the signs suggest, if anything, only a modest tendency for contemporary worldview A to be related to self-reported technological knowledge. The overall index of self-rated knowledge correlates +0.09 and +0.14 with contemporary worldview A and +0.08 and −0.14 with contemporary worldview B.

Certain specific technologies appear to be implicated in this pattern of findings and in the contemporary worldviews to a greater extent than others. Thus, nuclear power, nuclear weapons, water fluoridation, pesticides, lasers, food preservatives, and motor vehicles show a high incidence of significant relations between facets of their public perceptions and the contemporary worldviews. In contrast, although opiates are judged on the average to be among the most risky technologies within this set, individual variations in this judgment are unrelated to contemporary worldviews. Tranquilizers, suspension bridges, solar collectors, and movie special effects are also minimally related to contemporary worldviews.

In summary, the results indicate a general relation between contemporary worldviews and attitudes toward technologies. The relation is also found in the case of perceived benefit and perceived risk. Contemporary worldview A is associated with a favorable attitude and with perceived benefit, while contemporary worldview B is associated with the perceived risk of technologies. The contemporary worldviews are related to several facets of public perceptions in the case of some technologies and to none or few in the case of others. Individual variations in self-rated knowledge are not substantially related to the contemporary worldviews.

Societal Decision Options

Our research procedures recorded the participants' views on three sets of issues concerning the societal process of risk management: (1) Who should make decisions about technology and technological hazards? (2) How should these societal decisions be approached? and (3) What criteria are desirable attributes of the various formal and informal approaches to societal decisions?

The Locus of Societal Decisions. For each technology, participants were asked to express their preferences as to who should make decisions about the ways each technology is used in our society. Seven options were presented: (1) regulatory agencies, (2) business leaders, (3) elected officials, (4) professionals-experts, (5) the general public, (6) individual consumers, and (7) the judiciary (the courts). For each technology, these seven options were ranked from most preferred to least preferred. For each participant, the mean rank for a given option across all technologies provided an overall preference index.

In sample 1, this procedure was completed twice. In the first instance, participants

made their judgments with regard to general decisions about whether it is in our society's interest to use the technology and, if so, to what extent and in what ways. In the second instance, they completed the same procedure, making judgments concerning who should make decisions about levels of safety (regarding injuries, illness, and death) and deciding how safe is safe enough. The correlations between the general and safety procedures aggregated across technologies for each of the seven kinds of decision agents ranged from +0.71 to +0.92 for sample 1. These strong associations led to the use of a single procedure for sample 2 that asked about general decisions regarding technology that consider "economic, political, environmental, and many other factors, including safety."

Without doubt, this procedure fails to capture the complexity of the societal decision process in the development of any technology, which typically entails several, if not all, of these kinds of agents in various sequences and combinations. However, it constitutes an initial exploration of the important issue: Who should decide? Table 9 indicates that professionals and experts are consistently favored for both general decisions and those concerning levels of safety. The general public and individual consumers are also preferred to the judiciary, elected officials, and business leaders. Despite some differences in wording and a difference of 25 technologies as the basis for the overall preference index, the rank order correlation between the means for samples 1 and 2 regarding general decisions is +0.95. Compared to the findings for general decisions, the results for judgments regarding levels of safety yield some preferential gain for regulatory agencies and loss for individual consumers. However, the rank order correlation for the means from the two procedures in sample 1 is +0.86.

Approaches to Societal Decisions. Risk management encompasses not only the issue of who shall be involved in making decisions but also of how societal decisions should be approached and considered. Several approaches to societal decisions are available, in-

Table 9. Preferences for the Locus of Decisions

	Sample 1		Sample 2		CWV A		CWV B	
					Sample 1	Sample 2	Sample 1	Sample 2
	Mean	SD	Mean	SD	*r*	*r*	*r*	*r*
General decisions								
Regulatory agencies	176.48	57.65	87.81	25.94	0.15	0.19[a]	0.05	−0.04
Business leaders	100.34	54.96	46.61	26.96	0.24[b]	0.26[b]	−0.41[c]	−0.43[c]
Elected officials	87.86	51.92	43.10	23.61	0.01	0.03	−0.02	−0.03
Professionals-experts	243.89	37.68	120.43	22.30	0.17[a]	0.43[c]	−0.06	−0.08
General public	183.86	49.87	94.55	27.21	−0.21[a]	−0.33[c]	0.21[a]	0.30[c]
Individual consumers	183.79	50.84	94.98	24.70	−0.22[b]	−0.38[c]	0.10	0.17[a]
Judiciary (the courts)	81.88	51.68	43.69	25.10	−0.12	−0.22[b]	0.25[b]	−0.01
Safety decisions								
Regulatory agencies	200.52	63.69			0.11		0.07	
Business leaders	89.71	63.57			0.17[a]		−0.39[c]	
Elected officials	93.40	59.79			0.04		−0.10	
Professionals-experts	262.82	36.74			0.16[a]		−0.12	
General public	165.97	61.32			−0.10		0.16[a]	
Individual consumers	157.82	60.24			−0.09		0.16[a]	
Judiciary (the courts)	87.87	66.69			−0.19[a]		0.23[b]	

[a] $p < 0.05$. [b] $p < 0.01$. [c] $p < 0.001$.

Table 10. Approaches to Societal Decisions: Descriptive Characteristics[a]

Characteristics (1–5)		Bootstrapping					Formal			
		Prof J	RP	IP	NS	RC	CBA	DA	EP	Pol J
Comprehensive	$\bar{X}$	3.80	2.78	3.05	2.89	2.93	3.17	3.81	3.27	2.92
	SD	0.92	1.22	1.21	1.31	1.27	1.26	0.93	1.15	1.31
Logically sound		3.93	2.91	3.23	3.25	3.23	3.70	3.68	3.21	2.75
		0.93	1.15	1.08	1.34	1.21	0.95	1.00	1.21	1.28
Practical		3.75	3.05	3.30	3.14	3.29	3.49	3.44	3.24	3.11
		0.89	1.14	1.05	1.23	1.08	1.00	1.03	1.18	1.21
Open to evaluation		3.35	3.03	3.28	3.35	3.40	3.50	3.57	3.76	2.93
		1.16	1.16	1.12	1.18	1.11	1.12	1.03	1.06	1.31
Politically acceptable		3.29	3.28	3.56	3.12	3.18	3.59	3.44	3.98	3.97
		1.09	1.03	1.05	1.14	1.10	1.03	1.00	1.02	1.10
Accountable to the public		3.11	3.16	3.22	3.23	3.14	3.17	3.51	4.28	3.34
		1.33	1.22	1.26	1.38	1.27	1.31	1.01	0.96	1.28
Fair		3.24	2.86	3.01	2.98	2.94	3.09	3.43	3.48	2.75
		1.11	1.15	1.22	1.25	1.24	1.22	0.93	1.12	1.29
Straightforward		3.15	3.08	3.20	3.24	3.40	3.27	2.99	3.73	3.00
		1.17	1.13	1.17	1.24	1.11	1.18	1.23	1.05	1.14
Unbiased		3.35	2.69	2.87	2.79	2.82	2.99	3.38	3.11	2.56
		1.21	1.25	1.24	1.31	1.26	1.31	1.06	1.22	1.33
Wise		3.56	2.74	2.99	3.06	3.01	3.10	3.63	3.17	2.69
		1.17	1.28	1.20	1.30	1.26	1.20	0.96	1.15	1.28
Familiar		3.82	2.79	3.07	3.07	3.09	3.10	2.74	3.53	3.92
		0.90	1.02	1.07	1.06	1.04	1.20	1.06	1.06	0.99
Understandable		4.11	3.49	3.81	3.81	3.76	3.67	3.31	4.09	4.09
		0.64	0.87	0.76	0.82	0.76	0.84	0.88	0.81	0.71

[a] Prof J = Professional Judgment; RP = Revealed Preferences; IP = Implied Preferences; NS = Natural Standards; RC = Risk Comparison; CBA = Cost–Benefit Analysis; DA = Decision Analysis; EP = Expressed Preferences; Pol J = Political Judgment.

cluding political judgment, public opinion or expressed preferences, professional and expert judgment, formal analyses, and methods of bootstrapping. Formal analyses include cost–benefit analysis and decision analysis; bootstrapping methods include revealed preferences, implied preferences, natural standards, and risk comparisons or compendiums (Fischhoff et al., 1981).

Our participants were presented with brief descriptions of a set of approaches to societal decisions and then asked to describe and evaluate them on a series of rating scales. For sample 1, nine approaches were presented, for sample 2, four approaches. These approaches were to be considered in terms of their bearing upon societal decisions about both the use and safety of technologies. The instructions for the procedure and its accompanying brief descriptions are presented in Appendix A.

Table 10 presents the mean descriptions that our sample 1 participants rendered of nine approaches to societal decisions. The approaches entailing professional judgment, expressed preferences, and decision analysis received positive ratings most often. The generally favorable showing of decision analysis is noteworthy because it is also considered the least familiar and least readily understood. At the same time, political judgment tends to be rated extremely low on these dimensions despite its high standing among the most familiar and readily understood.

For sample 2, four approaches to societal decisions were presented. They were selected on the basis of findings from sample 1. Two approaches, expressed preference and cost–benefit analysis, were repeated. Two additional approaches, societal scenario and societal emergent, were included with the intention of offering possiblities that would be seen as relatively more future-oriented, intuitive, and creative. The set of descriptive characteristics for sample 2 was altered in part to check upon these aims and to confirm that cost–benefit analysis is perceived as economically oriented. Each of these expectations is supported by the findings reported in Table 11.

Evaluative judgments were made of each decision approach at two points. Initial ratings were made immediately after reading and considering the brief description of each decision approach; they recorded how much emphasis the participant thought should be given to the approach (from "highest priority" to "none") when societal decisions regarding technology are made. Following this set of judgments, participants recorded an overall comparative evaluation of the set of approaches, rating each from "very favorable" to "very unfavorable." Table 12 presents the mean judgments for the overall comparative ratings only. For sample 1, the rank order of means for the comparative evaluations with regard to general decisions is exactly the same as the two sets of mean judgments made initially after considering each approach (i.e., initial evaluations regarding general decisions and decisions concerning levels of safety). The rank order correlation for the results of the overall comparative judgments presented in Table 12 for general decisions and those concerning levels of safety is +0.84. In the safety context, risk comparison and revealed preference gain favor slightly and cost–benefit analysis loses slightly.

Desirable Attributes of Approaches to Societal Decisions. As Fischhoff et al. (1981) have noted, choosing a decision approach is itself a metadecision problem. In their comparative analysis of decision approaches, they employ seven evaluative criteria: comprehensive, logically sound, practical, open to evaluation, politically acceptable, compatible with institutions, and conducive to learning. In our exploration of public perceptions of facets of risk management, research participants were asked to judge the relative desirability of an expanded array of criteria. A total of 30 possible criteria were rated for relative desirability by at least one sample, with 11 being rated by both samples. These ratings were

Table 11. Approaches to Societal Decisions: Descriptive Characteristics

Characteristics	Societal scenario		Cost-benefit analysis		Societal emergent		Expressed preference	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Comprehensive (1–7)	4.48	1.76	3.92	2.04	5.23	1.71	4.86	1.70
Logically sound (1–7)	4.35	1.73	5.20	1.66	4.53	1.88	4.67	1.70
Politically acceptable (1–7)	4.42	1.57	5.07	1.57	5.11	1.68	5.49	1.53
Compatible with institutions (1–7)	4.66	1.57	5.56	1.31	4.29	1.99	4.05	1.87
Accountable to the public (1–7)	4.06	1.73	3.89	1.83	5.46	1.72	5.75	1.54
Straightforward (1–7)	4.30	1.77	4.28	1.87	4.78	1.83	5.24	1.59
Decisive (1–7)	3.51	1.79	5.20	1.59	4.02	1.90	4.49	1.67
Economically oriented (1–7)	4.10	1.69	6.02	1.42	3.83	1.80	4.15	1.69
Intuitive (1–7)	4.88	1.63	3.48	1.87	4.96	1.61	4.55	1.64
Future-oriented (1–7)	5.56	1.46	4.04	2.01	4.77	1.59	4.60	1.58
Creative (1–7)	5.35	1.48	3.72	1.93	4.85	1.70	4.57	1.72
Past-oriented (1–7)	4.10	1.73	4.64	1.70	4.62	1.51	4.63	1.42
Familiar (1–5)	2.94	1.11	3.43	1.15	3.12	1.14	3.42	1.03
Understandable (1–5)	3.59	0.92	3.68	0.88	3.66	0.80	3.73	0.82

Table 12. Approaches to Societal Decisions: Comparative Evaluations[a]

	Sample 1									Sample 2			
	General				Levels of safety					General decisions			
	Mean	SD	CWV A *r*	CWV B *r*	Mean	SD	CWV A *r*	CWV B *r*		Mean	SD	CWV A *r*	CWV B *r*
Prof J	4.12[b]	0.88	26[d]	−11	4.20[b]	0.89	30[d]	−16[f]	SS	5.58[c]	1.34	−08	18[f]
RP	3.18	1.13	31[d]	01	3.31	1.11	31[d]	07	SE	4.90	1.41	00	18[f]
IP	3.23	1.03	34[d]	−03	3.25	1.04	19[f]	−02	CBA	4.73	1.77	43[d]	−29[d]
NS	3.44	1.21	19[f]	16[f]	3.56	1.20	08	15[f]	EP	5.18	1.65	14	23[e]
RC	3.37	1.26	19[f]	02	3.80	1.18	18[f]	−03					
CBA	3.74	0.99	34[d]	−13	3.35	1.25	45[d]	−09					
DA	4.09	0.86	07	02	3.89	0.87	09	−08					
EP	3.81	0.92	07	14[f]	3.68	0.98	06	10					
Pol J	3.12	1.24	31[d]	−08	2.97	1.17	38[d]	−14					

[a] See Table 10 for definitions of abbreviations.
[b] 1–5 rating scale. [c] 1–7 rating scale.
[d] $p < 0.001$. [e] $p < 0.01$. [f] $p < 0.05$.

made following the completion of descriptions and evaluations of 11 (sample 1) or 4 (sample 2) approaches to societal decisions. Thus, the participants provided judgments of relative desirability after having used a subset of the criteria in describing an array of societal decision approaches.

Table 13 provides a listing of the 30 criteria, with the descriptive phrase used to convey

Table 13. Attributes of Decision Approaches: Descriptions

Rank of 11 selected attributes			
Sample 1	Sample 2	Attributes	Description
		Wise	Leads to sound decisons.
1	1	Comprehensive	Takes into account the full complexity of the decision problem; does not exclude important factors.
		Aids clear thinking	Helps decision makers to think through the basic issues of the decision problem.
		Unbiased	Gives appropriate weight to all factors of the problem, does not systematically overemphasize certain considerations.
2	2	Logically sound	Analyzes the problem in a clear, logically consistent way.
		Conducive to learning	Educates participants and leads to increasingly better decisions.
		Fair	Treats justly the interests of all those affected by the decision.
		Open to evaluation	Reveals the details of the procedure itself, permitting those affected to evaluate the process.
		Practical	Can be readily used to reach decisions; is feasible, realistic.
		Timely	Yields decisions when they are needed.
		Dependable	Produces similar decisions for similar information and problems; not dependent upon irrelevant factors or the specific individuals involved in reaching the decision.
		Sensible	Guided by common sense and reasonable principles.
3	4	Straightforward	Readily understood by the ordinary citizen.
4	7	Decisive	Yields clear-cut, final decisions.
		Flexible	Responsive to changing conditions.
5	3	Accountable to the public	Potentially responsive to public disapproval of the decision process.
		Versatile	Applicable to diverse decision contexts.
		Probability-oriented	Takes account of the uncertainty in available information about the decision-problem.
6	6	Future-oriented	Emphasizes novel events, unprecedented conditions, new developments and possibilities.

(*continued*)

Table 13. (continued)

Rank of 11 selected attributes		Attributes	Description
Sample 1	Sample 2		
7	5	Creative	Generates inventive or clever decisions.
		Intuitive	Aids in the understanding of the problem and the fundamental isues without explicit reasoning.
		Sturdy	Functions adequately even if many special circumstances do not exist and all requirements are not met.
8	8	Economically oriented	Emphasizes monetary, dollars-and-cents considerations.
9	9	Politically acceptable	Compatible with our form of government and political system.
		Relies heavily on human judgment	Requires for each decision a large amount of direct, immediate human determination and choice.
		Inexpensive	Needs few resources—money, staff, time, etc.—for execution.
10	10	Past-oriented	Emphasizes past conditions, precedents, previous judgments.
11	11	Compatible with institutions	Optimally fits in with the way relevant institutions usually do things.
		Fast	Yields decisions quickly.
		Complex	Has a large number of separate steps and operations before a decision is produced.

their meanings. The criteria are listed in rank order from wise (the most desirable) to complex (the least desirable) as judged by our participants. The within-set rankings for the 11 criteria judged by both samples are also given. The rank order correlation between the two sets of sample means is +0.92, indicating a reliable trend across samples.

Contemporary Worldviews and Societal Decision Options

Evidence for the relation of contemporary worldviews to perceptions of technologies has already been presented. We can now examine whether contemporary worldviews are related to interindividual variations in preferences for the locus of societal decision making, evaluations of approaches to societal decisions, and judgments of the relative desirability of criteria for decision approaches.

Table 9 presents the correlations between contemporary worldviews A and B and the overall preference index for the locus of societal decision making. For sample 1, results are given for general decisions and decisions on levels of safety; for sample 2, the results are presented on general decisions. The pattern of findings is similar across the three procedures. Contemporary worldview A is positively related to a preference for business leaders as a locus of societal decision making and contemporary worldview B is negatively related. The reverse finding holds in the case of the general public as a locus of decision making. Contemporary worldview A is also positively related to a preference for professionals and experts while a similar negative relationship to a preference for individual consumers is

attenuated when the focus is upon decisions regarding levels of safety. In the case of the judiciary, a positive relation with contemporary worldview B and negative relation with contemporary worldview A is somewhat enhanced when the focus is shifted to decisions regarding levels of safety.

Table 12 presents the relations of contemporary worldviews A and B with evaluations of the approaches to societal decisions. The trend for contemporary worldview A is clear and indicates a generally positive evaluation of the various approaches to societal decisions, with the exception of expressed preferences and possibly decision analysis. In the latter instance, a significant relation is obtained on the initial evaluative rating but is not found for the comparative rating. Contemporary worldview B is positively associated with favorable evaluations of only two decision approaches: expressed preferences and natural standards.

Analysis of personality factors differentially associated with endorsements of contemporary worldviews A and B (Buss, Craik, & Dake, 1982) suggested that other societal decision approaches with descriptive characteristics of being intuitive, creative, and future-oriented would show a positive relation to contemporary worldview B. For sample 2, two approaches considered to have these characteristics were presented. The options of societal scenario and societal emergent did receive high ratings on these characteristics, compared to cost–benefit analysis and expressed preference (Table 11). The relations of contemporary worldviews A and B to evaluative judgments of these approaches to societal decisions are presented in Table 12. Significant positive relations between contemporary worldview B and evaluations of both societal scenario and societal emergent are obtained. In addition, the results for cost–benefit analysis and expressed preferences are replicated (that is, correlations are positive for contemporary worldview A and negative for contemporary worldview B with regard to cost–benefit analysis, and the correlation between contemporary worldview B and expressed preference is positive).

Findings on the relation of contemporary worldviews A and B with desirability ratings on criteria for societal decision approaches tend to underscore the results on direct evaluative ratings of the decision approaches. Table 14 presents the correlations of contemporary worldviews A and B with the 11 attributes that were judged by both samples 1 and 2. The four attributes that appear to display especially distinctive relations to the worldviews are

Table 14. Attributes of Decision Approaches: Desirability Judgments

	Sample 1		Sample 2		CWV A		CWV B	
	Mean	SD	Mean	SD	Sample 1 *r*	Sample 2 *r*	Sample 1 *r*	Sample 2 *r*
Comprehensive	8.11[a]	1.51	6.21[b]	1.26	−0.03	0.05	0.09	0.14
Logically sound	7.81	1.47	6.08	1.22	0.22[d]	0.38[c]	−0.02	0.07
Straightforward	7.12	1.90	5.82	1.56	−0.01	−0.06	0.13	0.18[e]
Decisive	7.05	1.95	5.45	1.40	0.34[c]	0.30[c]	−0.05	−0.19[e]
Accountable to public	6.99	1.89	5.95	1.11	−0.12	−0.16[e]	0.29[c]	0.33[c]
Future-oriented	6.43	1.96	5.48	1.29	0.19[e]	0.07	0.08	0.18[e]
Creative	6.24	2.25	5.52	1.42	.0.20[e]	−0.11	0.13	0.30[c]
Economically oriented	5.99	2.25	4.70	1.60	0.52[c]	0.42[c]	−0.17[e]	−0.34[c]
Politically acceptable	5.90	2.20	4.66	1.61	0.29[c]	0.33[c]	−0.10	−0.24[d]
Past-oriented	5.64	2.10	4.57	1.50	0.37[c]	0.18[e]	−0.01	−0.11
Compatible with institutions	5.11	2.30	4.45	1.75	0.41[c]	0.39[c]	−0.19[e]	−0.22[d]

[a] 1–9 rating scale. [b] 1–7 rating scale.
[c] $p<0.001$ [d] $p<0.01$. [e] $p<0.05$.

economically oriented, compatible with institutions, politically acceptable (positive with contemporary worldview A and negative with contemporary worldview B), and accountable to the public (positive with contemporary worldview B and negative with contemporary worldview A). Three attributes—past-oriented, decisive, and logically sound—show replicated significant positive associations with contemporary worldview A while the variable creative shows a replicated positive direction for contemporary worldview B. From among the attributes that were judged by only one sample, contemporary worldview A shows significant associations with fast (+0.27), sturdy (+0.28), probability-oriented (+0.18), timely (+0.18), and versatile (+0.19). Contemporary worldview B shows significant associations with intuitive (+0.22) and conducive to learning (+0.26).

SUMMARY AND IMPLICATIONS

In a 1983 address to the National Academy of Sciences in Washington, D.C., William D. Ruckelshaus, then administrator of the U.S. Environmental Protection Agency, highlighted the basic distinction in dealing with technological hazards that can be drawn between risk assessment and risk management. Risk assessment seeks to arrive at an expert and typically probabilistic formulation of possible adverse outcomes regarding technologies; risk management deals with the governmental and societal consideration of risk assessments and other salient factors in moving toward decisions about the application and use of technologies (Ruckelshaus, 1983). Our current research program illustrates the need for psychological perspectives in the understanding of both risk assessment and risk management.

The results of our analysis of the perceptions of technologies continue a line of research that is well under way (Cole & Whithey, 1981; Fischhoff et al., 1978; Otway & Thomas, 1982; Slovic et al., 1980, 1982). These modal findings show that public attitudes vary widely across an array of technologies and that perceived risk as well as perceived benefit is related to attitudes toward technologies. Furthermore, individual variations among persons in their perceptions of technologies and their related risks and benefits are systematically related to their contemporary worldviews. Contemporary worldview A is associated with more favorable attitudes toward technologies and perceived benefits of technologies. Contemporary worldview B is associated with less favorable attitudes toward technologies and with perceived risk of technologies. These relations hold as summary tendencies across the domain of technologies studied but also appear to be focused upon a particular subset of technologies including nuclear power, nuclear weapons, water fluoridation, pesticides, lasers, food preservatives, and motor vehicles. A wider search of the domain of technologies for others that are especially implicated in these contemporary worldviews may help to clarify the differential linkage of some, but not other, technologies to these sociopsychological perspectives and outlooks.

The findings from our analysis of the psychological aspects of risk management represent a newer line of inquiry. In communicating technical risk assessments to the general public, an understanding of ordinary citizens' notions of risk, grasp of probabilistic analysis, and other topics is required. Similarly, in communicating the process and outcomes of decision making and seeking to involve the public in risk management, research is needed on ordinary citizens' preferences for the locus of societal decision making on matters of technology, familiarity with and evaluation of approaches to societal decisions, and judgments of desirable criteria for appraising and choosing decision approaches. The results for our samples as a whole suggest that professionals-experts and the general public are viewed favorably, and the courts, elected officials, and business leaders are viewed relatively less favorably as loci

for decisions concerning technology. In addition, professional judgment and decision analysis are evaluated positively as approaches to societal decisions about technology, while revealed preference and political judgment are evaluated relatively less favorably. Such criteria as comprehensive and logically sound are generally viewed as relatively more desirable than political acceptability and compatibility with institutions as criteria for appraising approaches to societal decisions.

As in the case of perceptions of technologies, contemporary worldviews are systematically associated with societal decision options. Contemporary worldview A is associated with a preference for business leaders, professionals, and regulatory agencies, while contemporary worldview B is associated with a preference for the general public, the courts, and individual consumers as the loci of societal decisions. Contemporary worldview A is related to a positive evaluation of cost–benefit analysis, political judgment, revealed preference, professional judgment, and implied preference as decision approaches, while contemporary worldview B is related to a positive evaluation of expressed preference, societal emergent, and societal scenario as decision approaches. As criteria for appraising societal decision approaches, contemporary worldview A is related to positive judgment of these attributes: economically oriented, compatible with institutions, logically sound, decisive, past-oriented, and politically acceptable. In contrast, contemporary worldview B is associated with positive judgments of these criteria: accountable to the public, intuitive, future-oriented, and conducive to learning.

Two major cautions regarding these findings are warranted. First, the aim of the general public samples for this research program was to obtain a broad cross section of respondents to permit the estimation of correlations among measures of interest. The objective was not to estimate population values through the level of representative sampling required in survey research. Thus, the results on average values for the samples must be taken as provisional indications of public perceptions.

Second, the use of verbal terms to represent technologies in the studies of technological perception and the use of brief descriptions for obtaining impressions and evaluations of societal decision approaches suffer possible methodological limitations. Responses to brief verbal presentations of these entities may not be representative of reactions that occur in the flow of everyday life. The reliable mean values across the two samples, the replicated correlations, and the coherent pattern of findings within and across procedures do, however, afford encouragement concerning the meaningfulness of the results.

Study of the perception of technologies can be extended to other more specific contexts, such as issues in the adoption of technologies for personal use, or in the siting of specific technologies. Studies of approaches to societal decisions can be developed further in procedural ways. For example, alternative formats for describing the approaches can be used, detailed statements of the pros and cons of each approach can be introduced, and the contexts for the use of the approaches can be varied (e.g., dealing with routine decisions versus decisions regarding new technologies). In addition, the extent to which contemporary worldviews A and B differ in preferences regarding societal decision options might be examined in the review and evaluation of case studies of the risk management sequence for certain specific technologies.

The most distinctive implications of the results are to be found in the evidence that the encounters of individuals with the sociotechnological environment display systematic patterns, that these patterns extend across perceptions of technologies and preferences regarding societal decision making, and that contemporary worldviews of the individuals offer useful psychological constructs for understanding trends of reactions and choices in this realm.

Important Issues for Future Research

The current research program suggests four lines of future inquiry.

Perception of Technologies. Our current research suggests the possibility of developing a psychological taxonomy of technologies that would complement taxonomies of technologies based upon causal sequences in their development (Hohenemser et al., 1982). Each technology can be assigned a value on such psychological dimensions as (1) favorability of attitude, (2) perceived risk, plus the perceived risk factors identified by Fischhoff et al. (1978), (3) perceived benefit, (4) familiarity, (5) preferred locus of societal decisions (scores for regulatory agencies, business leaders, etc.), (6) judged appropriateness of societal decision approaches (scores for cost–benefit analysis, expressed preferences, etc.), and others.

A basic issue in studying the perception of technologies is identification of the domain of entities and its properties. That is, what is the cognitive structure of the category: technology? The recent contributions of Rosch and associates in cognitive psychology (Rosch, 1975, 1978) may be useful in exploring judgments of prototypical versus peripheral members of that category. Furthermore, technologies have manifestations in the everyday physical environment, as well as conceptual properties. What perceptual cognitive categories and what descriptive dimensions are appropriate and useful in studying perceptions and impressions of technological equipment and facilities? This issue is being addressed in more general terms in the analysis of environmental perception (Ward & Russell, 1981; Craik, 1981). This direction for research on the perception of technologies leads to issues in the siting of hazardous technological facilities. In these cases, it becomes clear that the perception of technology encompasses emotional as well as cognitive components. Although fear and dread have been raised as issues in the perception of risk (Slovic et al., 1980), links to research on the psychology of emotion and stress need to be expanded (Craik, 1985).

Preferences Regarding Societal Decision Options. Psychological analysis of the risk management process complements psychological perspectives on risk assessment. To the extent that relatively less well-known approaches to decisions, such as the various bootstrapping methods and formal analyses, become important components of risk management, then public perceptions of them also become salient issues. Within the process of fostering public communication and participation, the ordinary citizen's grasp of the rationale of revealed preference is as central as his or her understanding of fault tree analysis or probabilistic estimates.

In understanding individuals' perceptions of risk management, orientations that extend beyond the technological realm may be worthy of attention. Thus, individuals may differ in their perceptions of which hazards and related risks should be minimized or tolerated by society. That is, the cultural interpretation of risk choice offered by Douglas and Wildavsky (1982) may have a parallel at the level of personality. Initial explorations of this issue have been reviewed elsewhere (Buss, Craik, & Dake, 1982). Confidence in risk management may also follow from a more general level of confidence in the larger society and the political regime. Thus, aspects of political orientation and attitudes bear upon psychological issues in risk management.

Contemporary Worldviews and the Domain of Attitudinal Orientations. Our current research points to the usefulness of the psychological constructs of contemporary worldviews for interpreting the individual's links to the technological system via perceptions of technologies and preferences for societal decision options concerning technologies. A

fuller understanding of contemporary worldviews A and B can be sought by attempting to locate them within the general domain of attitude orientations. How do these contemporary worldviews relate to the structure of present day political issues put forward within the political party system? How do they relate to liberal versus conservative commitments?

A more difficult route to understanding contemporary worldviews is through a life-span developmental analysis. The theory of Erikson (1964) points to adolescence as a critical period for identity formation and often a time when ideological commitments become important concerns and influences. Studies are needed concerning the development of contemporary worldviews A and B in persons younger than those we have studied thus far.

Research on political socialization (Cutler, 1977) points to the possibility of significant generational cohort effects in attitude formation. Is contemporary worldview B merely a generational anomaly of the 1960s-1970s, a blip in the attitude structure of public perceptions that will continue to appear, but at increasingly older age levels as that generation moves through its life course? Or does contemporary worldview B represent a momentous evolution and restructuring of sociopolitical issues in our modern industrial societies, perhaps leading to a reorganization of party identities and alignments (Milbrath, in press)?

Personality Factors and Contemporary Worldviews. Although one major avenue to understanding contemporary worldviews moves outward toward the sociopolitical system, another moves inward toward the broader structure of personality. What personal values, lifestyles, and personality dispositions relate to contemporary worldviews A and B (Buss & Craik, 1983b; Buss, Craik, & Dake, 1982)? What factors of personal background, family history, and occupational role are associated with the two contemporary worldviews?

A second issue regarding personality and contemporary worldviews is the distinction between perspective and activism. The personality characteristics associated differentially with the two contemporary worldviews are unlikely to be the same as those associated with a more versus less active manifestation and advocacy of them in public life. The personality correlates of liberal versus conservative political orientation among political party leaders, for example, differ from those that distinguish the party leaders from the general population (Costantini & Craik, 1980).

A third issue is the distinction between the kind of perspective or worldview held and the style of its expression. Given the degree to which issues of negotiation, reconciliation, and compromise are central ingredients in public life in pluralistic societies (Spangler, 1982; Menkes, 1981), personality characteristics such as tolerance, dogmatism, and "tough versus tendermindedness" may be worthy of study in conjunction with contemporary worldviews A and B.

Without doubt, the method of choice for exploring content and style issues of activism and advocacy within the realm of risk management would be the intensive personality assessment of exemplars of contemporary worldviews A and B. In this kind of research program, individuals would be brought together in small groups with staff members at an assessment center. Assessment of personality through interviews, inventories, and staff observations could be combined with special sessions dealing with risk management. For example, evaluative reviews of specific case studies in risk analysis might be the focus of working group discussions and appraisals. This research strategy has been employed in the intensive assessment of outstanding individuals in a variety of professions and fields, including architecture, mathematics, research science, literature, and medicine (Barron & Egan, 1968; Gough & Hall, 1975; Gough & Woodworth, 1960; Helson & Crutchfield, 1970; LaRussa, 1977; MacKinnon, 1962). Such intensive assessments would provide a major contribution to our knowledge of contemporary worldviews, the way in which they relate

to personality, and their relations to perceptions of technology and preferences for societal decision options concerning technology.

CONCLUSIONS

The perception of technology, with the attendant issues of risk and its management, may be studied as discrete and isolated issues or within a broader framework linking the personality system to the societal and environmental systems. Guided by a formulation of the interrelationships among these systems, our research has focused upon the broader strategy. From this perspective we view technology as a joint function of the societal and environmental systems.

Two samples of the general public in California were assessed on three major sets of variables. First, perceptions of technologies were assessed through separate judgments of their perceived risk, perceived benefit, overall attitudes, and judged self-knowledge. Second, the personal system was assessed with respect to two broad and encompassing orientations termed contemporary worldviews. Contemporary worldview A embodies the notions of a high-growth, high-technology, centralized free enterprise society, with a pro-business stance on regulation, materialistic goals, and rational, quantified decision-making processes. Contemporary worldview B, the second orientation, stresses leveling off material and technological growth, concern about social and environmental impacts of growth, redistribution of resources from richer to poorer nations, lower levels of consumption, decentralization of population and technology, and participative decision making guided by nonmaterialistic values. Third, preferences were assessed with respect to societal decision options for managing technologies. These assessed preferences included (1) Who should make decisions about technology (e.g., professionals-experts, the general public)? (2) How, or by what procedures, should the decisions be approached (e.g., cost–benefit analysis, expressed preferences)? and (3) What attributes should decision procedures possess or maximize (e.g., economic consideration, political acceptability, accountability to the public)?

Analyses were guided by two strategies, one entailing an examination of modal group perceptions and preferences, and the second an assessment of differences among individuals in their perceptions and preferences. Across the two general public samples, modal perceptions of technology and preferences for societal decision options were highly reliable. For example, nuclear weapons and opiates were consistently seen to be highly risky and low on benefits, while nuclear power was seen as risky, yet intermediate on benefit. With regard to who should make decisions about technology, professionals-experts and the general public were ranked by both samples as more preferred decision-making agents than elected officials and business leaders. Analysis at the modal group level provided information about the generally perceived and preferred aspects of the technological system.

Analysis of systematic individual differences within each sample, via correlational analysis, yields information about the linkages among the three major sets of variables. Overall indices of attitudes toward and perceived benefit of technologies were substantially positively correlated within these samples with endorsement of contemporary worldview A. Perceived risk tended to be positively correlated with contemporary worldview B, while self-rated knowledge about technologies was generally unrelated to either of the two worldviews.

The contemporary worldviews were also significantly related to preferences for societal decision options. Contemporary worldview A was associated with a preference for business leaders, professionals-experts, and regulatory agencies as loci of societal decisions, while

contemporary worldview B was associated with a preference for the general public, the courts, and individual consumers. Contemporary worldview A was related to positive evaluations of cost–benefit analysis, political judgment, revealed preferences, professional judgment, and implied preferences as decision approaches, while contemporary worldview B was related to a positive evaluation of expressed preferences, societal emergent, and societal scenarios as decision approaches. Regarding desired criteria for societal decision approaches, contemporary worldview A was associated with positive evaluations of: economically oriented, compatible with institutions, logically sound, decisive, past-oriented, and politically acceptable. In contrast, contemporary worldview B was positively linked with: accountable to the public, intuitive, future-oriented, and conducive to learning. Thus, analysis of the individual differences in the contemporary worldviews provides a basis for psychological interpretation of perception of technologies and preference regarding societal risk management.

The discussion section of this paper stressed the implications of our findings and pointed to future directions for this line of research. Promising topics for future investigation include closer examination of the cognitive categorization of technology by laypersons and emotional reactions to technologies, particularly in the context of siting decisions; the study of the relation of perceptions of risk management to orientations beyond the realm of technology, such as political party affiliation and general confidence in societal institutions; scrutiny of the developmental origins of contemporary worldviews, the role of socialization agents, and generational cohort effects; and intensive assessment of the personality, dispositions, backgrounds, family histories, occupational careers, lifestyles, and activism that characterize persons who are prototypical representatives or advocates of each of the two contemporary worldviews we have examined thus far.

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Appendix A: Descriptions of Approaches to Societal Decisions

In this modern age of technological change, our society is constantly faced with important decisions about the new and unusual technologies continually coming into existence.

For each of these developments, general decisions must be reached about whether it is in our society's interests to employ the new technology and, if so, in what ways. These general decisions involve economic, political, environmental, and many other factors. Whether or not the technology is to be used, decisions must include judgments and values about acceptable levels of safety (regarding injuries, illness and death); that is, judgments about how safe is safe enough.

Over the years, a number of approaches have been suggested as ways of dealing with decisions about the use of technologies and the safety of technologies. In what follows, you will find brief descriptions of these approaches to societal decisions about technology.

The actual process that takes place when a society does adopt or reject new technologies is much more complicated, of course, and may not always include self-conscious or explicit "societal decisions." Also, the process varies from case to case and may involve several or all of these approaches, either all at the same time or in various sequences. However, each

approach has certain identifiable emphases, assumptions, advantages, and disadvantages. We would like to have your views on each of these.

You should keep in mind that these decision approaches are presented in capsule form and are necessarily simplified.

Cost–Benefit Analysis

Cost–benefit analysis is an approach to societal decisions that calculates, in dollar form, the economic costs and economic benefits associated with available alternative solutions to a problem. The first step in cost–benefit analysis is to list the main alternatives. In the case of energy production, the cost–benefit approach would list available sources of the desired energy services. The second step is to list the consequences associated with each alternative. These consequences would include the costs incurred by each alternative (for example, the dollar value of the materials, transportation, environmental damage) as well as the benefits (for example, the dollar value of homes heated, factories run). Thus, the consequences of each alternative are assigned a total dollar value of costs and of benefits. The difference between costs and benefits for each technology can then be used in making comparisons among the alternatives available.

How does cost–benefit analysis handle the issue of levels of safety? The dollar value of deaths, injuries, and illnesses associated with a unit of each technology is estimated (for example, the dollar value of lost work days due to illness per unit of electricity generated). These dollar costs can then be added to other costs for a given alternative and tallied with them in calculating the total cost of the option.

In other applications, cost–benefit analysis can be used to show the implications of alternative courses of action. Suppose the use of a certain level of a new technology increases the productivity of an industry by $20,000,000 per year but causes four deaths per year. A different version of the technology, used at the same level, raises productivity by only $16,000,000 with two deaths per year associated with its use. A decision to select the second technology would imply that the lives saved are worth at least $2,000,000. Although other factors warrant consideration, this example illustrates how the approach clarifies the implications of alternative decisions by considering openly the economic costs associated with them (for example, in setting differing levels of safety).

In summary, cost–benefit analysis as an approach to societal decisions identifies alternative courses of action, lists the consequences associated with each alternative, assigns dollar values to the total costs and benefits of the alternatives considered, and compares alternatives in terms of the net difference between their dollar costs and benefits.

Decision Analysis

Decision analysis, as an approach to societal decisions, involves five steps. First, the problem is outlined. The main alternative solutions (for example, various energy technologies) are identified. The set of consequences associated with each alternative (for example, economic implications, human safety, impact on environment, effects on international relations) are listed. The degrees of uncertainty (for example, consequences that are not known with confidence) are estimated.

Second, participants in the decision analysis are asked to make their value judgments about the relative desirability (or undesirability) of each possible consequence. Thus, an important part of decision analysis is to decide to what extent each of the consequences is positive and favorable or negative and unfavorable.

Third, estimates are made in number form (probabilities) of the present and future uncertainties of the problem (for example, the probability that we will run out of fossil fuel in the near future). Expressing uncertainty in number form requires combining data with individuals' judgments about the likelihood of each consequence, if a given alternative is adopted. Experts or the participants in the decision analysis usually supply the estimates about the certainty–uncertainty of consequences.

Fourth, those participating in the decision analysis must express their attitudes toward risk and value trade-offs; that is, what kind of chances do they want to take, given their judgment of the present state of knowledge about the consequences that follow from each alternative. For example, we are often faced with one option with very desirable consequences that are unlikely to occur, while another option has moderately desirable consequences that are more likely to occur. Which to choose? Decision analysis tries to include judgments of this kind within the process of reaching decisions.

Fifth, each alternative (for example, each of several energy technologies) is evaluated separately. Each identified consequence of the alternative is assigned a relative desirability value and an estimate of the likelihood that it would come about if the alternative were selected. The desirability value of each consequence is combined with the likelihood that it will occur. These combined values are added across all consequences to provide an overall desirability value for the alternative. By applying this process to every alternative, a comparison can be made of their overall desirability values.

The implications of thinking through the elements of the problem, identifying the consequences of available options, estimating the likelihood of the consequences, and calculating the overall desirability values for each alternative can then be considered in reaching societal decisions concerning technology.

Expressed Preferences

Expressed preferences, as an approach to societal decisions, brings the general public directly into the decision process.

In this approach, public discussions of the issues surrounding new technologies take place. Alternative possible decisions (which may be suggested by experts, government officials, interest groups, or concerned citizens) are aired and examined in the media, at public meetings, etc. Whether the new technologies should be used, when and how they ought to be used, their relative costs (monetary and other), and matters of human safety can be explored, along with other aspects of the new technology.

Next, the public preferences for the alternative solutions are expressed by means of voting, opinion surveys, public hearings, or other means. For example, if a number of technologies can be used to provide equivalent energy supplies or services, then the expressed preferences approach would ask the general public to indicate its choices among these energy sources. Thus, this approach to societal decisions would consider direct information on what the citizens would most like to see used, and on the amount of agreement or consensus that prevails on the issue.

Implied Preferences

The implied preferences approach to societal decisions starts with the assumption that our legal, regulatory, and administrative records provide a set of the implied preferences of our society concerning issues raised by new technologies.

This decision approach examines legal rulings and previous regulatory and administra-

tive actions on specific cases. On the basis of the judgments about societal benefits and costs implied by these rulings and actions, standards for future decisions can be established. The previous legal and regulatory decisions are thought to represent society's best efforts to arrive at acceptable guidelines about how technologies are to be used, levels of safety, and other issues. These judgments include court records (for example, settlements for damages against manufacturers in lawsuits dealing with liability for injury or deaths) and regulatory and administrative rulings (for example, in setting air pollution standards and product safety standards).

If a technology is proposed to provide a new source of energy, for example, then the implied preference approach might examine the laws and existing agency regulations about energy and related technologies currently in use. For example, the safeguards about levels of human safety already established for them would provide a basis for judging whether the new technology might be able to meet these standards.

Thus, this approach finds within a society's legal record of past decisions and its regulatory and administrative rulings a set of society's implied preferences regarding how technologies should be used, levels of human safety, and the way the balance between societal benefits and costs can be considered.

Natural Standards

The natural standards approach to societal decisions tries to measure and consider the conditions that we as a species have been exposed to during the evolution of the human race. New technologies are examined according to the degree to which they appear to alter the conditions that have prevailed during the history of mankind. For example, the earth and the sun each give off a certain amount of radiation that we are currently exposed to and that the human species has been exposed to throughout the course of history. The amount of radiation generated by a new technology should not be judged in an absolute sense, but instead within this evolutionary context. If the increased amounts of radiation from a new technology do not add too much to the levels prevailing in the past, then it may be acceptable. If it adds a large amount to the levels that have prevailed in the past, then the new technology may not be accepted. The same considerations would be applied regarding the level of carcinogens found in foodstuffs.

Thus, the guiding assumption is that we as a species have survived well enough under past evolutionary conditions. New technologies should be evaluated according to the degree to which they alter these conditions that have prevailed in the past and continue in the present. The natural standards approach would consider technological issues regarding human safety and environmental impacts, for example, within this context.

Political Judgment

Political judgment, as an approach to societal decisions, has an appropriate branch of government (for example, the city council, the legislature, the president) reach the decision.

The political process has many phases. Discussion of the problem takes place among elected officials, experts, government officials, citizen groups, scientists, interest groups, the media, business interests, and so forth. Efforts at persuasion, lobbying, and debate are all part of this political process.

When the issue deals with a new technology, whether it is in the best interest of society to use the technology, how and when to use it, as well as its safety, can be considered in the political process along with other aspects of the technology. Whatever the various sources

of input, political judgment as an approach to societal decisions fundamentally involves having a branch of government eventually reach the decisions.

Professional Judgment

The first step in professional judgment as an approach to societal decisions is to select the relevant professionals or experts to define the problem or to address a problem that others have defined for them. Professionals bring to the problem their technical experience, accepted professional practice, and perhaps the special interests of their clients (whether the public, specific organizations, or individuals). Experts then put together this diverse information and arrive at their professional judgments about the problem and their recommended approach to its solution.

The modes of thought that professionals use in their judgments come from a combination of their own experience and the accepted standards of their profession, which they have acquired during their training. Thus, professionals can take into account the collective trial-and-error knowledge that their profession as a whole has accumulated.

How are decisions about technology handled by an approach that uses professional judgment? In the case of energy technologies, for example, professionals identify the alternatives available, when and how they might be used, the positive and negative consequences of their use, including the issue of human safety, and many other aspects of the problem. Of course, complex technological problems can involve many different kinds of professionals and experts (for example, engineers, physicists, economists, public health specialists). Each profession considers the problem from the vantage point of its area of expertise. In summary, professional judgment involves selecting appropriate professionals and allowing them to apply their expert knowledge to a problem about technology and to consider what society might do about it.

Risk Comparison

Comparative risk analysis selects a basis for comparing existing technologies and for considering societal decisions about new technologies. A number is assigned to each technology that represents some aspect of the consequences of its widespread use. In examining risks to human safety, for example, that number might be the number of deaths per year associated with the technology.

An ordering of technologies can then be made. At the top of the list are technologies that involve higher risk of this kind (that is, annual fatalities). At the bottom of the list are technologies that have lower risk of this kind associated with them. See the example below:

Technology	Annual fatalities
Motor vehicles	50,000
Electric power (current sources)	14,000
Diagnostic X ray	2,300
Private aviation	1,300
Home appliances	200
Commercial aviation	130
Power mowers	24
Vaccinations	10

Once the list is constructed, each technology may be compared with every other technology in terms of degree of risk of this kind associated with it.

If the risk associated with a new technology can be estimated (such as the expected annual fatalities), then it can be compared with existing technologies on this basis. In considering decisions about new technologies, a standard might be selected (for example, the annual deaths associated with commercial aviation) to aid in considering the acceptability of new technologies. Similar lists can be developed for other consequences of new technologies (such as environmental impacts, decreased employment). Thus, the major emphasis in comparative risk analysis as an approach to societal decisions is that of comparing each technology with a list of other technologies in terms of a common measure of risk.

Revealed Preferences

The revealed preferences approach to societal decisions starts out with the assumption that society has already reached an acceptable balance between the advantages and disadvantages associated with the many technologies already in existence and use. This balance is revealed in each society, in that people seem to accept the negative as well as positive features of its current technologies; that is, for existing technologies already in use, the relation between their contributions to the level of societal benefits (for example, health, standard of living, education, income level) and their level of societal costs (for example, accidental deaths, environmental impacts) can be calculated. The revealed preference approach suggests that the kind of balances between societal benefits and costs that have been traditionally acceptable can provide guidance for decisions about new technologies.

In deciding about a new technology, the revealed preferences approach evaluates the disadvantages associated with it (for example, the number of accidental deaths per year). It then compares this level of societal cost with that of technologies already in use that provide a similar level of benefit to society. This approach suggests that a new technology would be acceptable if the societal costs are not greater than those associated with comparable technologies currently in use that provide comparable benefits. However, if the societal costs are greater than those of present technologies providing similar levels of societal benefit, then the new technology may not be acceptable.

In summary, this approach to societal decisions assumes that society's judgments about the balance between costs and benefits of technologies has been revealed many times historically by its acceptance of technologies that have been adopted and are currently in use. New technologies are considered with respect to whether or not they fall within the range of trade-offs between societal benefits and costs that has been traditionally accepted.

Societal Emergent

The societal emergent approach emphasizes the complexity of inputs into decisions and assumes that no single person or group bears direct responsibility for decisions. Decisions, in this approach, are not arrived at in one point in time, but rather emerge from an evolving series of factors embedded in the culture. Some of these factors might be public discussions, media airing of issues, expert testimony, political maneuvering, talking to neighbors, and so on. No one of these factors is responsible for the decision or makes it. Instead of a single decision-making group, a consensus from the society emerges, usually after a prolonged airing and societal discussion of the issues.

In summary, there are many inputs into the evolving and changing issues related to a

decision; no single individual or group bears responsibility for the decision; the issues involved in the emerging decision may change shape over time, perhaps becoming broader in scope than initially posed in the discussions, or perhaps focusing more narrowly on specific components of the interrelated issues, but a consensus eventually emerges from these societal discussions. This consensus becomes the decision.

Societal Scenario

One technique used by experts to guide decisions is the societal scenario. A societal scenario is a description of potential changes in society over time. A scenario is not a prediction of how society will be, or should be, but rather is a picture of how policy analysts think society could evolve.

These scenarios provide an image that highlights the range of choices and the consequences of decisions. Scenarios also present a framework in which the experts' assumptions about social, economic, technical, and physical aspects of policy can be woven into a story about what our future could be. In forming scenarios, experts make projections about social patterns, economic activity, and technological development. These projections are then combined with other assumptions about the rate of future discoveries, future prices, future population size, and so on. In this manner, possible links between current decisions and the kind of future society we could have are clarified. For example, decisions about the social acceptability of technologies are set against a backdrop of possible consequences for human health, environmental quality, and economic prosperity.

Thus, scenarios are "thought experiments" which are broad enough to portray experts' assumptions about decisions and also nontechnical enough to be helpful in making choices. Of course, many uncertain assumptions are used to write scenarios, and much must be omitted or simplified. But scenarios are useful "what if" tools which may clarify many general decisions regarding technology.

REFERENCES

Aberle, A. K., Cohen, A. K., Davis, M. J. Jr., & Sutton, F. X. The functional prerequisites of a society. *Ethics*, 1950, 60, 100–110.

Barron, F. & Egan, D. Leaders and innovators in Irish management, *Journal of Management Studies*, 1968, 5, 41-61.

Burton, I. & Kates, R. W. The perception of natural hazards in resource management. *Natural Resources Journal*, 1964, 3, 412–441.

Burton, I., Kates, R. W., & White, G. F. *The environment as hazard*. New York: Oxford University Press, 1978.

Buss, D. M. & Craik, K. H. The act frequency approach to personality. *Psychological Review*, 1983, 90, 105–126.(a)

Buss, D. M. & Craik, K. H. Contemporary worldviews: Personal and policy implications. *Journal of Applied Social Psychology*, 1983, 13, 259–280.(b)

Buss, D. M., Craik, K. H., & Dake, K. M. Perceptions of technological hazards and their management. Paper presented at the 20th International Congress of Applied Psychology, Edinburgh, Scotland, July 1982.

Cole, G. A. & Whithey, S. B. Perspectives on risk perceptions. *Risk Analysis*, 1981, 1, 143–163.

Costantini, E. & Craik, K. H. Personality and politicians: California party leaders, 1960–1976. *Journal of Personality and Social Psychology*, 1980, 38, 641–661.

Cotgrove, S. *Catastrophe or cornucopia: The environment, politics and the future*. New York: Wiley, 1982.

Craik, K. H. The assessment of places. In P. McReynolds (Ed.) *Advances in psychological assessment, Volume two*. Palo Alto, Calif.: Science and Behavior Books, 1971. pp. 40–62.

Craik, K. H. An ecological perspective on environmental decisionmaking. *Human Ecology*, 1972, 1, 69–80.

Craik, K. H. Environmental psychology. *Annual Review of Psychology*, 1973, 24, 403–422.

Craik, K. H. The personality research paradigm in environmental psychology. In S. Wapner, S. B. Cohen, & B. Kaplan (Eds.) *Experiencing the environment*. New York: Plenum Press, 1976, 55–79.

Craik, K. H. Multiple scientific paradigms in environmental psychology. *International Journal of Psychology*, 1977, 12, 147–157.

Craik, K. H. Environmental assessment and situational analysis. In D. Magnusson (Ed.) *Toward a psychology of situations: An interactional perspective*. Hillsdale, N.J.: Erlbaum, 1981, 37–48.

Craik, K. H. Psychological perspectives on technology as societal option, source of hazard and generator of environmental impacts. In V. T. Covello, J. L. Mumpower, P. J. M. Stallen, & V. R. R. Uppurli (Eds.) *Technology assessment, environmental impact assessment and risk analysis: contributions from the psychological and decision sciences*. New York: Springer-Verlag, 1985, 211–236.

Craik, K. H. & Zube, E. H. (Eds.) *Perceiving environmental quality: Research and application*. New York: Plenum Press, 1976.

Cumming, R. B. The urge to shout. *Risk Analysis*, 1981, 1, 165–168.

Cutler, N. E. Political socialization research as generational analysis: The cohort approach versus the lineage approach. In S. A. Renshon (Ed.) *Handbook of political socialization: Theory and research*. New York: Free Press, 1977. pp. 294–326.

Douglas, M. & Wildavsky, A. *Risk and culture: An essay on the selection of technological and environmental dangers*. Berkeley, Calif.: University of California Press, 1982.

Dunlap, R. E. Ecological "news" and competing paradigms. *Technological Forecasting and Social Change*, 1983, 23, 203–206. (a)

Dunlap, R. E. Ecologist versus exemptionalist: The Ehrlich-Simon debate. *Social Science Quarterly*, 1983, 64, 200-203. (b)

Dunlap, R. E. & Catton, W. R. Jr. Environmental sociology. *Annual Review of Sociology*, 1979, 5, 243–273.

Ehrlich, P. R. That's right—you should check it for yourself. *Social Science Quarterly*, 1982, 63, 385–387.

Elsner, G. & Smardon, R. C. (Eds.) *Our national landscape: A conference on applied techniques for analysis and management of the visual resource*. Berkeley, Calif.: US Forest Service, 1979.

Erikson, E. H. Psychological reality and historical actuality. In E. H. Erikson *Insight and responsibility*. New York: W. W. Norton, 1964. pp. 159–216.

Feimer, N. R. Environmental perception and cognition in rural contexts. In A. W. Childs & G. B. Melton (Eds.) *Rural psychology*. New York: Plenum Press, 1983, 113–149.

Fischhoff, B., Lichtenstein, S., Slovic, P., Derby, S. C., & Kenney, R. L. *Acceptable risk*. Cambridge: Cambridge University Press, 1981.

Fischhoff, B., Slovic, P., Lichtenstein, S., Read, S., & Combs, B. How safe is safe enough? A psychometric study of attitudes toward technological risks and benefits. *Policy Sciences*, 1978, 8, 127–152.

Goldberg, L. R. A historical survey of personality scales and inventories. In P. McReynolds (Ed.) *Advances in psychological assessment: Volume two*. Palo Alto, Calif.: Science and Behavior Books, 1971, 293–336.

Gough, H. G. & Hall, W. B. The prediction of academic and clinical performance in medical school. *Research in Higher Education*, 1975, 3, 301–314.

Gough, H. G. & Woodworth, D. G. Stylistic variations among professional research scientists. *Journal of Psychology*, 1960, 49, 87–98.

Helson, R. & Crutchfield, R. S. Creative types in mathematics. *Journal of Personality*, 1970, 35, 48–51.

Hohenemser, C., Kasperson, R. E., & Kates, R. W. Causal structure: A framework for policy formulation. In C. Hohenemser & J. X. Kasperson (Eds.) *Risk in the technological society*. Boulder, Colo.: Westview Press, 1982. pp. 109–139.

Holdren, J. P. Science and personalities revisited. *Risk Analysis*, 1981, 1, 173–176.

Hsu, F. L. K. (Ed.) *Psychological anthropology: Approaches to culture and personality*. Homewood, Ill.: Dorsey Press, 1961.

Inhaber, H. Energy production risks: Science and personalities. *Risk Analysis*, 1981, 1, 9–10.

Kates, R. W. Perceptual regions and regional perception in flood plain management. *Papers and Proceedings of the Regional Science Association*, 1963, 11, 217–228.

Kates, R. W. Experiencing the environment as hazard. In S. Wapner, S. B. Cohen, & B. Kaplan (Eds.) *Experiencing the environment*. New York: Plenum Press, 1976. pp. 133–156.

Kates, R. W. *Managing technological hazard: Research needs and opportunities*. Boulder, Colo.: Institute of Behavioral Science, University of Colorado, 1977.

Kleinmuntz, B. *Personality and psychological assessment*. New York: St. Martin's Press, 1982.

Knutson, J. (Ed.) *Handbook of political psychology*. San Francisco: Jossey-Bass, 1973.

La Russa, G. W. Portia's decision: Women's motives for studying law and their later career satisfaction as attorneys. *Psychology of Women Quarterly*, 1977, 1, 350–364.

Lovins, A. B. *Soft energy paths: Toward a durable peace*. New York: Harper & Row, 1979.

MacKinnon, D. W. The nature and nurture of creative talent. *American Psychologist,* 1962, 17, 484–495.

Menkes, J. Risk or angst? *Risk Analysis,* 1981, 1, 237–240.

Milbrath, L. W. Environmental beliefs and values. In M. Hermann (Ed.) *Political psychology: Contemporary problems and issues*. San Francisco: Jossey-Bass, in press.

Otway, H. & Thomas, K. Reflections on risk perception and policy. *Risk Analysis,* 1982, 2, 69–82.

Pervin, L. A. *Personality: Theory, assessment and research.* (2nd ed.) New York: Wiley, 1975.

Rapoport, A. *Human aspects of urban form: Towards a man-environment approach to urban form and design.* New York: Pergamon Press, 1977.

Reuyl, J. S., Harmon, W. W., Carlson, R. C., Levine, M. B., & Witwer, J. C. *Solar energy in America's future: Preliminary assessment.* Stanford, Calif.: Stanford Research Institute, 1977.

Rosch, E. Cognitive representations of semantic categories. *Journal of Experimental Psychology: General,* 1975, 104, 192–233.

Rosch, E. Principles of categorization. In E. Rosch & B. B. Lloyd (Eds.) *Cognition and categorization.* Hillsdale, N.J.: Lawrence Erlbaum, 1978.

Rowe, R. D. & Chestnut, L. G. (Eds.) *Managing air quality and scenic resources at national parks and wilderness areas.* Boulder, Colo.: Westview Press, 1983.

Ruckelshaus, W. D. *Science, risk and public policy.* Washington, D.C.: U.S. Environmental Protection Agency, 1983.

Russell, J. A. & Pratt, G. A description of the affective quality attributed to environments. *Journal of Personality and Social Psychology,* 1980, 38, 311–322.

Russell, J. A. & Ward, L. M. Environmental psychology. *Annual Review of Psychology,* 1982, 33, 651–688.

Saarinen, T. F. *Environmental planning: Perception and behavior.* Boston: Houghton Mifflin, 1976.

Shabecoff, P. Reagan order on cost-benefit analysis stirs economic and political debate. *New York Times,* November 7, 1981, p. 7.

Simon, J. L. Paul Ehrlich saying it is so doesn't make it so. *Social Science Quarterly,* 1982, 63, 381–385.

Slovic, P., Fischhoff, B., & Lichtenstein, S. Facts and fears: Understanding perceived risk. In R. C. Schwing & W. A. Albers, Jr. (Eds.) *Societal risk assessment: How safe is safe enough?* New York: Plenum Press, 1980.

Slovic, P., Fischhoff, B., & Lichtenstein, S. Why study risk perception? *Risk Analysis,* 1982, 2, 83–94.

Smelser, J. J. & Smelser, W. T. (Eds.) *Personality and social systems.* (2nd ed.) New York: Wiley, 1970.

Smith, M. B., Bruner, J. S., & White, R. W. *Opinions and personality.* New York: Wiley, 1956.

Spangler, M. B. The role of interdisciplinary analysis in bridging the gap between the technical and human sides of risk assessment. *Risk Analysis,* 1982, 2, 101–114.

Stokols, D. Environmental psychology. *Annual Review of Psychology,* 1978, 29, 253–295.

Sundberg, N. D. *Assessment of persons.* Englewood Cliffs, N.J.: Prentice-Hall, 1977.

Thompson, M. Among the energy tribes: The anthropology of the current policy debate. Laxenburg, Austria: International Institute for Applied Systems Analysis, unpublished report, 1981.

Vayda, A. P. (Ed.) *Environment and cultural behavior: Ecological studies in cultural anthropology.* Garden City, N.Y.: Doubleday, 1969.

Ward, L. M. & Russell, J. A. The psychological representation of molar physical environments. *Journal of Experimental Psychology: General,* 1981, 110, 121–152.

White, G. F. The choice of use in resource management. *Natural Resources Journal,* 1961, 1, 23–40.

White, G. F. (Ed.) *Natural hazards: local, national, global.* New York: Oxford University Press, 1974.

Wiggins, J. S. *Personality and prediction: Principles of personality assessment.* Reading, Mass.: Addison-Wesley, 1973.

Williams, A. Cost–benefit analysis: Bastard science? Or insidious poison on the body politick? *Journal of Public Economics,* 1972, 1, 199–225.

5

Risk, Relativism, and Rationality

Marx W. Wartofsky

TOWARD A CULTURAL THEORY OF RISK: SOME PRELIMINARY CONSIDERATIONS

Animals don't take risks. Only human beings do. Risk is an ineluctably social construct. What counts as a risk, what weighs in the balance as a comparatively greater risk than some other, or as a risk worth taking in view of the expected benefit, or indeed, as a risk one is obliged to take despite the expected harm—all of this depends finally on some system of values within which such assessments can come to be made. And value systems are socially constituted, socially learned, and socially enforced. Though animals certainly respond to dangers and may behave in ways which put them in danger, they are incapable of taking risks. For whatever may be the stereotypical instinctive mechanisms or biological norms which have been selected out by species evolution as enhancing species survival, or whatever animals are capable of learning in order to cope with novel or species atypical threats, none of this yet counts as a system of values in terms of which something can come to be assessed as a risk, and judged to be acceptable or not. Being in danger or threatened by harm is not the same as being at risk—a distinction I hope to make clearer as I proceed. To put it differently, being at risk entails being in danger, but danger does not entail risk; the terms are not coextensive. Instinctive or learned responses to danger or threat among animals are, in this sense, neither risk taking nor risk avoiding. The category doesn't apply to animal life. Human beings, by contrast, are a risk-taking and risk-avoiding species. For humans, the category of risk is indissolubly bound up with that of culture and with history, with the distinctive modes of cognitive praxis which are characteristic of human life. That is to say, risk is defined in relation to perceived values; and these in turn are possible only for a self-conscious creature who is capable of estimating present actions either in the light of norms or general principles, or of future outcomes. This is not to say that every occasion of risk taking or risk avoidance involves conscious calculation or casuistical judgment, interpreting an instance in terms of a rule; but it is to say that risk cannot be reduced to just any situation of threat or danger. To take or avoid risk requires more than animal response, more than flight-or-fight behavior, more than caution or cunning, more than exposing oneself to danger.

Marx W. Wartofsky • Department of Philosophy, Baruch College, City University of New York, New York, New York 10010.

To take a risk, to avoid a risk, to be put at risk—all of these, I would argue, entail a recognition that there are reasons for acting in a certain way in the situation, and that an account may be given which explains one's actions. Further, such an account would also function as a way of understanding one's actions. In short, what I am proposing here is that risk, as a category, applies only to actions of socially conscious agents, capable of understanding an account of their own actions or of the actions of others in terms of reasons, and therefore, capable of functioning within a culture constituted by structures of norms and values.

The sociality of risk, its essentially cultural character, makes possible a variability in human responses to danger and opportunity which incomparably exceeds the fixed repertoires of genetically embedded animal responses as well as the range of learned behaviors of which animals are capable. Indeed, the cultural variability of risk perception raises a problem which doesn't exist at the biological level, namely, that of the rationality of decisions concerning risk. We cannot complain that instinctive behavior is irrational, nor, on the other hand, can we marvel at how rationally well suited to their environments the instincts are, for rationality, like risk, is categorially irrelevant here. Nature is neither rational nor irrational; only human beings are, or can be. Animals other than humans can make mistakes and can learn, but they cannot answer for their errors or give reasons for their behavior. Human beings typically can and do. What makes the contexts of risk coextensive with the contexts of rationality is that actions which involve risk are taken in consciousness of the possibility of error, and on the grounds of reasons which are, or could be given as justification for one decision rather than another. The plasticity of culture-laden responses to risk, or of the social construction of risk has its source here: for we may give different reasons for what is ostensibly the "same" action, and engage in different, even conflicting actions for what are ostensibly the "same" reasons. Rationality, far from guaranteeing universal assent, opens the Pandora's box of difference, of choice among alternatives, of the relativity of decision to information. Only in the idealized contexts of decision making under conditions of perfect knowledge—that is, only for a LaPlacean deity—could rationality reduce to an algorithmic procedure. Human rationality, evolved in the precincts of practice, tainted with the varying teleologies of human weal and woe, is a messy business. On the one hand, it is bound to its historical contexts, to local values, to interests, to ideology; on the other, it transcends localism, can serve to criticize ideology, and tends toward universality. It is, in all the complex connotations of those terms, both subjective and objective. Yet, it is only within this messy complexity of rationality that the essentially normative concept of risk can be defined. We cannot detach risk from this involvement, and look at it pure. On the most hard-nosed view of "objective" risk, we are nevertheless bound to ask "Whose risk?" and "A risk of what as against what else?" and "According to whom?"

The variability of the cultural perception of risk cannot, therefore, be brought before the court of reason for some ordering in terms of universal, objective, and necessary judgments about what is really the case, for "what is really the case" with respect to risk involves a decision about what counts most, and this, in turn, involves a decision about what counts at all; that is, the choice of parameters in determining what is a danger, what is harmful, what is an opportunity or a benefit inevitably implicates a system of values. Now it may be argued that for humankind as a whole, whether we regard it from the contexts of biology or culture, there are transcendent values which are as universal, objective, and necessary as one could wish: life, health, freedom are good; death, disease, domination, pain, and suffering are bad. Sufficiency is better than want, and happiness is to be preferred over misery. The trouble begins, of course, with the small print, and with the spelling out. So-called objective assessment of risk, even short of the question of acceptability, involves

valuation as to what will count as a harm or a danger. And since the concept of risk involves a notion of choice, as I will argue, the determination of those dangers with regard to which we may be said to be at risk also entails a notion of avoidable harm. With regard to inevitable harm, we are never at risk. The outcome is a sure thing. So objectivity here is already conditioned by considerations of evitability, and hence of choice, with regard to alternative possible actions. Take this one step further: the acceptability or nonacceptability of a risk then becomes part of the "objective" determination that it is a risk at all, in the first place. Thus, while we may, for purposes of analysis, distinguish the determination of risk from the acceptability of risk, as if this were a two-stage procedure, the valuative character of the determination of something as a risk already smuggles in considerations of acceptability, *nolens volens*. Acceptability then becomes a comparative matter: is one outcome more or less acceptable than another?

Let me make this clearer with an example: A so-called objective assessment of risk may propose that at present levels of the industrial emission of toxic wastes, a specific percentage increase in deaths due to this toxicity will occur within a given time. This, we may say, is an objective determination of fact, in terms of a scientifically grounded prediction, or an estimate based on empirical and theoretical knowledge (emission analysis, pathology, statistical methods, etc.) But it is the implicitly valuative notion of avoidable harm which transforms what seems like a straightforward matter of objective, dispassionate fact into a situation characterizable as a risk. A mere account of what the harm will be, given the present levels of emission, is not yet an assessment of risk; it is a description of a danger, of harm that will ensue, much like a hurricane forecast. But such a description bears within itself the implicit valuation which the term *toxic waste* connotes. The transformation from "objective fact" to "risk" is already made for us. It is built into what we sometimes glibly regard as "value-free" facts, and it is built into our language. The very phrase "industrial emission of toxic wastes" carries with it the connotation of evitable harm, just as the term *murder* carries with it the connotation of wrongful homicide. And it is the evitability of the harm which enjoins us to decide whether or not to avoid it. Rationality or plain common sense dictates that harm which can be avoided at no cost—whether of other harm, or loss of opportunity, or honor, or violation of obligations—ought to be avoided. Cost-free benefit, like inevitable harm, involves no risk. But the elimination of toxic wastes from industrial emission, as we know, involves a cost, to be compared with the cost which the toxicity incurs. Hence, the assessment as risk already involves us in considerations of comparative acceptability of risks. Thus, too, the very language of our "objective description" of danger is itself an expression of a form of life, replete with values, intentions, hidden imperatives. By our use of language, we already cut and fit our world in certain ways, select certain "facts" as "risks," and engage in the social construction of our reality.

Yet, a shared language and a shared culture, with its embedded system of values, does not always or often lead to a shared perception of risk. If there are different and conflicting perceptions of risk within a culture, we cannot adduce a coherent linguistic culture or a shared rationality as their source. We must presumably look elsewhere: to differences within a culture, whether in its practices, its organizational forms, its division of roles and functions, or its stratification. In its analysis of cultures, structuralist anthropology has typically attempted to find cross-cultural universals, abiding forms which may transpose themselves in apparently different ways in historically different cultures, but whose deep structures remain invariant through transformation. *Plus ça change, plus c'est la même chose*. In such a view, archetypical intracultural differentiation yields patterns of social organization, of hierarchy, of attitude, of style in which typical conflicts and typical resolutions are played out, though in different keys, in both preliterate and modern cultures, in agrarian and in industrial

societies. The structuralist's Platonic eye is on the abstract universal forms which persist through their various cultural mappings. Thus, though such an approach accommodates intracultural differences which can lead to value conflicts or alternative perceptions of risk, the suggestion is that such differences occur in the same typical ways in historically or socially distant cultural formations.

With regard to the analysis of risk as a cultural construction, such a view would seek to show similarities or analogies between the ways in which such historically diverse cultures select risks. The argument may be made to show that in all of these cases, whatever the differences in the perception of risk, such perception is socially constructed. That would count as the weak thesis of a cultural theory of risk. However, the argument may be made to show not only that risk is a social, collective construct, but also that there are comparable or archetypical modes of risk selection, and indeed, archetypical contexts of risk—e.g., pollution risks—that may be traced to isomorphisms in social structure or organization between widely different cultures. This is the stronger thesis of a cultural theory of risk.

An argument of roughly this sort is made in the recent work, *Risk and Culture,* by the authors, Mary Douglas and Aaron Wildavsky. As my preliminary considerations suggest, I would strongly uphold a cultural theory of risk; but, as the subsequent discussion will show, I disagree in crucial respects with their theory. In their introduction, the authors write: "In order to show that risks are socially selected, . . . we compare 'advanced' views with those of 'primitive' peoples. Readers are welcome to see if they can discern differences between 'us' and 'them' in the way that dangers are selected for public concern."[1]

There is an ambiguity here, between the weak and the strong thesis: Is it that risk selection is social, both among the Hima (who are nomadic cattle breeders in Uganda), the Amish and Hutterite sects in America, and us "moderns"? That's plausible, if the point is to show that, across such variations, risk and culture nevertheless go hand in hand. Or is it (the stronger thesis) that the pollution beliefs of the Hima, of the Amish and Hutterites, and of contemporary environmentalists, play essentially similar roles in the economy of social life, and that there are structurally common aspects of social organization that explain the similarity? That, to me, is implausible, though provocative. It is implausible for reasons I will give; but they depend, in turn, on a further discussion of the concept of risk, of its relation to rationality, and to the historicity of rationality. I will argue that a cultural theory of risk is indeed right about the genesis and contexts of risk perception but only if at the same time it is a historical theory—that is, one which gives full importance to the historically concrete and specific contexts of risk selection, and doesn't lose this specificity in abstract and misleading comparisons of formal structure, across all differences. The methodological caveat I am suggesting has its classical expression in Marx's remark: "when we speak of production, we always have in mind production at a definite stage of social development, production by individuals in a society. . . . Just as there is no production in general, there is no general production. Production is always a particular branch of production. . . . "[2]

Analogously, one may argue that there is no risk selection in general, but only risk selection in particular and concrete social contexts. On the other hand, this does not deny that there may in fact be formal similarities between widely different social contexts. The question is not, therefore, whether what a given society chooses to count as a risk is a matter of social construction; nor even whether there are, or may be, comparable uses to which a given type of risk selection is put, across widely different cultures. The question is how such an analysis is made in the given case, and whether the imputed similarities serve to mask crucial differences; in short, whether historically concrete specificities are ignored in the service of establishing abstract universals.

I will return to this discussion in the final section of this paper. In order to approach

it, however, I want to broach some further preliminary considerations of the concept of risk, and of its sociocultural and historical genesis. To begin, I want to show that epistemological considerations of the concept of risk already suggest that it is an essentially social construction embedded in a scheme of valuative, technical, and scientific-empirical modes of cognitive practice. In short, I will argue that the contexts of risk perception are not the contexts of value-free "pure" reason, but of impure, practical judgment and bounded rationality. Here, I will focus first on a conceptual analysis of what I will call the permutations of risk. This will lead to a consideration of the problem of relativism, in the perception of risk, and a discussion of how such relativism is related to a characterization of the sociality and historicity of rationality itself. Then, I will return to an examination of the proposal for a cultural theory of risk that Douglas and Wildavsky make in their book. Finally, I will recommend (but only barely) some of the directions that a cultural theory of risk should pursue for its further development.

THE PERMUTATIONS OF RISK: FROM EPISTEMOLOGY TO SOCIAL THEORY

To begin with, we may lay out some fairly standard and obvious characteristics of the risk situation. I will call these the permutations of risk.

Some risks are taken by us; some are imposed on us. In either case, we may be aware that we are at risk, or we may not. Thus, in the literature on risk, a fairly standard distinction is made between voluntary and involuntary risk, and further, between knowledgeable or conscious risk and ignorant or unconscious risk. Again, one may distinguish between risker and riskee: they may be the same person, as when someone puts himself or herself at risk; or they may be different people, as when someone is put at risk by another. Or there may be only a riskee, in the case where someone is put at risk in a situation involuntarily, but not by the action of anyone else, as when natural conditions create a risk no one has chosen or could anticipate, or plan in advance to avoid.

What is common to this first set of permutations is that all of them involve some framework of social meanings and values for their determination. To take a risk or to avoid one is to undertake an action for some end in view, in the face of a danger or threat of harm or loss of which one is conscious or knowledgeable. To impose a risk on someone else knowledgeably also presupposes acting with some end in view. In both these cases of knowledgeable risk, the agent is generally held responsible for making a reasonable judgment, that is for weighing the risk in the face of what one could reasonably be expected to know about the anticipated outcomes of one's action. On the other hand, the very nature of a risky situation entails that such knowledge is incomplete and imperfect, and that therefore the rationality demanded in such judgments is bounded by these limits. To be put at risk without knowledge—the case of involuntary, ignorant risk—nevertheless entails that there be some framework of knowledge and valuation such that if there were knowledge of the situation (on the part of the riskee or anyone else) it would be judged to involve danger or a threat of harm or loss that could be avoided by an alternative course of action, though at some other cost. That is, even in the case of ignorant risk, it can count as a case of risk only if, counterfactually, were there knowledge of the danger, it would then require (or make possible) a choice between risk-taking and risk-avoiding action. Finally, in the case of ignorant and involuntary risk not due to anyone else's action or choice, but in consequence of natural circumstances which one could not know or control, the counterfactual situation also holds: if one were to know the circumstances and could control them—both of these

contrary-to-fact conditions—then one would have been able to choose to take or avoid the risk. The traditional interpretation of such situations of involuntary ignorant risk is revealing: whether in the contexts of theology or of disaster insurance, they are denoted as "acts of God." Only theology, however, seeks to understand why God "put us at risk" in such situations. It typically seeks to fathom the divine rationality of such "acts of God," or alternatively assigns them to a reason beyond our understanding so that we should accept such disasters as tests of faith. Thus, even natural disasters and dangers over which we have no control come to be characterized as risks by virtue of imputing a rationality which, if we were to possess it, would give us the choice of taking or avoiding the risk.

There appear to be two elements necessary to the constitution of a situation as one of risk. First is a system of values which catalogs benefits and harms, requirements and obligations, permissions and prohibitions, and which also specifies some ordering among these. This is the framework within which some situation could come to be defined as a risk in the first place. The second element is closely related to the first. It concerns the requirement that there be some knowledge or information upon which decisions concerning risk are to be based. Such requisite "background knowledge" seems to me to have three components: (1) It is normative; that is, it is knowledge of the system of values of the culture, of what counts as benefit or harm, as better or worse, as obligatory, or as forbidden. It also functions, by exclusion, as knowledge of what is indifferent or inconsequential, and thus of what may be ignored. It is knowledge, therefore, of the rules and of the way they ought to be applied. In short, it is moral knowledge and casuistical skill in interpreting the application of rules to cases. In its theoretical form, such knowledge includes moral theory, legal casuistry, the articulated, systematic, and analytical modes of reflective rationality, with regard to normative questions. But even in its practical everyday contexts, such moral and casuistical judgment presupposes a complex culture, a history of traditions, laws, and institutional forms and practices, as well as a rich structure of social relations within which such knowledge has purchase, can be acquired, preserved, transmitted, and changed to meet new circumstances. (2) The knowledge on which decisions concerning risk are based is also technical or instrumental. It is knowledge of how to get from here to there; it is knowledge of means, of what is required to attain a given end. Risk-taking and risk-avoiding actions are essentially teleological, that is, actions undertaken with some end in view. As such, they count as rational only if they are appropriate or contribute in some way to achieving that end; or more problematically, they are taken to be rational, within a given culture, only if, within that culture, they are perceived as appropriate to the end in view. (Here, initial problems about the relativity of rationality to culture surface, about which more later.) Thus, in a situation of risk avoidance, one must be able to do what is reasonably expected to avoid the risk; and in risk taking, the choice is rational only where the expected benefit or other outcome is reasonably linked to the action as means to its attainment. The relation between the first and second components, between normative and technical or instrumental knowledge is classically expressed in Kant's dictum: ought implies can. (3) The final component of such knowledge is scientific-empirical. It concerns not only the know-how of technical knowledge, but the theoretical formulation of such knowledge in the systematic, hypothetical form of testable general propositions, from which predictions can be made within a logically ordered mode of inference. In situations of risk, such knowledge would concern those invariances or lawlike propositions by which past experience has been ordered, or which derive from other warranted theoretical statements. Within this mode of knowledge, one would then be reasonably entitled to expect, if not yet to be certain, that certain predicted consequences would follow from certain actions. Yet, the apparently well-ordered forms of

such theoretical knowledge cannot emerge, or function to any effect in decision making, unless they are linked to the technical and procedural knowledge of appropriate actions for given ends.

The normative, technical, and scientific components of the background knowledge which is requisite for decisions about risk are not separate and cleanly distinguishable, but rather interact with each other. All three aspects presuppose a complex culture and social life of a cognitive-technological sort, in which valuation intrudes at every level. There is no "pure" technical or scientific knowledge which is sealed off from the normative considerations of social life, though specialization, division of labor, and a particular historical ideology of science have led to the abstraction of these components from each other, and from the matrix of their interaction. With respect to contexts of risk, certainly, the valuative, the technical, and the scientific are intermeshed. Thus, if the determination and selection of risk necessarily involve the social and valuative ambience of culture, in terms of human interests, it would seem that scientific objectivity with regard to risk is inevitably relativized to the values, whether coherent or conflicting, which characterize a given culture. There would seem to be no appeal to a culture-transcending rationality, and no criticism of any given approach to risk selection which is not itself based on some contrary social interest.

The problem of the "subjectivity" or relativism of risk selection may be put in a balder way, by contrasting it to a Spinozist notion of cosmic "objectivity." In Spinoza's exalted view, what we call the "birth" and "death" of stars, solar systems, galaxies; the emergence of living species and their decline; the flooding, icing over, erosion of vast geographical regions—none of these involves good or ill, better or worse. Nature simply is. In nature, nothing is at risk. It just is or isn't; it comes into being, perdures, passes away. *Sub speciae aeternitatis,* there is no harm, no loss, no danger—thus, no risk. We may, if we like, venerate Being as such, as Spinoza did; but if we follow that serene and austere vision, we may not then attribute any providence or malevolence to the cosmos or to God with regard to human weal or woe. Such projection of anthropocentric interest upon the cosmos Spinoza called the "asylum of ignorance." Such a sublime view of the total indifference of nature leaves us alone in the universe to create and support such values as we have, and to stand by them in the face of their cosmically local character. But this means that if we are to take a cultural theory of risk seriously, we cannot then imagine that there is some other, transcendental recourse by which the cultural boundedness of our selection of what will count as risk can be measured against some objective, universal standard, and found adequate or wanting. Where perceptions of risk differ or conflict, it would seem that there is no supervening or critical authority, no higher rationality to which we may appeal, in order to transcend such a socio- or culturocentric predicament.

Thus far, then, we have argued that the concept of risk entails contexts of valuation and knowledge, that such contexts are essentially cultural and social, and that therefore, risk—risk taking, risk avoiding—is the exclusive precinct of the only cultural species we know of—us. Further, this gives us no recourse to any more universal or objective ground for the determination of risk than what a culture provides, by way of its value system and its modes of knowledge or cognitive praxis. And if cultures and subcultures vary or conflict in their perception of risk, then we face the problem of relativism—*Chacun à son risque*—if not among atomically discrete individuals, then at least among atomically discrete social groups and cultures.

We have further suggested that judgments concerning risk involve a bounded rationality, in the sense that, by definition, a situation of risk is one in which decisions are made on the grounds of incomplete and imperfect knowledge. But such "bounded rationality" can be

defined only by contrast with some conception of "unbounded rationality." This is the model of deductive or mathematical rationality which operates by deductively valid inference from essentially complete and perfect knowledge.

The classical model of such rationality is the Cartesian one, with its Platonistic–Augustinean roots. It is the unbounded rationality of the sure thing, of epistemic certainty. It has two aspects: first is the immediate intuition of certain primitive truths. Such truth "wears its seal on its forehead," and is immediately intuited as clear, distinct, and incorrigible. In this view, rationality is thus ultimately grounded in certainty, and certainty itself in the immediate illumination of the mind by what "could not be conceived to be otherwise." The second aspect of this unbounded rationality is that from these initial certainties, all others may be derived by equally certain steps of inference, each one intuitively incontestable. Such a method for the attainment of immediate and derived truths is algorithmic: an explicit, mechanically formulable stepwise procedure which guarantees correct solutions to properly formulated problems. Rationality here is reduced to computation, and such computation by algorithm is error-free and truth-preserving. If the premises are true, one is assured of a true conclusion; and on this model of rationality, the premises are taken to be necessary, incontrovertible truths, *per hypothesi*. Such algorithmic conclusions are therefore taken to be necessary and universal, hence, objective. No two persons using the same algorithm and starting from the same premises could end up in disagreement about the conclusion. In short, such computational or mathematical rationality is sure, and carries no possibility of risk, in the sense of uncertainty in the outcome of an inference, if the premises are secure.

It may at first seem that such rational certainty—that is, predictive certainty about the outcome of one's actions—may yet be compatible with being at risk in a different sense. One may know for certain that a given course of action will lead to harm; yet in view of equally certain benefits which would accrue, and which outweigh the harm in our view, we may choose that course of action nevertheless. But in choosing certain or assured harm (along with certain or assured benefits), we do not yet risk harm, because the outcome is not in doubt, or hazardous in this sense. Instead, it is a sure thing, and not a risk, cognitively, though one is certain to suffer harm in the outcome. The concept of risk seems to entail not only the notion of avoidable harm (in the sense that one can choose to avoid a risk rather than to take it) but also the notion that the outcome of harm (or benefit) from an action is a matter of chance or probability, and not a sure thing. Thus, to face certain harm as the outcome of a choice of action is not yet to risk harm, but rather to accept its certainty or inevitability as an outcome. The element of chance, of probability, of hazard, doesn't enter in here. Where one accepts an inevitable or assured harm as the cost of an anticipated benefit, or as an obligatory cost (e.g., of one's honor, or of just punishment, or of conscience), then this is not a situation of risk but of sacrifice. One makes a sacrifice in accepting a certain harm; one takes a risk in undertaking some action which may lead to harm, but also may not. But sacrifice operates under conditions of unbounded rationality, of certainty regarding outcomes. A sacrifice may entail a weighing of comparative values, but these are weighed in the context of certainty regarding the outcomes of the alternative actions in view. Risk, by contrast, operates only under conditions of bounded rationality, where we chance or hazard an outcome in view of a perceived or expected benefit. There is no risk of hell for true believers: they know exactly what will get them there and what will keep them out. One can't gamble with an all-knowing Deity, except out of ignorance. One may, of course, pay the cost of one's eternal felicity for nearer and more urgent benefits. Faust didn't gamble with the Devil; he sacrificed one thing for another. There was no risk involved; he made a deal for a sure thing.

In all these permutations—of voluntary and involuntary risk, of knowledgeable and

ignorant risk, of the epistemological conditions which constitute a capacity for risk taking or risk avoiding—valuative, instrumental-technological, scientific-empirical—and of the characteristic modes of bounded rationality which mark judgments of risk—there is the irremediable component of sociality, of culture. But what precisely are the cultural constraints or influences on judgments of risk? If risk is socially constructed against the background of a value system, then it might seem that in a given society with a prevailing value system, there would be wide if not universal agreement on matters of risk, and a common method for ascertaining how to proceed. Yet there is wide and even passionate disagreement over the assessment and acceptability of risks; and indeed, there are theoretically incommensurable alternative accounts of how one ought to go about determining policy and action with regard to risk. Both the substance and the method of decision-making about risk are at issue then. But if risk is a social construct, and there exists such intrasocietal variability and sharp disagreement in approaches to risk, there must therefore be grounds within a given society—e.g., ours—for such different value systems that would lead to such differences about risk.

REFLECTIONS ON DOUGLAS AND WILDAVSKY

I turn now to a sustained study which attempts to explore this question. In their recent book, *Risk and Culture,* Mary Douglas and Aaron Wildavsky propose a thesis to explain differential perceptions of risk on the grounds of different sociocultural types, which characterize not only our own contemporary society but which, the authors suggest, have some deep cross-cultural and transhistorical validity as alternative structures of social life. We select what will count as risks differently because we choose different forms of life, different goods. The authors write: ''the choice of risks to worry about depends on the social forms selected. The choice of risks and the choice of how to live are taken together. Each form of social life has its own typical risk portfolio" (p. 8).

The understanding of risk, then, depends upon understanding what "a form of social life" is, and how, in particular, a given form would entail a given "risk portfolio." The specific problem, or case study which the authors pose for themselves, focuses on the contemporary perception of the risks of environmental pollution, on the different "forms of social life" that are at the root of environmentalist and antienvironmentalist positions on pollution risks, and on the cultural changes in the perceptions of this risk that have developed in the last two decades. In short, Douglas and Wildavsky propose the broad outlines of a cultural theory of risk, and apply it to a contemporary case study.

A cultural theory of risk may come to no more than the platitude that our perception of risk is influenced by our interests. In a recent book review in the New York Times, Christopher Lehmann-Haupt writes (about the book *Acid Rain,* by Robert H. Boyle and R. Alexander Boyle): "So an industrialist with an interest in cheaper energy and higher productivity would not seem altogether implausible were he to dismiss Mr. Boyle for being one of those nature sentimentalists more interested in preserving scenic views than in getting American industry on the move again."[3]

Mr. Robert Boyle, we may add here, is a sports writer and an environmentalist, as the reviewer reminds us; so it is to be presumed as a matter of simple sociological inference that he must put the great outdoors above profit. But Douglas and Wildavsky are not proposing anything that simpleminded. What they have to offer instead is a typology of "ways of life''—complexes of social organizational forms, styles of decision making, systems of belief about human nature, and about nature itself—which underlie different selections of risk. The cultural types they identify are three: market individualism, hierarchy, and sec-

tarianism. The first two are seen as located at the "center," in the sociopolitical topology which Douglas and Wildavsky propose; and "center" means, roughly, "establishment." Thus, the established center is already divided between two alternative approaches to the selection and management of risk. But neither of these types suffices to characterize the structure and goals of the environmental movement, which is the special case of risk orientation upon which this study focuses. This alternative type is characterized by the authors as sectarian, and its sociopolitical topos is the "border," as opposed to the "center." It is, as one might suspect, antiestablishment. Such cultural types are, in the language of the authors (and in the spirit of Weberian sociology), "models of rational behavior under institutional constraints." That is, each cultural type provides a rationale, in terms of ideology, explanation, and approved methods of decision making, for a chosen way of life and a given cluster of values.

Metaphor is the motor of the sociological imagination. *Center, border, hierarchy, sect,* and *market* are all more (and less) than theoretical or technical terms in the social sciences. They are richly connotative metaphors, replete with associations of imagery and formal structure, with echoes of value. The terms also have a history in social theory, which is laden with its own weight of meanings. By the 14th century, Ibn Khaldun had already proposed a "border" theory of the desert as the source of those reforming, purifying antiestablishment prophets and leaders of sects who periodically cleansed the corrupted "centers" of Islamic culture. The ideology of the "frontier" in American history is a complex reverberation of older "border" theories; and the role of sects in the earliest shaping of the New World cultures is plain, from the Puritan "Holy Commonwealth" on through many others—(two of which, the Amish and the Hutterites, are analyzed and compared at length by Douglas and Wildavsky). So too, "hierarchy" or "bureaucracy" as a sociocultural and organizational type has a long history of interpretation and analysis in the social sciences, as does "market individualism." (Start with Hobbes, if you like; proceed on through any variation on utilitarian or rational-choice theories of decision making; then go to the political theorists like C. B. MacPherson for a historical account of classical, so-called possessive individualism.) In short, the choice of types that Douglas and Wildavsky propose is not new, nor is it intended to be original. What is original is their interpretation of these types with respect to their correlative risk orientations, and also their elaboration of what one might call the social psychology of members of these alternative social forms.

Here, their argument for a cultural theory of risk seems to run into serious trouble. For in deriving alternative types of risk selection (or alternative choices of "risk portfolios," as they put it) from the structural features of social organization of such groups, Douglas and Wildavsky seem to reduce the explanation of differential risk perception almost to an algorithm: what will be taken to count as a risk will depend on how the choice of that risk functions to promote the social cohesion of a group, against the "others," or what will be chosen as a risk to be dealt with by a group will derive from the social or political "location" of that group in the cultural topology of "center" and "border." The "bias" which inclines toward the selection of one sort of "risk portfolio" as against another is thus a function of formal features of social structure, or of cultural "locus," and correlatively, a function of the instrumental uses to which such a bias can be put, in preserving or promoting the social structure.

The trouble with such an explanatory scheme is that it is overdetermined. Because of its abstractness, it "explains" too much too glibly. As a result, it leaves crucial features of risk selection unexplained, and leaves one with a view of social rationality as no more than an instant reflex of social structure. It is not that Douglas and Wildavsky leave out the details; details abound. They give an informed and often interesting account, for example,

of the growth of the contemporary environmentalist movement, in the context of the political aftermath of the 1960s, and they link this to a social-structural analysis of the leading organizations—e.g., the Sierra Club, Friends of the Earth—to show how their theoretical scheme applies. But their details are in the service of an almost mechanical functional analysis which clouds substantive questions of risk selection in a fog of vacuous analogies. Thus, for example, they write: "Leaders looking for positions may discover the environment as their predecessors discovered labor unions" (p. 158). Or again: "Since perceptions of environmental impurities form part of a critique of the existing social system, we would expect people who stand outside industrial society to be more concerned about risk from pollution. It is not only that people who take part in production feel more kindly about its processes but that their fortunes are tied to those of the central society" (p. 161).

The glories of sociological generalization blaze here in their full light. Once the schema defines "interest" as a function of "locus," and interprets social issues (the organization of labor unions, the concern over industrial pollution) as no more than opportunities for leadership for the footloose individuals of a marginalized professional and service class, then the explanation of risk selection reduces to simple deductions from such structuralist–functionalist premises. What disappears from view here, or worse yet, becomes mystified, is the question of whether pollution risks have objectively increased so as to justify increased concern, or whether the increasing unacceptability of such dangers is a result of better information. True, risk selection is a social process; but what is this social process? Is the social rationality of risk selection no more than an epiphenomenon of one or another "type" of social organization? How is the epistemic validity of such various social judgments of risk to be assessed? Snide suggestions that environmentalism is simply the product of the leadership-seeking propensities of displaced "border" intellectuals from the affluent suburbs fails to answer, or even to address such questions. And it leads to wrong answers to the questions it does ask. "People who take part in production" are, in Douglas and Wildavsky's view, all of a piece: they are all center types who belittle pollution risks because they are more fixed on the "bottom line." But surely, this loses a crucial distinction between even the perceived interests of a pollution-denying board of directors out to make a buck, and "those who take part in production" and are directly exposed to the risks.

To be fair, Douglas and Wildavsky's argument for a cultural theory of risk starts off well. They clearly recognize, and argue, that differences in judgment about risk cannot be resolved either by an appeal to theories of subjective individual preference, or expectation, or by an appeal to theories of the objective, technical determination of risk. They write: "Between private, subjective perception and public, physical science, there lies culture, a middle area of shared beliefs and values. The present division of the subject that ignores culture is arbitrary and self-defeating" (p. 194).

This is, perhaps, the most notable contribution their work makes to the theory of risk, for it perceptively stakes out the proper domain in which social choice about risk actually operates. Neither the utility functions of ideal individual rational choosers, nor the physicochemical analysis of the toxic or otherwise dangerous properties of substances, nor the technical or statistical determination of the consequences of certain processes or actions capture the sociocultural and essentially normative features of risk selection. But having started from the standpoint of a cultural theory of risk, the success of the argument depends entirely upon what Douglas and Wildavsky make of "culture." And what they make of it is at once odd and incoherent. Let me give an example: On the one hand, the authors argue that what is ultimately determining—or socially constituting—in risk selection is the choice that people make of a given form of life or social structure or catalogue of goods and values. The authors write: "We believe that people's first and fundamental choices are personal,

moral, and political; the intellectual arguments justify what has been decided: first the good society, the good life, and a place in it. If we agreed on what polity we desired, we could consider what risks would be worth facing for establishing it" (p. 82).

Very well, then: people decide their risk orientations by choosing a social framework that guides their selection and management of risks. The emphasis here is on choice, on the agency of the person. (For the moment, I will ignore this blithely voluntarist or emotivist theory of choice, which assigns rationality or cognition to the clean-up function of "justification.") But then, Douglas and Wildavsky tell us that it isn't really a matter of choice at all: "Humans turn out, after all, to be sensible creatures who have handed over the majority of their decisions to some kind of automatic pilot. . . . Humans are not isolated individuals. Their sociality should be included in the analysis of how their minds work. In risk perception, humans act less as individuals and more as social beings who have internalized social pressures and delegated their decision making processes to institutions" (pp. 79–80).

There is a three-step sleight of hand here: First, people are characterized as personal, moral, political choosers of what they take to be the good life. Second, they are characterized as not merely individual choosers but as social beings, who internalize the goods and values of their society. Third, in doing so, they turn out not to be choosers at all, but are said to delegate their decision making to institutions. Moreover, in doing so they are approvingly characterized as "sensible creatures''! From the ambiguous premise that people are social beings, we are quickly pushed to the conclusion that their sociality tends toward some form of holistic automatism. From moral choosers of a way of life, they have suddenly become transformed into the witless vehicles of its imperatives, as if sociality entailed social determinism or herd behavior.

There is much wrong with this argument, but I will focus on one flaw here. A cultural theory of risk correctly both eschews asocial, individualist theories of risk determination of the abstract "rational chooser" sort, and also eschews an algorithmic objectivism of a purely technical sort. So far, Douglas and Wildavsky have my hearty agreement. But then, "objectivism" has many guises. If "purely technical" modes of risk determination are regarded as an inadequate model of social choice, then a cultural theory of risk cannot then assign the same sort of algorithmic mode to "culture" or "society," for then these agencies become as "objectivistic" as any mode of technical determination could be. In effect, "society" or the "institutions" which take over the decision-making functions ceded to them by "social beings" become "decision machines," no less than the "physical-scientific" modes of risk determination that Douglas and Wildavsky reject as inadequate and inappropriate to the representation of social choice. Furthermore, as the authors themselves point out, the allegedly "objective" modes of "physical-scientific" decision making are themselves shot through with (largely tacit) social and ideological values. Thus, if the authors argue that social and cultural institutions embody value structures in contrast to "physical-scientific" modes of risk determination and selection, and then acknowledge that the cultural institution of science also embodies such value structures, than the contrast cannot be between a cultural mode of choice and a noncultural one, but rather between two alternative cultural modes of choice. If, as the authors themselves point out, purely technological risk assessment is equally laden with the value orientations and selectivities which characterize the culture of science, then they cannot reject such mechanisms of choice in "science" as "purely technological" and then approve "automatic pilot" mechanisms in culture as somehow "sensible." Such a view makes the contrast that the authors draw between "public, physical science" and "culture" at least problematic, if not incoherent.

The first problem, then, with this cultural theory of risk is that it adopts too holistic

and deterministic a view of culture as some semiautonomous Durkheimian structure which imposes itself on its individual members as its passive passengers, along for the ride and going wherever the culture takes them. But there is a second problem, which is more fundamental and less easily resolvable than the first. It is the generic problem of cultural theory—namely, that of cultural relativism. It is a problem which Douglas and Wildavsky face head on; but they fail to resolve it. And it is so central to the question of risk assessment that it deserves a separate excursus.

RISK AND RELATIVISM

The relativity of perceived risk to one's social situation, one's interests or the value system of one's culture is not yet, in itself, problematic. One could resolve such a prospectively benign relativism by pointing out that there is a far greater number of dangers and threats of harm than those which come to be selected as risks that demand attention or action. Therefore, one might argue, different "risk portfolios" simply pick out different "investments" from among the range of possible prospects, with no conflict or disagreement among different groups. "Jack Sprat could eat no fat, his wife could eat no lean; and between the two of them they licked the platter clean" might be the moral of that tale. But of course, that's not how it works. In the real world of risk, where what is at issue is policy choice among risks within the same society, where different groups have conflicting interests or value schemes and therefore profound disagreements about what the risks are, how they compare, and what actions to take about them, relativity becomes a matter of concern. For then, what is at issue is not simply a descriptive account of what different groups choose as risks, or even of how such alternative choices may be seen to follow from different "models of rational behavior," each justified, so to speak, by its premises, or by the differential choice of goods or ends among alternative cultural types. What is at issue instead is the normative question of the right choice, the best choice among such conflicting alternatives, on some grounds which are not relativized to one or the other of these alternatives. But since "right choice" or even "rational choice" cannot be defined apart from some idea of the ends for the sake of which the choice is made, or the values against which something will be defined as a risk, and found acceptable or unacceptable, there would seem to be no culturally context-free way of transcending the limits of any given standpoint; there would only be an alternative standpoint. There can be no recourse to what we may call a realist notion of risk, that is, to a notion that there are objective risks independent of what anyone may think of them, or that there is an objectively real ordering of risks, or an objectively right method to choose among risks, independent of any culture, interest, or standpoint. The only recourse there can be, beyond the cultural variability of risk perception, is to some ostensibly "universal" standpoint which transcends all partial or historically limited ones.

The conceptual difficulties here are familiar. Whether we are talking about the culture-boundedness of risk perception or the value-ladenness of scientific norms, or the theory-ladenness of observation, or the ideological character of one or another social or economic theory, the basic problem remains that of how to ground judgments concerning the comparative validity of norms without falling into the circularity of the inclusion of these grounds themselves among the norms to be judged.

If we take risk to be an ineluctably social construct, as we have thus far, there would seem to be no appeal beyond relativism. For nothing counts as a risk by nature, or in itself, but only because it threatens some held value or endangers well-being; and nothing is a

value or constitutes well-being except what is valued or held to be good. But this creates a quandary. Surely, one might argue, there are those things which ought to be valued, or taken as goods, and those things which ought to be recognized as risks of these values, even if no person has as yet come to recognize them. For otherwise, values are relativized to whatever a culture or a group construes them as, and "ought" is reduced to social ideology. One culture's norms are another's nothings, one person's "ought" is another's "Who cares?" and the specters of skepticism, nihilism, or amorality haunt the precincts of human endeavor. If anything goes, we are left without grounds for our convictions or actions.

On the other hand, if it can be shown that the claim to transcendent values, to objective "oughts," to truly perceived and objectively measured risks, is itself nothing but a sedimented sociohistorical construction, if the demand for transcendent absolutes and transcultural universals can itself be seen as socially and historically situated, if it can be effectively argued that we need no more foundations for our truths than what culture itself provides—then skepticism, nihilism, and amoralism can themselves also be interpreted as social postures, the postures typical of those who are at the fringe rather than at the center of a culture's norms. Thus, not only are perceptions of value—and hence of risk—*standortsgebunden,* in Mannheim's phrase (bound to the concrete social situtation of the perceiver), but so too are demands for a supervening objectivity.

It was Mannheim who formulated the problematic for the sociology of knowledge in the face of the quandary between two traditional epistemological postures, which we may conveniently label realism and relativism. The first view holds that there are objective truths (the prototype of which are mathematical truths) independent of the knowledge or values of the thinker or perceiver. The second view is defined in relation to the first: to the extent that any perception or belief is dependent on the subjective situation of the knower, it is merely relative, and fails to have any objective grounding. "Relativism," Mannheim writes, "is a product of the modern historical sociological procedure which is based on the recognition that all historically situated thinking is bound up with the concrete position of the thinker."[4]

Mannheim traces this view of the relativity of thought to its social contexts. He writes: "To begin with, a given social group discovers the situational determination (*Seinsgebundenheit*) of its opponent's ideas. Subsequently, the recognition of this fact is elaborated into an all-inclusive principle according to which the thought of every group is seen as arising out of its life conditions."[5]

For Mannheim, however, this situation of the concrete or situational boundedness of thought is "relativistic" only by contrast to the notion that there is some absolute standpoint. Such relativism is problematic, he argues, only if one expects that there can be some value- or context-free absolute truths, which will be taken as "objective" in contrast to the "subjective" nature of situationally bounded thought. Against such a view of relativism, Mannheim posits what he calls relationism, which he sees as nonproblematic in this sense. Thus, he writes:

> A modern theory of knowledge which takes account of the relational as distinct from the merely relative character of all historical knowledge must start with the assumption that there are spheres of thought in which it is impossible to conceive of absolute truth existing independently of the values and position of the subject and unrelated to social context. Once we recognize that all historical knowledge is relational knowledge, and can only be formulated with reference to the position of the observer, we are faced once more with the task of discriminating what is true and what is false in such knowledge.[6]

This is indeed odd! If we are all *standortsgebunden,* how do we detach ourselves from our locus even to raise the question of "true and false"? Haven't we simply shifted the margin of what lies to one side of relativism, by rechristening it as "relational," and univ-

ersalizing it for "historical" (that is, social or cultural) knowledge? Mannheim answers this objection thus:

> It seems inherent in the historical process itself that the narrowness and the limitations which restrict one point of view tend to be corrected by clashing with the opposite points of view. The task of a study of ideology, which tries to be free from value-judgments, is to understand the narrowness of each individual point of view and the interplay between these distinctive attitudes in the total social process. We are here confronted with an inexhaustible theme. The problem is to show how, in the whole history of thought, certain intellectual standpoints are connected with certain forms of experience, and to trace the intimate connection between the two in the course of social and intellectual change.[7]

The quandary between realism and relativism is then to be solved, ostensibly, by a rational critical examination of conflicting "subjective" standpoints, by means of which we will come to understand how they arise out of the social situatedness of the perceivers, and how they change historically; for, says Mannheim, "not only does the content of thought change, but also its categorical structure."[8]

Mannheim's hope for the relative "detachment" which would permit such a view from above the battle of conflicting standpoints rested in his own view (also socially situated, one would presume) of the social situation of a freewheeling *freischwebende Intelligenz,* a disembodied intellegentsia with no firm anchor in the establishment, or in any other social class. The *Seinsgebundenheit* or the situatedness and sociality and historicity of thought, even of the categorical forms of rationality itself, is thus conditionally overcome by the very recognition of the relationalism of all standpoints, from the standpoint of criticism. Not the happiest resolution of the problem of relativism, to be sure.

I go on about Mannheim here because he formulates the problem of the social situatedness of thought as an object of sociological study in much the same terms that the authors of *Risk and Culture* do. Moreover, Douglas and Wildavsky take a similar approach to the problem of relativism in the contexts of risk perception which they examine. For them, too, it is a question of critically viewing the variety of social situations in which alternative or conflicting perceptions of risk arise, in order to recognize the source of these differences, and hence, to explain them. In this very act of criticism, they presumably rise above their own "situation," or at least acknowledge where they are situated in the sociopolitical geography of "center" and "border" that they map. But they sit uncomfortably on both sides of the problem of relativism. On the one hand, they criticize the strong relativist position, which holds that "each thinker is a prisoner inside his definable cognitive scheme." Of this view, they write that "it supposes that there is no taking in of new ideas; one can only rearrange a new experience so that it conforms to what one knows already" (p. 192). The relativist critic would need, in effect, a "theory of the non-transmissability of ideas," they add. Instead, they argue, they prefer the idea of knowledge as "the changing product of social activity." On the other hand, as we have seen, their typology of social structures seems to suggest that the "automatic pilot" mechanisms to which people assign their social choices operate to produce just that sort of "prison" of cognitive schemes which the authors criticize. Presumably, what liberates people from the limits of their social situation as a cognitive determinant is the awareness of alternative views, and thereby, a degree of self-consciousness which would permit critical self-reflection.

To be fair, the authors qualify the structuralist rigidity of their account of "types." They confess that it is "necessarily given in extreme form" (though why this is necessary is unclear). So we are led to conclude, finally, that social structures are not quite so determinative of risk portfolios as the original formulation suggested; that hierarchists, market individualists, and sectarians can sit down and swap stories, learning from comparisons with

each other's value schemes to see beyond the boundaries of each one's cultural type; and finally, that this free exchange of overviews is not bound by any external constraints as to what is independently, objectively, "really" better or worse, since in the end, it is what they collectively take to be better or worse that constitutes the "reality" of these social constructs. "Knowledge," the authors write, "is like a many-sided conversation in which being ultimately right or wrong is not at issue. What matters is that the conversation continue with new definitions and terms made deep enough to hold the meanings being tried" (p. 193). With this irenic image of rational consensus as the result of conversation, I take it that the problem of relativism with regard to risk selection is transcended, on the authors' view. For they make clear that they reject the view that truths are relative to social structure. Thus, they write: ''Cultural analysis would be undermining its own conditions for producing conviction if it were teaching that every social situation generates its own truth and that there are as many truths as there are communities. Cultural analysis need not become a conversation stopper which allows anyone to block an argument by referring reductively to its social genesis. Its own claims to attention would be destroyed at the same stroke" (p. 193).

But if truths are not thus relativized to social structures, what about decisions about risk? Presumably, matters of truth are not at issue here; or at best, it is only such constituted "truths" as are products of some method of social consensus that count in these contexts. But cultural analysis, we are told, ought not to block argument by referring reductively to social genesis. And yet, we have been further told, risk policies are matters of social decision, and such social decision is itself a function of social structure. How indeed are we then to "keep the conversation going''? How are we to avoid the relativization of risk to the limits of whatever social horizon is imposed by a given structural "type''? Since "being ultimately right or wrong" is not at issue, according to the authors, it would seem that our final recourse in matters of risk selection is the consensus arrived at after a critical analysis and overview of alternative policies, in that mode of freewheeling discourse in which we transcend our own parochialisms, and attain to a critical overview of the sources of our differences and of the rationales offered to support them.

It seems to me, however, that the relativity of such a critical "consensus" is no less problematic than the relativity of "many truths" that the authors eschew. For, as far as I can tell, the epistemic grounds for the larger consensus are no different than those which support any agreement that a more limited community might reach in determining its own "truths." One might argue that the difference is both a matter of scope (alternative risk-portfolios generated by different social structures are now included and compared) and of method (the different views are examined from a critical perspective in which they are rationally tested for their logical coherence, and for the consequences that flow from one or another posture). But suppose that the consensus is one that is arrived at by lion and lamb, by hierarchist, market-individualist, and sectarian, by polluter and pollutee: does such an agreement among originally antithetical or alternative perspectives signal the end of relativism and the dissolution of its problems? Or isn't it the case that such a consensus is simply the product of yet another social structure, and that its risk policy, in turn, may be seen in the same terms that the authors have used to characterize, e.g., "sectarian" or "market-individualist" risk selection? Are we not led, ultimately, to that same "reduction to social genesis" that the authors claim to evade? To be sure, this new "social structure" is a complex one, in which the norms are those of free discussion, enlightened criticism, the airing of differences, etc. But why should we accept these norms rather than those characteristic of other consensus-forming social structures? This is not intended as a rhetorical question. What is needed is the rationale, the argument for such a supervening consensus, and given the authors' claim,

some argument to show that this decision procedure escapes the relativism of those determinations of risk that flow from less inclusive perspectives.

What I am suggesting, in short, is that what Douglas and Wildavsky propose as the resolution of the problem of relativism is itself another historically identifiable and contingent social structure or "type" of ideal rationality, namely, that of liberal democracy. That this is an eminently noteworthy model of decision-making is not in question. It has its model in the "republic of science," e.g., in Robert Merton's account of the ethos of the scientific community; and in its most recent incarnation, in neo-Kantian garb, it is represented in what Habermas calls "the ideal speech community." I have nothing against the authors championing such a view. What I object to is their presentation of it as an answer to the problem of relativism, and as somehow superior to the structure-bound, and thus structure-relative views of those "trapped" inside their "individualist," "bureaucratic," or "sectarian" cages. For the liberal democratic ideal of a rational community which arrives at its decisions after full airing and criticism of all views is itself just another such "type," identifiable with a certain sort of social structure which is in tandem with a certain view of the good life. That is to say, there is nothing in the authors' presentation of this model of rational decision making that makes it immune to just the same sort of analysis that they have given of the three social models of risk selection that they examine, and therefore nothing which establishes the claims about the method of consensus as in any way better grounded than the claims that may be made for the "truths" or risk policies of any of these other groups.

My criticism, however, is not that Douglas and Wildavsky fall under the same analytical knife that they have used to dissect other norms, but that the analysis is flawed in all these cases in the same way. The fact that the thesis of a cultural theory of risk may itself be presented as the outcome of a certain type of social structure, following Douglas and Wildavsky's own mode of cultural analysis, means that the theory has no more purchase than any other view, and that either there are as many "truths" as there are communities, or anything goes, and risk is ultimately relativized to social structure. Cultural analysis would then indeed be the "conversation stopper which allows anyone to block an argument by referring reductively to social genesis" in the nasty, reflexive way that I have just done.

There is something wrong with this. We are not, I think, constrained to the choice between a Platonistic essentialism with objective, universal norms which are independent of any social genesis, on the one hand, and on the other, a cultural relativism in which norms have their ultimate justification in the mere fact that they have been adopted, or that they serve as the rationales of some "vision of the good life." Douglas and Wildavsky have proposed the domain of social construction of norms as the alternative to a subjective individualism or a scientific-technical objectivism, arguing that neither of the latter two approaches capture the social process by which decisions about risk are made. But in attempting to do justice to the social character of this normative practice, they have stripped it of the very content of that moral and political choice which they adduce at its core. For if moral and political choice is to be more than an epiphenomenon of social structure, and also more than a matter of irrational or emotive preference, it has to be grounded in an analysis of the social and historical circumstances of such choices, and in a critical argument as to why, in given circumstances, one choice is better than another. But the ground they adduce for such choices finally flaws their argument, in my view, and makes it a reductive one. For it follows from what they say that whatever people in a given situation take to be the basis for their choices in matters of risk, they are really acting on the basis of hidden imperatives or desiderata which reduce to the demands that a given social structure makes to ensure its stability. They end up as the witless instruments of the structure's own ho-

meostatic mechanisms. Thus, the very recourse to a method of social or cultural analysis of risk selection recreates the domain of that analysis itself in the image of the very objectivism or subjectivism which the authors had decried in the standard alternative theories of risk.

On the one hand, the authors state that what lies behind one or another choice of a risk portfolio is the moral or political choice of a vision of the good life. On the other hand, once this choice is made, the social structure associated with the realization of this vision determines the perception of risk which conforms to that standpoint; for in effect, the authors argue that the perception of risk is itself principally a means of sustaining or reinforcing that social structure. Thus, the function of a given risk perception is finally the instrumental one of preserving the social structure intact. It has no validity beyond that, since there is no "objective" criterion to which one could appeal which lies beyond the social construction itself. The explanation of the social determination of risk is thus essentially a functionalist one: People think they are making choices about matters of risk, but what they are really doing is preserving a given set of social relations to maintain a certain social structure. What are we left with, then?

We are left with two things: an emotive theory of choice, concerning preferences among alternative visions of the good life, on the one hand; and on the other, a structurally determined risk policy which maps that choice onto risk selection and defines the perception of risk for all members of a given social structure. There is no room here for moral or political criticism, or for real moral or political choice in the assessment of risk. For the assessment itself is bound to the "facts" about risk as they are construed within a given framework; and because there is no framework-free access to the facts, relativization to social genesis is complete and irremediable on this view. Even when we have recourse to the consensus which is supposed to emerge from a comparative and critical overview of alternative risk policies, and of their sources in such social structures, the pattern simply repeats itself, for the consensus-forming structure is, albeit at a higher or more inclusive level, just another such social structure, chosen on the grounds of preferences for a certain form of the good life. And these grounds, in turn, seem to be emotive. That is, what justifies the choice of the "consensus" mode of risk selection is simply the "commitment" that those joining in that "form of life" make to it. Thus, it would seem that if we accept Douglas and Wildavsky's functionalist "explanation" of the social process of risk determination as ultimately nothing but a means of preserving a given social structure, we are caught in a hermeneutical circle: what determines our choice of one rather than another interpretation of the facts about risk is our commitment to a certain social structure; and what determines our commitment to this social structure is a certain interpretation of the facts about risk. But since such an interpretation can only derive from a prior commitment to a certain social structure, we are back where we started. We have no mode of access to questions concerning risk outside of this sociocentric predicament.

There are two ways to deal with such a circle: we may accept the ultimate relativization of risk to social structure as the inescapable condition of the cultural analysis of risk, or we may reject the strong thesis of such a theory that argues (despite protestations to the contrary) for the reduction of any argument to its social genesis in terms of the imperatives of social structure or organization. It may seem that the latter course entails an abandonment of a cultural theory of risk. But it only entails the abandonment of this cultural theory, that is, the rejection of the view that types of social organization algorithmically entail types of risk selection, on structuralist–functionalist grounds. One may maintain a theory of the socio-cultural process of risk selection on other grounds; moreover, on grounds which acknowledge the normative content of such decisions as crucial, and as subject to explicit and rational argument concerning their validity. It is the reduction of this moral, political, and cognitive

content to structural or functional determinants that seems to me to flaw the Douglas–Wildavsky theory. Worse yet, by hypostatizing structural components of risk determination, the theory mystifies the normative issues, or hides them behind the veil of its formalist approach to cultural analysis.

CODA: SOME ALTERNATIVE APPROACHES TO A CULTURAL THEORY OF RISK AND SOME PARTING SUGGESTIONS

In their concluding chapter, Douglas and Wildavsky write: "The idea that public perception of risk and its acceptable levels are collective constructs, a bit like language and a bit like aesthetic judgment, is hard to take. The central thesis that the selection of dangers and the choice of social organization run hand in hand goes against the grain of contemporary thought" (p. 186).

On the contrary, I find the idea that risk perception is a collective construct "a bit like language and a bit like aesthetic judgment" very easy to take. In fact (as I have argued elsewhere[9]), I take this to be true of scientific judgment as well, and also of clinical judgment in medicine, legal judgement in the courts, technical judgment in engineering, and moral judgment in matters of practical everyday life. What is involved in all of these cases is the heuristic and hermeneutical mode of thought, rather than the algorithmic or logically deductive mode. Therefore, I am more than ready to agree that a proper theory of risk as a "collective construct" involves a rich sort of social rationality which has much to do with wisdom, good judgment, knack, good taste, moral uprightness—all the hallmarks of practical judgment. Moreover, such practical judgment need not be a matter of explicit deliberation in every instance. The sociality of such a mode of judgment makes it often tacit or inexplicit in its practice, so that whereas reasons could be given, after the fact, for why one decision is to be preferred over another, this is a matter of reconstructing the judgment rather than an explicit element in a decision procedure. Social rationality in risk determination therefore may well be, or become, a matter of "second nature," as a "collective construct" which shapes the propensities of our judgments. If this is what Douglas and Wildavsky mean, then I have no problem with it. What I do not find easy to take, however, is the way in which "the selection of dangers and the choice of social organization run hand in hand," according to the authors. However much my perception of risk may be influenced by my social situation, it is not legitimated by it. To whatever degree collective judgments about risk may correlate with the "situational determination" of that group, this says absolutely nothing about this judgment normatively or critically, as yet. It may be interesting to discover how the sociohistorical development of the "border" culture of the 1960s led to the burgeoning of the environmental movement, and how certain risks were selected because they were more manipulable politically than others. But this tells us nothing at all about whether the environmentalists are right or wrong, or whether their vision of the good life is better or worse than that of the "center" types who are either antienvironmentalist or indifferent to the issues. Douglas and Wildavsky tend to "do a job" on the "border sectarians" of the environmental movement, and justify this focus with the claim to be "evening the score" a bit, since everyone is always beating up on the bureaucrats and market-individualists anyhow. But they leave no room for a discussion, much less an argument, as to whether the claims about increased and unacceptable environmental risks have any normative validity. They are content, instead, to invoke what is a form of the genetic fallacy: having suggested (or "explained") that environmentalists get that way because of their social situatedness in the spectrum of sociological "types," they either imply that this puts their judgment about risk

in question, since it only answers to desiderata which flow from the social structure of border sectarianism, or they substitute a sociological critique of the selective biases which form the sectarian view for an epistemic and moral critique of the judgments about risk themselves. This sort of explanation is akin to that which ascribes Stalinism to "oriental despotism" as a "type" correlated with the Asian land mass and its irrigation systems, or ascribes radicalism in politics to unresolved Oedipal conflicts. But what grounds are there here for a critique of the normative content of Stalinism, or of radical politics? Was Stalin right or wrong? Is the radical's critique of society true or false? Whether the domain of "structural" explanations is as large as the geopolitical or as small as the familial or as middle-sized as the sociocultural doesn't matter. In any case, the explanation eliminates the normative question entirely, or reduces it to an algorithm of structure or function.

But perhaps this is not what Douglas and Wildavsky intend. Perhaps their view is rather that in matters of linguistic usage and aesthetic judgment, what prevails finally as "right" or "good" or "better" or "worse" is a consensual judgment which is the outcome of a process of "keeping the conversation going." This won't do. For what it leaves out of account is the fact that aesthetic judgment and language, like collective constructs concerning risk, demand a normative commitment to standards of better and worse which is not merely a matter of procedure or of noncognitive preference, but of critical discourse. Such a discourse concerns itself not merely with the fact of consensual agreement or of common practice—a phalanx of fools may come to agree, after all—but with agreement (or disagreement) based on a head-on critical confrontation with the issues of aesthetic taste and linguistic usage themselves. Such a confrontation is never reducible to questions concerning the sources of one's judgment, or even of the uses of one's judgment (to effect some other, extraaesthetic or extralinguistic ends). So too, a confrontation among alternative judgments about risk cannot be reduced to an argument about where the judgment is coming from, or about what other uses it may be put to, in the economy of social life. Nor can it be reduced to an ostensibly value-free survey followed by a context-free choice, in terms of some "ultimate" or unarguable aesthetic or linguistic or moral or political preferences. Choices of risk are socially and historically situated. But that means only that one must include the concrete contexts of choice as parameters of one's analysis, to understand what is intended by the choices and why they may have come to be made as they were. This is as yet no substitute for a critical approach to the epistemic or normative validity of the choices, to the question of whether they are right or wrong, even in that context. This is not an argument for context-free Platonic "truths" or absolute norms as criteria of the good. On the other hand, it is an argument that Plato's problem concerning the validation of norms cannot be escaped. What if the Hima in Uganda "use" pollution risks as a way of enforcing a social structure? What does this say about the truth or validity of their claims about the risks? What if the environmentalists in the United States "use" pollution risks as a way of leveling a social critique at the "establishment"? What bearing does this have on the truth or validity of their claims about current risks? What if we were even to grant the strong thesis of Douglas and Wildavsky, that social structure explains the collective construction of risk? What does that tell us about the truth or validity of the claims made by those whose decisions are thus "explained"? I submit that such an account, though it may be relevant to an understanding of why people choose as they do, tells us nothing about the normative grounds of their choices, and keeps us, moreover, from any serious consideration of such grounds, by the illusion that we have already solved the problem or addressed the question.

What is the alternative? Is social science to become social theory? Is explanation to be confused with justification or legitimation? May one not engage in an inquiry about risk selection without getting embroiled in the normative arguments of risk selection? Douglas

and Wildavsky recognize that the problem stated here is not easily resolved. In their final chapter they engage in what seems an agonizing flirtation with the questions of relativism and with the problem of moral choice. They say (in what seems like an acknowledgment of the point I have been making): "The way to end the stalemate of ethical relativism is to bring our moral and political judgment to bear openly on basic assumptions." And they add: "This is what we have tried to do" (p. 195). I agree with their proposal. But I cannot find where they have followed it in the book. Yet, they believe this is what they have done. So it must be the case that what they take to be "bringing moral and political judgments to bear openly on basic assumptions" means, for them, criticizing the grounds on which they allege that risk selection takes place, that is, on the grounds of the "hidden agenda" of social-structural or social-psychological imperatives. People are thus understood as acting from motives which they fail to recognize, which distort their perception of risk in the service of other needs or ideological commitments. This is in the classic mold of Mannheimian *Ideologie-Kritik*. But critique implies a standpoint, whether it is explicit or tacit. And I find no argument for a standpoint, though there is obviously argument from a standpoint, and even an acknowledgment, at the end, of what that standpoint is: "By choosing resilience (as against stability as an institutional ideal), which depends in some degree on trust in institutions, we betray our bias toward the center" (p. 198). But why? Are we to conclude, using the authors' own thesis as a critical instrument, that they too are simply products of their situation, and end with that?

I think not. Instead, what I think is needed for an adequate cultural theory of risk is a theory of social rationality in matters of choice. Such a theory would recognize the condition of bounded rationality, would acknowledge that risk is a collective social construct, would start from the truth that perception is framework- and interest-dependent, and that social structure shapes our ways of knowing. But it would go on to give a historically informed analysis of the comparative validity of cognitive and value claims, by constructing criteria of the objectivity of our social knowledge. It does not follow from the fact that all knowledge is, in Mannheim's phrase, relational, that any cognitive or normative claim is on the same footing as any other, or that we have no access to a critical standpoint from which the validity of conflicting claims may be addressed. Yet, such a critical standpoint is not itself situated above the battle in some detached realm of pure reason. It is itself historically and socially situated; and yet, in the self-conscious recognition of its own situatedness, such a critical approach may attempt to understand not only what rationales are offered in support of one or another claim, but how social rationality develops historically, how our knowledge grows, and how our norms change. We simply do know more about pollution than our ancestors did, more than the Hima or the Hutterites did; and if our social biases lead us to ignore or exaggerate risks, or to use risk policies for other ends, then there must be some core of knowledge about risk with respect to which we may judge that a risk is being ignored or exaggerated. Such a core of knowledge would be what we should be able to defend as "objective," without meaning by this that it transcends the social-constructive contexts of our historically developed cognitive practices, but only that we are ready to defend it with moral, scientific, and political arguments and with a general theory of rationality. There is a tacit assumption of this sort that runs through *Risk and Culture*. What is missing is the critical argument which would support this assumption. Thus, it is left with no more ground than the conflicting claims or beliefs which it criticizes or seeks to explain.

Such critical arguments in support of a notion of social objectivity would ultimately have to be arguments about values, about what is of greatest moment for human weal and woe, about what the good life is. It is not enough to say, as Douglas and Wildavsky do, that risk portfolios derive from moral choices of the good life, however true that is. Finally,

our rationality is tested by an explicit consideration of why some choices of the good life are better than others, in the present, and in the face of the circumstances which currently threaten us. But it remains a fact that there are objectively conflicting interests, that the good life for A may entail a worse life for B, that what is a benefit for A may entail a cost for B without the benefit. How can there be any social objectivity about questions of risk, if there are objectively conflicting grounds from which alternative choices follow? Where shall we locate the sought-for objectivity if class or national or ethnic group or regional interests conflict? Clearly, if there is to be a theory of social rationality, it will have to come to terms with these political contexts of rationality as well. But if the broad human values of peace, justice, social stability, material well-being, health, opportunities for spiritual development, and enjoyment are to have any purchase at all, then a theory of social rationality cannot avoid the normative imperative to cope with these issues. Social rationality cannot be defined independently of them; nor can it be defined simply in the technical–formal terms of "maximizing utilities," when what is at issue is precisely the normative question of what should count as a "utility" in the first place. To defer this question to the abstract criterion of a "rational chooser" or to the empirical determinations of revealed or expressed preference leaves the substantive issues untouched.

To abdicate normative critique in favor of some mode of consensus substitutes method for substance as well. A theory of social rationality, therefore, is part and parcel of a theory of the good life; and a theory of the good life is a theory of the present. Whatever norms are up for our consideration, their translation into practices and choices requires the knowledge of present circumstances as conditions of our action, and as horizons of our possibilities. Thus, the determination of risk is not separable from our scientific knowledge of the world, or from the modes of our political practice, or from the general scheme of values of our culture. But this is to say that rationality in matters of risk is not something we achieve after we have "determined the facts," or after we have made our moral choices. It seems to me that in questions of risk selection, as in other normative contexts, the original error is to hold that there is a factual component, about which agreement can be reached in principle by some universal, objective method, and a valuative component, which clouds our perception of facts, or else biases our selection from among the available stock of facts about dangers, as to which we will take seriously and which we will ignore or live with complacently. Despite their perceptive remarks about the sociality of scientific rationality itself, Douglas and Wildavsky still remain within the confines of this fact–value distinction, seeing risk determination as a selection filter of a valuative sort, by means of which one rather than another of the "facts" about danger is chosen as a risk, or as an unacceptable risk. I argued earlier that this very distinction between fact and value—e.g., between assessment and acceptability—fails, because the very assessment of a risk itself already carries with it a set of imperatives concerning its acceptability; that is, the social rationality involved in risk selection is of a piece with our scientific and moral and political rationality. In short, risk selection is not simply a question of what will conform to our prior moral and political preferences, or what is coherent with what we know by scientific and technological means, but is at once part of what constitutes our mode of cognitive-normative practice and also an expression of it. The authors of *Risk and Culture* begin with the recognition of this cultural matrix as the necessary context for the understanding of risk. But, because they are so taken with establishing the correlation of social-structural typology with risk policy, and so intent on the formal analogies of the uses of risk in widely different cultures, they defer the crucial question of normative critique which a theory of social rationality demands. It is not that they give a wrong or inadequate answer to the question of how we ought to choose risks,

but that they fail to ask it. I do not pretend to give an answer to that question here, but I think it must be asked.

NOTES

1 Mary Douglas and Aaron Wildavsky, *Risk and Culture, An Essay on the Selection of Technical and Environmental Dangers*, Berkeley: University of California Press, 1982, p. 14. (All subsequent quotations from this work are indicated by page numbers in the text.)
2 Karl Marx, *Grundrisse, Foundations of the Critique of Political Economy (Rough Draft)*, tr. Martin Nicolaus, Harmonsworth, Middlesex, England: Penguin Books, 1973, pp. 85–86.
3 Christopher Lehmann-Haupt, Review of Robert H. Boyle and R. Alexander Boyle, *Acid Rain*, in *The New York Times*, Jan. 7, 1983, p. C 17.
4 Karl Mannheim, *Ideology and Utopia, An Introduction to the Sociology of Knowledge*, tr. L. Wirth and E. Shils, New York: Harcourt Brace and World—Harvest Books, n.d., pp. 78–79.
5 Ibid., p. 78.
6 Ibid., p. 79.
7 Ibid., p. 81.
8 Ibid., p. 82.
9 Marx W. Wartofsky, "Scientific Judgment: Creativity and Discovery in Scientific Thought," in T. Nickles, ed., *Scientific Discovery—Case Studies, Boston Studies in the Philosophy of Science*, vol. 60, Dordrecht and Boston: D. Reidel Publishing Co., 1980, pp. 1–16.

II

Risk Evaluation Methods

The growing need for society to cope with technological hazards has been paralleled by an increased need for improved risk analysis methods. Better methods are needed for identifying and categorizing risks, for assessing them, and for evaluating alternative coping strategies.

The development of improved risk analysis methods will depend upon careful research on difficult problems in a variety of substantive and methodological areas. First, fundamental questions need to be answered about how best to design and conduct risk analyses so that they provide useful information. Second, research is needed that compares and integrates current risk analysis methods in order to better understand the comparative strengths and weaknesses of available approaches. Third, research is needed leading to conceptual and methodological improvements in risk analysis, as is research contributing to a better understanding of how to make the best potential use of such methods. Finally, studies need to be conducted that address critical practical issues, such as how to extract more valid and reliable information from sparse data sets, how to describe and incorporate uncertainty into risk analyses, and how to communicate information from risk analyses to policymakers and others in a useful form.

Each paper in this section represents an attempt to address one or more of these critical needs. Although much remains to be done, these pioneering efforts move the frontier and help define the present state of the art.

6

Methods for Comparing the Risks of Technologies

Edward W. Lawless, Martin V. Jones, and Richard M. Jones

INTRODUCTION

This chapter is about comparative risk assessment, a relatively new term in an evolving area of research. Although comparative risk assessment (CRA) does not have a widely accepted precise definition or a textbook methodology, it is used in various forms in both personal and public decision making. Such decision making involves the identifying, weighing, and balancing of often uncertain advantages and disadvantages of alternate choices of action.

Examples include some in which a choice is required rapidly (e.g., a driver's decision in the face of danger or opportunity) and others in which time is available for analysis and planning (e.g., decisions involving place of residence, financial matters or recreational activities). Other examples include some in which the values of the alternative outcomes are only marginally different and potentially reversible (e.g., a series of small wagers) and some in which the potential outcomes may be dramatically different or irreversible (e.g., a choice of careers, a motorist's critical decision, or a choice involving surgery). We frequently make such decisions on an informal basis, drawing on personal knowledge, experience and perceptions, usually with little thought about the decision-making process itself. At other times, however, we try to be more formal, less subjective. We may gather information and data from several sources, organize and analyze it, consult with experts, and discuss the alternatives with others who will be affected by the decision. We try, in particular, to compare the expected benefits of the various alternatives with the anticipated costs of each.

Here we often encounter problems: the benefits and costs may be matters of considerable uncertainty and may even be in different units of value. The benefits are probably known or assumed (or forecast within a narrow range) with greater confidence than are the known or potential costs. The uncertainty of the potential costs (i.e., the risk of substantial adverse consequences) is frequently the most difficult part in making confident decisions either on the personal level or within larger institutions.

Edward W. Lawless • Environmental Systems Department, Midwest Research Institute, Kansas City, Missouri 64110. *Martin V. Jones and Richard M. Jones* • Impact Assessment Institute, Rockville, Maryland, 20850.

Larger institutions, such as government agencies, corporations, and other major private sector organizations tend to use more formal processes for decision making under uncertainty, although the degree of formalization that is available or is applied varies widely from case to case or institution to institution. Their decisions frequently involve issues relating to the management of risk, particularly long-term risks related to alternative technological developments, and to the accompanying policies, strategies, and tactics. Such decisions may affect numerous parties with dissimilar, even conflicting interests.

The formalization of the decision-making process, in general, and of the identification and assessment of benefits, costs, and risks, in particular, has developed differently in various fields of endeavor. Thus, different perspectives, procedures, and values are used in making decisions in such diverse fields as military operations, financial investments, energy and power generation, biomedical procedures, environmental protection, space exploration, flood protection, traffic safety, and computer security, to name just a few. The process has evolved somewhat separately in different scientific fields with various disciplines focusing at times on its distinct parts and developing specialized, unstandardized terminology.

Bills introduced into the last four sessions of the U.S. Congress have called for the development of "a coordinated and systematic approach to the conduct and use of risk analysis by . . . Federal agencies" and for the definition of "criteria and standards to guide the development and use of risk analysis." This proposed legislation reflects a feeling that the limited acceptance received by many risk analyses completed in the past has been due, in part at least, to the lack of a professional consensus as to which methods are credible and what constitutes a systematic approach.

This paper, in summarizing the findings of a recent project on comparative risk assessment methods,[1] presents an analytical framework for comparing comprehensively and consistently the risks–costs–benefits of alternative technological and program options.

PREVIOUS RELATED RESEARCH

Concern about possible but uncertain adverse consequences of technological change on man's health, environment, culture, and societal institutions has grown steadily during the last two decades. Systematic attempts to anticipate and analyze these consequences have progressed throughout this period. The concept of technology assessment and a methodological framework for it evolved during a series of conferences and pioneering research efforts during the late 1960s and early 1970s.[2–5] Similar research efforts have been directed toward developing methodological approaches for determining the environmental, social, economic, and energy impacts of proposed governmental actions and programs.[5] Concurrently, interest has grown in finding methods for determining the risks posed by existing or future technological and natural hazards, comparing them with related social benefits, deciding what level of risk was "acceptable" to the parties at interest, and developing a process for controlling risks at acceptable levels in the public interest. The terms *risk–benefit* (or *benefit–risk*) *analysis* and *risk assessment* came into frequent use in the early 1970s.[6] The term *comparative risk–cost–benefit study* was used by the U.S. Nuclear Energy Regulatory Commission in 1974.[7] The term *comparative risk assessment* was apparently first used by Kates and co-workers in 1975.[8] The state of the art of risk assessment methodology was summarized by Rowe in a U.S. Environmental Protection Agency report in 1975 and later in an expanded version as a book.[9] Interest in the area of risk assessment has grown rapidly since 1977. A recent bibliography by Covello and Abernathy[10] contains over 800 citations of papers, reports, and books. The number of relevant books or book-length collections

published on the subject has increased from about 15 for 1977 through 1979, to about 35 for 1980 through 1982.

Only a relatively small part of this literature, however, reflects original research on what can be called comparative risk assessment. It divides into about three categories: (1) efforts to compare technological risks (or the cost of society's efforts to control them) with natural or familiar risks, (2) efforts to compare the risks of alternative technologies for producing the same goal, particularly in the energy area, and (3) efforts to rank order potential hazards to allocate priority or resources, particularly by government regulatory agencies.

Comparison with Familiar Risk

Research of this nature includes that of Lowrance,[11] Wilson,[12] Cohen and Sing Lee,[13] and Crouch and Wilson.[14] Wilson, for example, used toxicological and exposure data to estimate the extent to which one would have to be exposed to each of numerous hazards in order to increase the risk of death by one in a million. Crouch and Wilson estimated the length of time required to accumulate average risks of dying of one in a million from several natural causes and lifestyle activities. They also compared the risk of death from several kinds of common cancers with the estimated risk from several potential sources of cancer.

Published Comparative Risk Asssessments

While many risk studies have required comparisons with reference points or with alternative risks, relatively few published studies have reported systematic attempts to perform comparative risk assessments. Probably best known are the studies (and critiques of studies) in the energy, hazardous waste, and food contaminants area, as indicated in the following paragraphs.

Pioneering research in the energy field was performed by the U.S. Atomic Energy Commission (AEC) and the Jet Propulsion Laboratory (JPL). A 1974 AEC report[7] compared alternative sources of electrical energy including nuclear power plants, while the JPL compared the impacts of terrestrial and orbital solar power plants.[15–16] The AEC report and another the following year on nuclear safety by the U.S. Nuclear Regulatory Commission[17] (frequently called the Rasmussen Report) drew considerable discussion of the adequacy of the methods used.

In 1978, Inhaber of the Canadian Atomic Energy Control Board reported a comparative assessment of the risks of using each of 10 energy sources. Both occupational and public health risks were considered. A total risk was calculated for each technology by summing up risks for six components. Risks of the alternative sources were compared on the basis of calculated number of man days that would be lost per megawatt year of electricity produced. Inhaber's report[18] sparked intense interest, comment, and analysis, particularly its conclusion that nuclear power carried only slightly greater risk than natural gas and less risk than all other sources considered. The methodology, which gave this conclusion, was criticized by several analysts (particularly by Holdren[19]) on the basis that it mixed risks of different types, used dubiously valid risk estimators, and was inconsistently applied to the various power sources. The debate continued for at least three years.[20]

In a second example of comparing the risks of alternative energy sources, Cohen focused on five metals that can cause cancer. He compared the risks to world populations from natural levels of these metals with risks that would be added by coal-fired power plants, photovoltaic solar energy, and industrial uses.[21]

Few broad-approach, systematic CRAs have been published in areas outside of energy.

Many technology assessments have examined health and environmental impacts, but did not attempt to quantify risks. Other examples include Moll and co-workers, who considered the risk–benefit framework for hazardous wastes and applied it to cadmium and asbestos,[22] and Graham and Vaupel, who compared the costs and benefits of 57 lifesaving programs of five U.S. government regulatory agencies and found striking discrepancies in the average cost per life saved.[23]

Priority-Setting

Several forms of comparative risk assessment have been used by organizations and individuals to reach decisions on the establishment of priorities. These decisions often involve allocating limited resources among a large number of needs and desires. For instance, a recurring problem of government research and regulatory agencies is the need to set priorities for addressing known or potential risks among several technological sources, especially when simultaneous exposure to more than one type of risk is known to occur.

Some particularly difficult priority-setting problems are presented by chemicals that may pose dangers to health or the environment. The National Cancer Institute, for example, must choose each year from among thousands of chemicals those which it will study either as potential carcinogens or as potential chemotherapeutics. It must further decide those which will be studied by less expensive short-test methods and those by more expensive long-term studies. Similarly the Food and Drug Administration, Environmental Protection Agency, Occupational Safety and Health Administration, and Consumer Product Safety Commission must put into priority for study and regulatory attention those chemicals that may be contaminating the food, air, water, ground, workplace, or household products.

CURRENT RESEARCH

The overall goal of our project was to help develop a methodological framework for systematically comparing risks, costs, and benefits of alternative choices involving technological systems. One objective was to develop a generic approach that makes the comparison as comprehensive and as flexible as possible, and useful for the wide range of analytical and institutional problems and constraints existing in the public and private sector. A second objective was to develop a reporting format that provides decision makers with as much factual information as possible, while retaining an easy-to-understand description of procedures and presentation of results. A third objective was to illustrate the applicability of such a methodological framework in case studies involving difficult decisions under uncertainty. Our intent, therefore, was to develop and demonstrate an analytical framework, rather than to produce a detailed algorithm for analyzing any specific risk or technological option, or to provide substantive input to current or prospective regulatory or other management decisions relating to specific risks.

Study Approach

The research consisted of several conceptual activities and substantive tasks, beginning with a literature review on risk assessment, risk–cost–benefit comparisons, and technology assessment (as summarized in the preceding section), and on related topics such as forecasting and decision-making approaches and techniques. Special attention was given to the substantial variations in usage of terms in this extensive literature and to the development of

an internally consistent set of definitions. Special consideration was also given to discussions and examples of several institutional factors that exist in the United States and that affect the ability to implement public or private risk–related decisions.

Because *comparative risk assessment* (CRA) is a relatively new term and does not have a precise, widely accepted meaning, we drew upon the existing terminology in the risk field, the growing literature on CRA, and a set of basic propositions to develop a definition and description of it. We further developed a set of goals, which CRA should support, and lists of characteristics, which are desirable in a CRA methodology and in the report of a completed CRA.

Information from all of the above activities were integrated to develop a generic methodological approach to CRA. In addition, a series of "validation checks" were identified, which a project team can use to verify the conceptual integrity of its assessment methodology, or which a reviewer or user can use to help evaluate results.

Finally, the generic analytical approach was applied in a series of brief pilot case studies to examine and illustrate its usefulness. Preliminary tests of a tentative generic framework with these case studies provided insights which were used to refine the framework.

The remainder of this section summarizes our view of the nature and promise of CRA, our generic approach to performing and validating a CRA, and the results of selected pilot case studies using this generic methodology.

Comparative Risk Assessment: Premises and Goals

Comparative risk assessment (CRA) is one of a class of policy studies for improving decision making under uncertainty. It presumes that citizens have multiple needs and face multiple risks, that there are alternative options for meeting these needs and reducing these risks, that trade-offs among benefits, risks, and costs are associated with selecting a preferred option, and that better information on these trade-offs can produce better decisions.

We view CRA as an approach for systematically and objectively organizing, analyzing, evaluating, and placing into perspective information abut the risks, costs, and benefits of technological alternatives as an aid to rational decision making in the management of risk. We believe CRA should be particularly useful in making decisions involving complex issues and the public interest, but should be applicable also to decisions of private institutions and individuals.

CRA in Decision Making. Decision making inevitably involves values and ethics in choosing goals and the means of achieving them when the full range of consequences are still uncertain. The decision making process may be particularly complex when the decisions involve alternative technologies, which serve human needs and desires but must be reconciled with societal goals and interests. It relies on information, data, experience, and judgment to evaluate uncertain future consequences. It involves both the perceived benefits and "disbenefits" of the alternatives. It may involve unquantified values as well as uncertainty in quantifiable values. The choice is made in favor of the alternative that has the greater expected utility to the decision maker or the decision maker's constituents, according to a set of criteria and within certain limitations. A generalized schematic for the process is shown in Figure 1.

Decision making involving the regulation of technology *in the public interest* is often fundamentally different from making business decisions. Business applications of decision analysis usually involve alternatives in which the consequences do not vary enormously and the probabilities can be estimated within reasonable limits (e.g., a 25% misestimation of

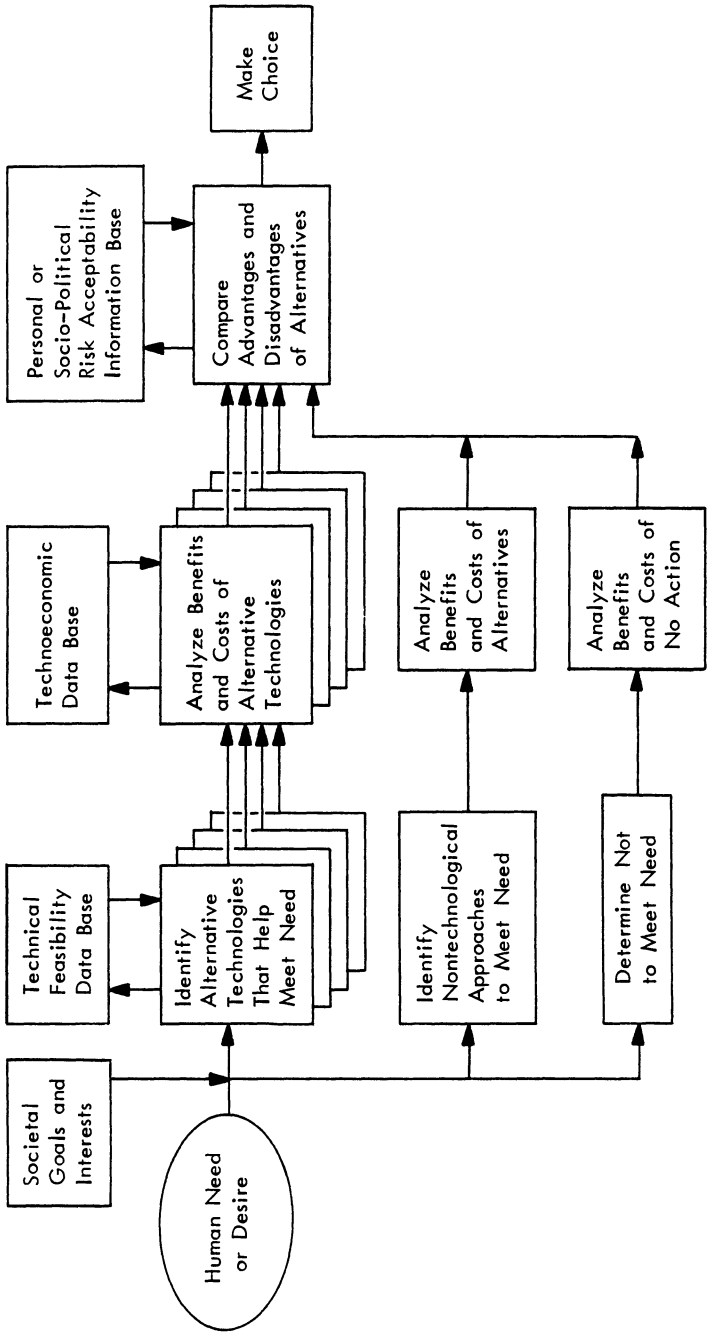

Figure 1. Process for decision making involving technology.

probability might mean the difference between a large profit and bankruptcy and is not a typical problem). Technology control decisions, on the other hand, may hinge on resolution of a scientific dispute of whether the risk is 10^{-4} or 10^{-8}, a form of expression that has little meaning for most people. CRA is viewed as an aid in giving clearer meaning to risk.

Comparative risk assessment is not a unique type of study. In terms of both its objectives and procedures, it has much in common with other types of interdisciplinary research such as technology assessment, environmental and societal impact analysis, policy science, and the decision and management sciences. All take a multidimensional approach to analysis in estimating and analyzing trade-offs among multiple and competing benefits, costs, and risks. Comparative risk assessment differs, however, in the greater emphasis that it places on the identification, estimation, and analysis of potential adverse impacts on human health, safety, and the environment (without neglecting risks of economic and social impacts). Comparative risk assessment emphasizes identification of the trade-offs between alternative risks, costs, and benefits and in placing these in perspective.

Goals for CRA. The CRA concept should be useful in the several kinds of applications identified below:

- CRA should help compare the risks posed by a given technology or program option with those posed by alternative technologies or options, particularly those that can meet the same human need, e.g., energy, health.
- CRA should help compare the reduction in risk that may be achieved by a given technology control option with that possible by alternative control options, including alternative control strategies, and alternative exposure standards.
- CRA should help compare the risks and costs of a given technology with its benefits and with the risks, costs, and benefits of alternative technologies.
- CRA should help compare the net risks, costs, and benefits of a given technology control option with the net risks, costs, and benefits of alternative options, including such regulatory decisions as whether to institute a ban, recall, cancellation of a permitted use or a standard, or to take no action.
- CRA should assist in evaluating the equity of consequences of each option to the various parties-at-interest.
- CRA should assist in comparing a given technologically derived risk with naturally occurring risks and other familiar risks.
- CRA should assist in placing into perspective the risks, costs, and benefits of a given technology with those of familiar technologies and practices.

Goals for a CRA Methodology. Several desirable features can be identified for a good CRA methodology:

- It should be systematic in approach, but flexible in operation. Although it should compartmentalize and allocate activities so that the research team does not become impeded by the multifaceting nature of the study, it should not attempt to be an algorithm or to be too mechanistic.
- It should be comprehensive within defined bounds. The CRA must consider a wide range of risk, cost, and benefit factors, including those related to health, the environment, finances, society, and institutions. These factors should be considered broadly, rather than narrowly, e.g., human health risks should include morbidity

(including psychological disbenefits) and mortality. Secondary, indirect, and unintended risks–costs–benefits should be considered as well as primary, direct, or intended effects.

- It should be consistent in treatment of alternative technologies or decision options. Consistency should be maintained in assumptions, temporal factors, discount rates, impact identification and valuation, and tests of confidence.
- It should be prepared to consider multiple risks of possibly quite different origins and natures, rather than focusing on minimizing a single risk or maximizing a single value. A CRA should avoid suboptimization, which may lead to decisions that increase risk inequity or even total risk.
- It should be imbued with a long-range perspective, e.g., a life-cycle view of alternative technologies.
- It should provide for treatment of important amorphous issues. It is better to analyze such issues in an approximate manner than to exclude them.
- It should strive to illuminate the scientific uncertainties and the explicit risk–benefit trade-offs posed by competing options.
- It should concentrate on risk–cost–benefit identification, estimation, and evaluation rather than risk management, but it must develop practical options for analysis.
- It should not attempt to dictate the "best buy" among these options.

Desirable Characteristics of a CRA Report. For the results of a CRA to be useful to policy makers, careful attention must be given to the way in which findings are reported. A CRA report should be an important input for making decisions and policies, but should not be mistaken for a policy analysis. It should consider factors bearing on implementation of alternative options (e.g., reasonableness in light of institutional and technical constraints), but should not become a detailed risk management analysis. In addition, a CRA report should give results that are comprehensible to the nonexpert, but defensible by scientific standards. CRA should make a matter simple, but not trivial. Finally, the results of a CRA should leave room for the decision makers to add interpretations, to consider factors that may have been beyond the defined bounds of the assessment, and to draw conclusions. A good CRA need not produce a litmus or triage test that attempts to put the answer in one of two or three positions. Rather, it must provide perspective.

A Generic Approach to Comparative Risk Assessment

An objective of the present study was to develop a generic CRA approach. This approach should pose the major general questions that should be asked in any CRA and should describe, in general, the steps that must be taken to answer them. The statement of these questions and steps tend to be similar for many kinds of technologies, hazards, and risk management situations. A useful foundation for a generic CRA methodology is provided by the fields of risk assessment, technology assessment, and some of the other decision aiding approaches (e.g., operations research, systems analysis, decision analysis, and management sciences). A generic approach should describe the methodological steps broadly rather than prescribe highly specific procedures. It should provide at minimum a checklist of tasks and subtasks to perform and an insight into how they interrelate. We have developed an eight step generic approach to CRA as summarized in Table 1. The sequence of steps does not necessarily have to be performed in this order in every CRA; a good CRA should in fact contain considerable reiteration among steps. The steps are discussed briefly below.

Table 1. Summary of a Generic Approach to Comparative Risk Assessments

1. Define the scope of the assessment
   Statement of the issue; audience and purpose the completed CRA will serve; time available; resources available; breadth, depth, precision, and validation desired; schedule and budget.
2. Identify assumptions
   Assumptions in scoping, data development and analysis, results; sensitivity to assumptions required during the study; explicit statement of them required in the report of findings.
3. Define decision objectives and options
   General decision question to be answered; specific options for which benefits, risks, and costs are to be compared.
4. Ascertain institutional factors
   Considerations that would affect the practical possibilities of adopting and implementing each of the decision options.
5. Determine potential stakeholders
   The major interest groups that would incur risks or costs and receive benefits, or otherwise be affected as a result of the adoption of each of the options.
6. Analyze benefits, costs, risks, and other impacts
   The varied consequences that would result from the adoption of each of the decision options; identification of uncertainties of each of the parameters analyzed.
7. Compare alternative consequences, perceptions, and management options
   An aggregation and assessment of individual and net benefits, costs and risks of each each option; comparison of alternative consequences and trade-offs for each option and interest group; comparison of estimated risks and cost–benefit ratios with familiar risks and ratios; comparison of estimated risk with publicly perceived risk; comparison of risk management capabilities and uncertainties.
8. Report and summarize findings
   A statement of the study's research, analysis, accomplishments, and limitations, including a concise recapitulation of the findings.

Step 1—Define the Scope of the Assessment. This step is critically important, because it will dictate what is done and what is accomplished in the rest of the research. Several determinations should be made and several questions should be asked and answered in this step as indicated in Table 1.

Step 2—Identify Assumptions. Assumptions will be required in every CRA. Particularly important are those that directly involve the technical performance of the study, including the decision options, the range of technological alternatives, and the ranges of benefits, costs, and risks to be considered. They may include assumptions made prior to the analysis (e.g., time horizon, data to develop, or information to forego if the literature is too voluminous) or during the analysis (e.g., approximations when data are limited). They may also include decisions on validation techniques or on presentation of results to direct them toward a particular audience. The mix of assumptions should not bias the assessmment toward one option or alternative. If this cannot be done for technical reasons (e.g., data limitations in one area), particular care must be taken to note these problem areas. The study team should carefully acknowledge these assumptions as they are being made, be aware that they exist during the course of the study, and state them explicitly in the report. Failure to do so may lead to a flawed study or strongly challenged results.

Step 3—Define Decision Objectives and Options. This step involves the following three tasks:

- Define the locus of the decision. Who makes the ultimate decision and who primarily will influence it.
- Define the general decision question being faced by the decision makers who will use the study results; e.g., what is the best way of getting from situation A to situation B?
- Develop two or more clearly stated specific options for resolving the general question. These options may involve alternative technologies, controls, or other decisions, e.g., to approve or disapprove, to regulate strictly or less strictly, to act or to wait.

Step 4—Ascertain Institutional Factors. A diverse assortment of societal institutions, practices, and relationships affect the feasibility of implementing alternative risk-related options. These factors affect both public and private decision making and warrant serious attention. Consideration of institutional factors admittedly increases the complexity of risk assessment and risk decision making. However, failure to consider these factors is likely to produce analytical findings that have largely academic, rather than practical, relevance. Decisions based on such restricted analyses may not be capable of adoption, and, if adopted, may not work effectively. On the other hand, institutional factors may often serve a powerful enabling or facilitating role. For instance, the political influence of organized groups or of a strong supportive public opinion may enhance the practical feasibility of particular options.

Attention should be given to such institutional criteria as implementability, adoptability, applicability, flexibility, equity, and acceptability in evaluating alternative options. Many kinds of institutional factors affecting public decision making may be identified. Seven important categories are: (1) legislation passed by Congress, state governments, and other legislative bodies; (2) regulations, standards, and criteria promulgated and enforced by government agencies at all levels; (3) judicial decisions controlling the discretion of regulatory agencies and imposing responsibilities on other institutions; (4) presidential executive orders affecting risk decisions, which modify regulatory, legislative, and judicial prerogatives; (5) attitudes of stakeholders and segments of the public toward both general and specific risks; (6) political reactions and strategies of those affected by risk decisions to influence public policy and citizens' views toward the regulation of risk; and (7) media influence in interpreting and disseminating the findings of scientific research and the public pronouncements of stakeholder groups.

Step 5—Determine Potential Stakeholders. A critical activity is to identify all the significant parties-at-interest or stakeholders for each decision option. These are those groups of people, companies, institutions, and governmental agencies that will be or perceive that they will be affected by the decision and its implementation. The process of determining the stakeholders involves four largely concurrent activities: identification, categorization, classification of interest area, and estimation of interest level.

Those stakeholders who will bear the direct and indirect costs or risk of adverse consequences of the alternative outcomes should be identified. In addition, it is highly desirable to identify the major beneficiaries and the important actors in the decisionmaking–implementation process itself. Identification of many of the potential primary gainers and losers of proposed technology related alternatives is usually easy. The identification of secondary and tertiary parties-at-interest is usually more difficult, but is also very important.

They may be strongly influential in the ability to implement any decision. Several techniques are useful for identifying potential stakeholders, including literature review, surveys, public meetings, scenario construction, modeling, and system analysis.

Stakeholders may be categorized in several ways; for example:

- Those of a given geographical location, occupation, or socioeconomic class; communities of interest; present or future generation.
- Those at risk of health effects, who may be subdivided by age groupings (children, adults), by status (child, man, woman, pregnant woman, nursing woman), by disorder (cancer, birth defect, heart disease, allergy), or by system affected (reproductive, circulatory, digestive, respiratory).
- Those involved in the decision-making process: decision makers, participants.
- Those with input to the comparative risk assessment process itself.
- Those at substantial risk of loss, but with little voice in the assessment or the decision.

Classification of interest areas will depend largely on the nature of the consequences of the decision for each stakeholder group. It will reflect the groups previously identified, but should reveal those areas where the interests of different groups overlap, reinforce, or tend to neutralize each other. A matrix display is useful.

Estimation of interest level includes an approximation of the numbers of stakeholders in each interest group and category, the degree to which they may be directly or indirectly affected, and the degree to which they may play an active role in reaching or implementing any of the alternatives being considered. These estimates are important inputs for designing and putting into priority the more systematic analyses of Step 6 to follow. Resources for making these estimates include statistical data and other literature, surveys, individuals with specific expertise, and analogy techniques.

Step 6—Analyze Benefits, Costs, and Risks. This step will usually require the most effort in the assessment. The determination of potential stakeholders in Step 5 will have already identified many or most of the benefits, costs, and risks to be analyzed; a systematic completion of this identification is needed. The major activity of this step, then, is to calculate, estimate, or evaluate the magnitude of the benefits, costs, and risks of the alternative decisions for each stakeholder group and to estimate the probabilities of their occurrence.

In some cases these magnitudes can be quantified. In other cases, they must be approximated ordinally by ranking, scoring, or some other qualitative unit of measure. In either case the study team must exercise caution in keeping the scope of the analysis within defined bounds. Every possible consequence usually cannot be determined, and every consequence cannot be tested equally because of inherent problems in benefit–cost–risk analyses.

The study team may select a combination of analytical methods from among many methods of varying degrees of complexity to analyze the benefits, costs, and risks of the alternative technology or technology control decisions. A single method is seldom practicable for all consequences: benefits, cost, and risks must be treated separately and different kinds of each may require separate techniques.

Many methods are used in risk and hazard assessment.[24] These range from mathematical–statistical techniques for determining the chances of success in games to specialized techniques for determining effects on materials, human health, the environment, and corporate finances. Some methods are used to help determine "threshold" levels of risk, below

Table 2. Methods Used in Risk Assessment

1. Engineering approaches
   Experimental tests
   Mathematical models
   Event tree/fault trees, etc.
   Engineering judgment
2. Exposure assessment
   Production/distribution/use patterns
   Occupational/residential/lifestyle patterns
   Exposure media: food, work, environmental areas, etc.
   Exposed populations
   Exposure models
3. Health effects assessment
   Health effects end points: death, nonfatal injuries/illnesses, etc.
   Health effects determination: indexes of potency, safe doses, actuarial data analysis, epidemiological studies, human experimentation, clinical studies, toxicological testing, dose–response extrapolation models, interspecies extrapolation, etc.
4. Environmental risk assessment
5. Economic risk assessment
6. Social impact assessment

which the risk is deemed acceptable by the societal segments involved, but above which decisions for appropriate action may be deemed necessary. Space does not permit a discussion of the many methods and techniques that have been used, but Table 2 lists a representative set with some illustrative examples.

An even larger number of methods and techniques have been used to make technological, economic, and other types of forecasting, to analyze costs and benefits of proposed actions, and to facilitate managerial decision making in general. These techniques can be useful resources to an assessment team that appreciates both their potentialities and their limitations. They can often enable an assessment team to extract maximum insight from a limited and uncertain information base, sharpening the judgment of a manager who must make important decisions under conditions of great uncertainty.

The choice of techniques often depends on the nature of the problems, and, more importantly, on the nature and adequacy of the information and data available. More sophisticated techniques are costly, and the seeming precision of the answers they provide can sometimes obscure, rather than highlight, the fundamental uncertainties that exist. A knowledgeable project manager will impose an "opportunity cost" criterion before allocating a project's finite resources to a costly sophisticated technique.

A number of nearly unavoidable problems will be encountered in analyzing benefits, costs, and risks, which increase uncertainty and lower confidence in results. They include:

- Identification of Effects—The identification of desirable and undesirable consequences may be incomplete. Particular efforts should be made to identify all low-level risks of potentially catastrophic magnitude.
- Information Factors—The accessibility, quality, quantity, and usability of the information that is available on various benefits, costs, or risks may be quite uneven.
- Definitional Factors—A given decision may have multiple consequences, some of which everyone might agree are either benefits or disbenefits for all parties-at-interest. Other effects, however, may be beneficial to some stakeholders, but detrimental to others; the magnitude of benefit and disbenefit may occasionally be equal, but may

more often be unequally felt; i.e., it helps (hurts) Party A a lot but hurts (helps) Party B only slightly.

- Value System—Different risks, benefits, and costs of a particular technology may be normally measured in different, noncommensurate units. Some of these values may be agreeably monetized, others may not. Comparable values should be measured similarly for consequence of alternative decisions.
- Accounting System—Consistency and equity may be difficult to achieve regarding utilized values, externalized values, and discount rates.
- Extrapolation–Interpolation—Laboratory, clinical, field, or statistical data must be extrapolated to large human populations or interpolated to a small stakeholder group. These mathematical operations are often the source of much confusion or dispute.
- Equity Factors—The persons who obtain the benefits of using a particular technology often do not bear most of its risks or indirect costs. Explicit explanation is needed of how the analysis treats compensated versus uncompensated risks and voluntary versus involuntary risks.
- Temporal Disparity—The benefits of a technology are frequently near term, whereas the indirect costs may be long-term and the risks uncertain. The benefits of a technology regulation may be long-term (or even probabilistic), while the costs are immediate. Special attention must be given to adverse effects, which may be essentially irreversible.

A common problem in all phases of CRA is achieving methodological consistency. Particularly important is giving consistent treatment to different options. Failure to do so may result in biased or inaccurate findings; removing a methodological bias may reverse the findings. It is not easy to achieve complete consistency of method when, as in the energy field, the alternative options differ so greatly in their design and operation. However, attention to the following eight guidelines will help.

- Similar operating design modes (e.g., optimum or ideal modes) of competing alternatives should be used.
- Similar technology time frames should be employed.
- Similar system life-cycle phases should be used.
- Benefits, risks, and costs of each alternative option should be analyzed through the same impact levels—primary, secondary, tertiary.
- Similar discount rates should be applied to future benefits, risks, and costs for each option.
- Multidimensional, rather than single-facet, measures should be used to compare the benefits, risks, and costs of each option; e.g., consider all health effects, not just mortality.
- Equivalent tests of uncertainty should be applied in evaluating the estimates of alternative benefits, risks, and costs.
- Simplifying assumptions that exclude from the analysis important differences among competing alternatives should be avoided, e.g., different citizen risk perceptions.

An important feature of the CRA process is a careful and explicit statement and aggregation of the uncertainties of data and information taken from the literature or determined in some manner during the study. The inherent existence of some uncertainty in all but the simplest physical measures is well recognized by scientists and engineers; even greater

uncertainty is common when the subject involves predictions of future socioeconomic, health, or environmental effects of technology. What is needed in this case is to identify significant uncertainties in an analysis and to take them into consideration when drawing conclusions. This need applies both to this CRA analysis step and also to Step 7.

The degree to which uncertainty exists in the analysis depends on several factors, including resource-related variables such as completeness of available data and the available time and effort to reduce data uncertainty. More important, perhaps, are methodology-related factors, such as number of options analyzed; type of options; number and variety of stakeholder groups; and the temporal factor (i.e., the magnitude of the risks, public perception and regulation of risks, and technological, economic, and cultural conditions all may undergo greater change over longer time periods). In addition, there may be operational factors leading to uncertainty such as questions of cause–effect relationships and quantifications. Certain techniques, such as sensitivity analysis, can help the analyst estimate the importance of various uncertainties to the study's findings. Other techniques, such as decision analysis, can help appraise the relative merits of obtaining additional information to reduce uncertainties.

Step 7—Comparative Analysis. Comparative analysis is the most important and most difficult step in making a comparative risk assessment. It also provides maximum challenge for the analyst to exercise subjective judgment and ingenuity as well as technical skills. Credibility in its performance is judged primarily by the extent to which the analyst makes the procedures and findings replicable. The search for common denominators, which can be used to express trade-offs among incommensurables, generates the most controversy in four situations:

- Equating or comparing benefits, costs, and risks that are subject to quantification with those that can only be expressed qualitatively.
- Equating or comparing benefits, costs, and risks that can be measured in financial terms with those that cannot be.
- Equating or comparing material considerations with humanistic considerations.
- Resolving distributional inequities for benefits, costs, and risks.

Among the numerous techniques that have been developed to assist in this task are cost–benefit analysis, cost-effectiveness analysis, decision analysis, and expected utility analysis. Most assessments will confront diverse stakeholder risks, benefits, and costs as well as conflicting expert opinions as to what the likely magnitudes and probabilities of these impacts might be. A different methodological approach may be used in each instance to analyze and aggregate the data. A detailed weighing–rating–scoring calculation, using both quantitative and qualitative data, may be used to analyze the several options in some CRAs, while less quantitative comparisions may be more appropriate in others.

An increasing realization is that many interactions involving societal elements, natural resources utilization, and environmental values have a zero-sum nature. It seems almost axiomatic that all decisions involving *the public interest* have substantial elements of the zero-sum game, when viewed from a long-range perspective; i.e., the benefit–cost ratio is usually not very far from unity, if all factors have been taken into account. If the results of this step's analysis indicate otherwise, the analyst should double-check the benefit, cost, and risk accounting of Steps 5 and 6.

Risk perception factors are often of critical importance. The decision maker's perception may influence the decision regardless of quantitative results; the public's perception will influence the acceptance and, thus, possibly, the implementability of the decision. These

perceptions will depend on several aspects of the technologies under consideration and on the threats they pose. These include familiarity and scale of the technology, understanding of the nature of the threat, catastrophic potential, and media attention, to name but a few. The public perception of some risks (and the adequacy of corresponding governmental regulations) may be at considerable variance from that shown by statistical data or other scientific analyses.

Hence, a conscious effort should be made in Step 7 of the CRA to place the risk into perspective. One approach is to compare the risk with familiar risks, either by reducing different activities to the same level of risk (e.g., one chance in a million of death per year), or by placing the risk within a range of other risks. Figures 2–4 provide other illustrative frames of reference.

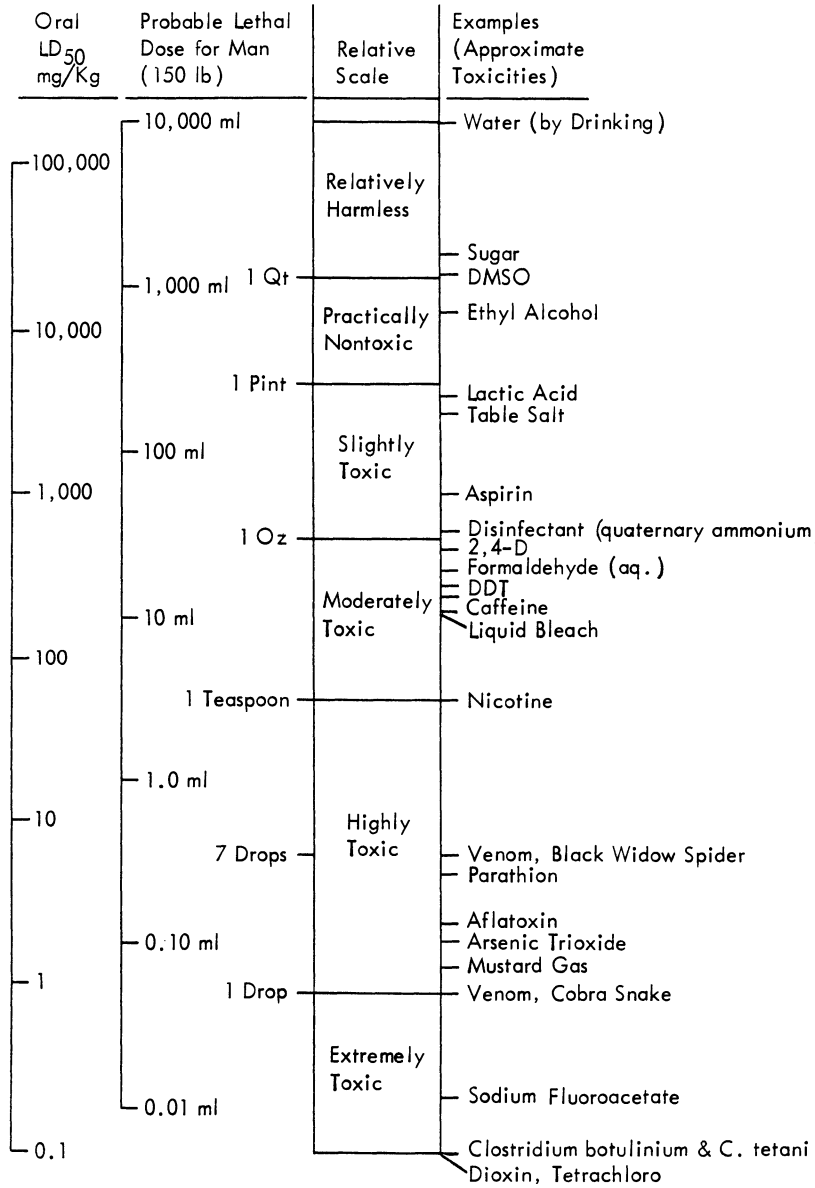

Figure 2. Comparative scales of acute oral toxicity of various substances.

Figure 2 compares the acute oral toxicity of a large range of substances. At the left of the figure is printed a logarithmic scale for the LD_{50} used in animals,* a corresponding scale of probable lethal dose for an average sized man (in scientific and familiar units), and a relative scale of danger taken from the literature; on the right are over 20 examples, chosen because they are either familiar to many people or have been in the news in recent years. This table shows, for example, that DMSO (an industrial solvent used by some persons in unapproved medicinal applications) is about 10 times more acutely toxic by ingestion than is water. Nicotine is about 250 times more toxic than DMSO, and cobra venom is about 100 times more toxic than nicotine. Overall, the botulism and dioxin at the bottom of the scale are about a million times more toxic than drinking the maximum tolerated amount (about 2.5 gal.) of water. Note that this is not the only, nor necessarily the best, method of comparing chemical toxicity for every application (e.g., it excludes death from repeated exposures and other health effects, such as respiratory distress, birth defects, or cancer, to name but a few).

Figure 3 compares the individual risk of death from several familiar sources, based on recent statistical data for the United States. Patterned after the preceding table, it provides a logarithmic scale at the left, covering 12 orders of magnitude, and a relative scale at the center, reflecting the ranges in which government controls are variously applied to the risk. Risks are on an annual basis with the exception that the risk of eventually dying (1.0) is shown for comparison. Figure 4 attempts to compare the risks of a very broad range of societal consequences (whereas Figure 3 compared individual risks). Again the logarithmic scale covers 12 orders of magnitude. The event classification scale is patterned after the toxicity ranges used in Figure 2. The hypothetical example consequences at the right range from the almost unthinkable to the almost unnoticeable (or desirable). Figures 3 and 4 illustrate one approach for putting risks into perspective. However, they are not suitable for every CRA. The study team should consider alternative innovations for accomplishing such a goal.

Comparative risk assessment does not extend to detailed risk management analysis, yet must include some preliminary consideration of the constraints related to the adoption and implementation of alternative decisions regarding the subject technology. These considerations may vary greatly from decision to decision. Ultimately, of course, the trade-offs are often made in a political context, rather removed from the details of the analysts' assessments.

Step 8—Report and Summarize Findings. Producing a lucid, credible project report is a challenging task since complex, detailed findings must be expressed in terms that are comprehensible to decision makers, journalists, citizens, and other nontechnical people. Rarely are sufficient time and money budgeted for this task.

A number of the techniques can facilitate this presentation task. Visual methods such as relevance trees, matrices, and graphics generally help in illustrating complex relationships among variables and in explaining relatively simply the message of many pages of text and statistics. A matrix display can be a useful device to recapitulate and integrate a study's detailed findings and to present them succinctly, especially to busy decision makers and to lay audiences.

Figure 5 illustrates the types of considerations that might be included in such a summary matrix or CRA Recap Sheet. The criteria at the left are illustrative; the major headings are

* Single oral dose that on the average will kill one-half of the test animals. Note that LD_{50} may vary greatly among test animals; e.g., guinea pigs are more susceptible to dioxin than shown here for mice.

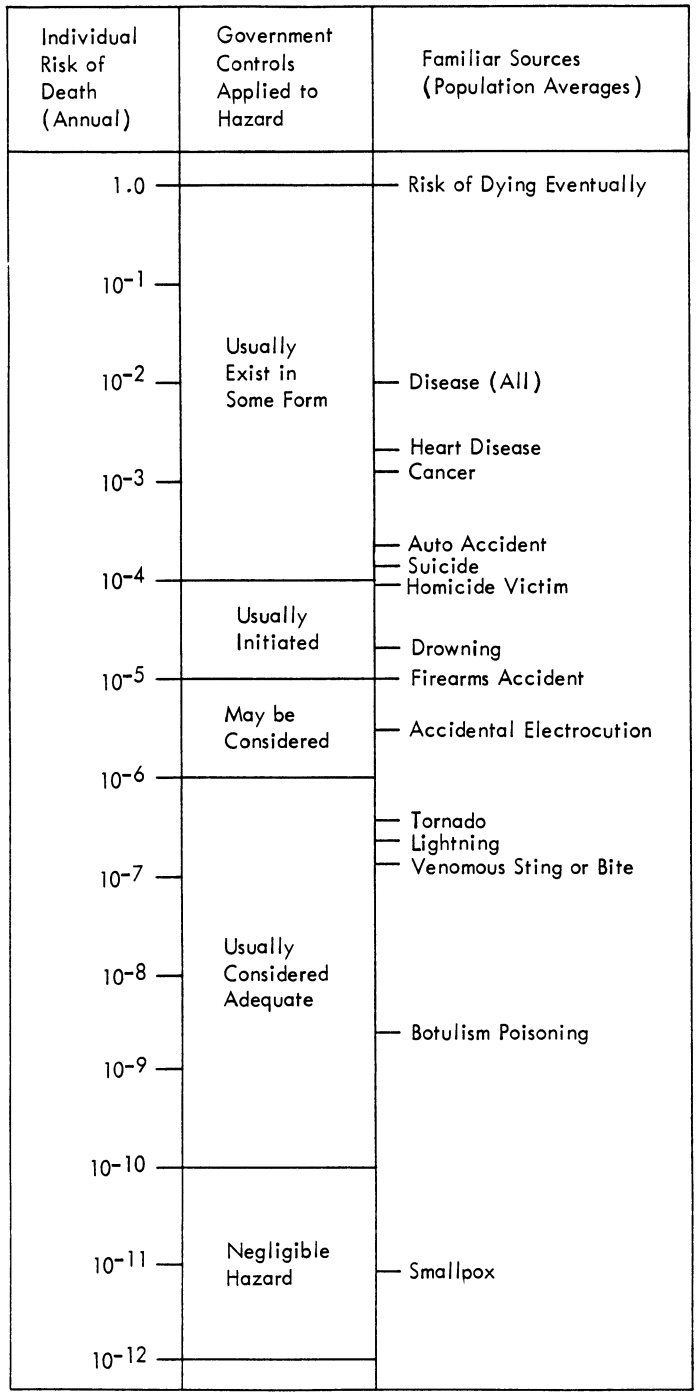

Figure 3. Comparative scales of individual risks of death from various causes.

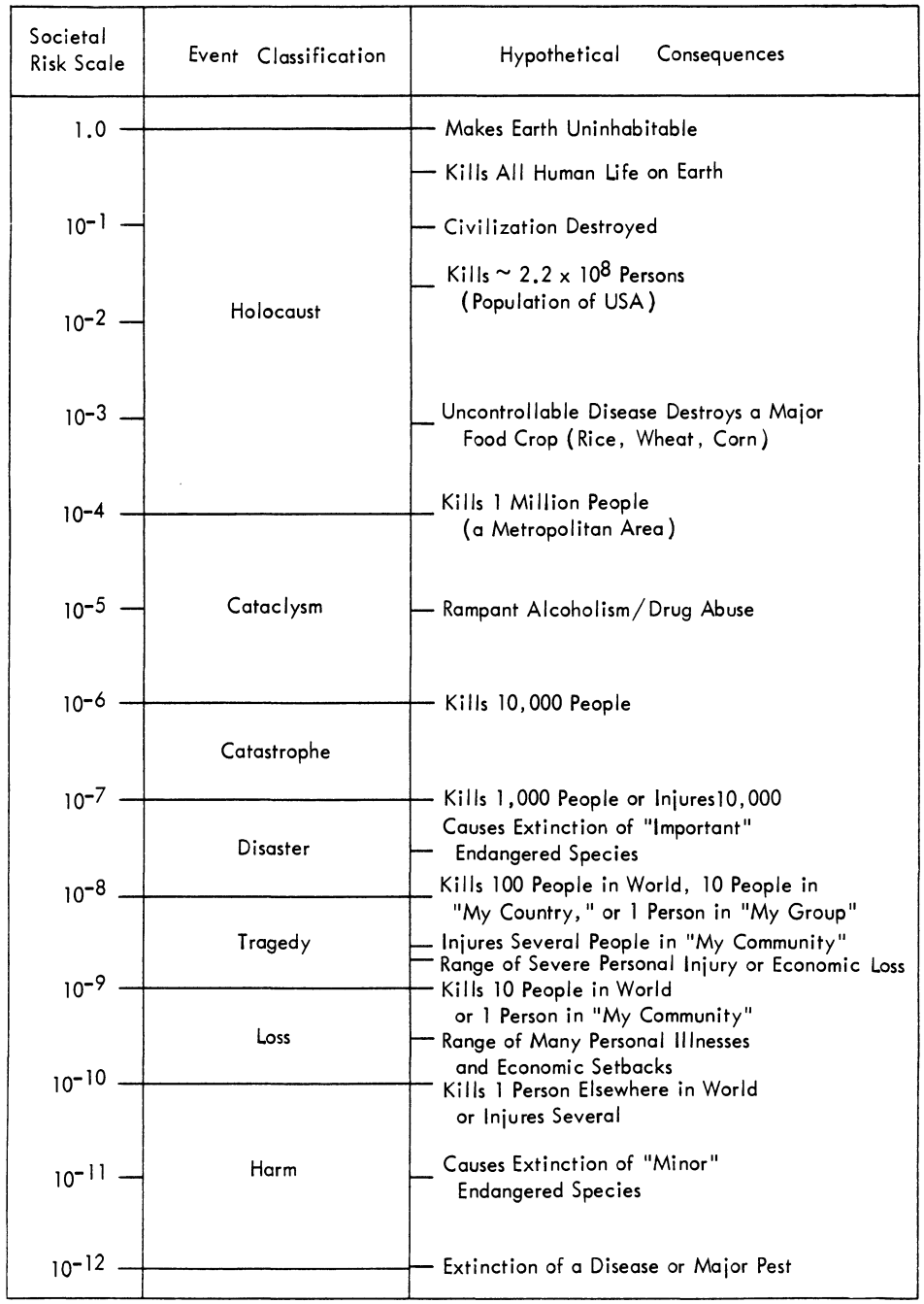

Figure 4. Comparative scales of societal risks of various kinds.

probably useful for most CRAs, but the subheadings should be varied from case to case to emphasize specific important facets. Many lists are available, which could be used to select the suitable criteria for summarizing a particular study.

The cells of the recap matrix could be used to compare and evaluate the alternative options, using any of a wide range of rating–ranking schemes. The simplest scheme is to use a series of *X*s to show that an effect or impact occurs. Multiple letters or alternative

CRITERIA	DEGREE OF EFFECT				
	OPTION				
	1	2	3	4	Other
BENEFITS Human Environmental Industry Worker Consumer Current Generation Future Generation					
RISKS Voluntary Involuntary Routine Catastrophic					
COSTS Government Industry Worker Consumer					
ADOPTION CONSTRAINTS Legislative Judicial Regulatory Political Public Perception					
IMPLEMENTATION Administrative Feasibility Market Imperfections Private Sector Burdens					
UNCERTAINTIES Option Description Benefit Estimates Risk Probabilities Risk Magnitudes Cost Estimates					

Figure 5. Sample project recap sheet: A multidimensional comparison of trade-offs among decision options.

letters may be used to indicate the intensity of the impact or something of its nature. Numbers may be used to indicate the weighting and rating. Ideally, ratings should be *ranges* that denote the degree of uncertainty rather than fixed point numbers, because some ratings may be quite precise and others very uncertain. The matrix should be adequately footnoted to stand alone if possible. In addition, however, a series of backup explanatory notes should be added to provide supporting evidence for the evaluations recorded in the recap matrix.

Validation Checks

Our study identified a set of "validation checks," which a project team can use to verify the conceptual integrity of its assessment methodoiogy, or which a reviewer or user of a study can use to evaluate it. Our insights were derived from several sources. The primary source has been the published critiques of representative completed assessments. Another source was the published commentaries of other risk assessment scholars who were assessing the state of the art in this field. Since comparative risk assessment is in many respects methodologically similar to technology assessment, environmental–societal impact analysis, and other forms of multidimensional research, some of our observations were drawn from prior experience and publications in those fields. Eleven general checks are summarized briefly below:

An appropriate balanced scope. Judiciously scoping a CRA is essential. Limited resources should not be spread so thinly over an inexhaustible list of issues that everything is analyzed superficially. Every effort must be made to be as comprehensive as possible.

Credible assumptions. Initial assumptions should be scrupulously reexamined. Were all critical assumptions identified and are they credible in the light of more complete information?

Replicable information. The study's factual information, method, and data must be documented and replicable to be credible.

Flexible methodologies. A comparative risk assessment methodology must accommodate the different institutional and analytical constraints under which risk decisions are made. Did the project team try to force the issue to fit an inappropriate framework for analysis?

Comprehensive analysis. Did the assessors make only a partial analysis, fail to take account of important risks, benefits, or costs, or neglect the full life-cycle impacts of the technology or decision?

Consistent comparisons. Comparative risk assessments, more so than in the study of single technology risks, must ensure that comparisons are consistently made.

Multifaceted decision criteria. In recent years support has grown for studies that assess the relative merits of alternative options in multidimensional rather than single-dimensional terms.

Legitimate sophistication. The degree of sophistication of a study's methodology should parallel the quality and quantity of available information.

Representative aggregation. Considerable care must be taken in explicit aggregation of dissimilar values, if one is to avoid losing credibility.

Appropriate units of measure. The units of measure utilized in making a risk assessment can often affect the outcome of a comparative analysis. Is the analysis sensitive to the way data or results are formatted?

Case Studies

Seven case studies were performed to illustrate various elements of the framework discussed in this chapter. Three case studies sought to illustrate the major role played by institutional factors in both personal and public risk decision making. One of these three studies was hypothetical in that it discussed the myriad considerations that a motorist might take into account in selecting the automotive speed at which to drive on a highway. The other two studies were retrospective in that they chronologically described the sequence of

Table 3. Saccharin Option Evaluation Recap

Criteria	Effects of regulatory options[a]	
	Ban	Don't ban
Benefits		
1. Avoid certain health risks	X	X
2. Freedom of choice		X
3. Psychological satisfaction		X
Risks		
4. Cancer	X	X
5. Diabetes aggravation	X	
6. Cardiovascular diseases	X	
7. Other obesity diseases	X	
8. Dental caries	X	
9. Fetal risks		X
Costs		
10. Industrial products reformulation	X	
11. Medical care plus work days lost	X	X
Adoption constraints		
12. Legislation		X
13. Public perception	X	
14. Political/regulatory	X	
15. Industry pressures	X	X
Implementation		
16. Availability of substitute		X
Uncertainties		
17. Magnitude of risks	X	X
18. Citizen response	X	

[a] An X denotes that the criterion is important or is affected if this option is exercised.

past events that led to public risk decisions relating to aluminum electrical wiring and plastic beverage bottles.

The other four case studies illustrated the application of the Generic Study Approach, several analytical techniques, and the summary recap matrix. In each instance, multidimensional benefit–risk–cost criteria were used in evaluating alternative options. One dealt with a federal-level decision involving nonnutritive food sweeteners, the second a state-level decision involving a children's vaccine, the third a federal–state decision relating to the use of a pesticide, and the fourth a personal decision relative to the choice of a surgical technique. Tables 3–6 present a recap matrix for each of these four cases, which summarizes some of the considerations that were evaluated in the comparison of alternative options. The text and footnotes to the recap sheets in our report[1] describe these considerations in detail.

IMPORTANT ISSUES FOR FUTURE RESEARCH

A discussion of unresolved risk assessment methodological problems must be placed in proper context. As noted earlier in this chapter, the task of making comprehensive, multidimensional comparisons of the risks, benefits, and costs of alternative options is one of a rather large class of studies. It is neither a new nor a novel type of research. Because

Table 4. Pertussis Vaccine Case Study Recap

	Effects of regulatory alternatives[a]	
	Inoculations mandatory	Inoculations optional
Benefits		
Maximum reduction of pertussis	X	
Risks		
Adverse health side effects	X	
Greater incidence of pertussis		X
Costs (financial)		
Epidemic loads on hospitals		X
Product liability lawsuits: vaccine manufacturers	X	
Patient pertussis treatment costs		X
Patient pertussis vaccine side effects treatment costs	X	
Adoption constraints		
News media "scare" stories	X	
Physicians' opposition		X
Personal freedom confrontation	X	
New legislation required		X
Implementation		
Resistance of certain religious groups	X	
Uncertainties		
Re effectiveness of vaccine	X	
Re side effects of vaccine	X	
Re incidence of pertussis without the vaccine		X

[a] An X denotes that the criterion is important or is affected if this option is exercised.

of this affinity with other types of research and decision making, it is fitting to view the problems in conducting comparative risk assessments from four perspectives:

Problems characteristic of all scholarly research. Example: quality and quantity of available information.

Problems often encountered in cost–benefit and other trade-off studies including risk assessment studies. Example: Placing a value on benefits and costs not readily translated into monetary units.

Problems peculiar to risk assessment. Example: Estimating future human risk from low-dosage exposure based on high-dosage animal experimental exposures.

Problems endemic to comparative risk assessment. Example: Consistently comparing technologies whose performance, design, application, benefits, risks, and costs are highly disparate.

The larger project report[1] on which this chapter is based suggests a number of important issues requiring further research. For example, the analytical framework proposed herein suggests that a set of institutional factors be identified and evaluated prominently in comparing

Table 5. Medfly Control Approach Comparison Recap

Criteria	Effects of decision options[a]	
	Ground and biological approach	Aerial bait application
Benefits		
1. Preservation of individual interests	X	X
2. Protection of agribusiness interests		X
3. Intrastate and international interests		X
4. Nationwide consumers	[b]	[b]
Risks		
1. Unanticipated spread of Medfly	X	
2. Public health	?	?
3. Occupational health and safety	X	?
4. Environmental effects		?
5. Property damage		?
6. Political career	X	?
Costs		
1. Labor	X	
2. Special equipment and supplies	X	X
3. Loss of ripening fruit	X	?
Adoption constraints		
1. Public perception/media attention	?	X
2. Public cooperation	X	
3. Political/regulatory		X
Implementation constraints		
1. Biology of the Medfly	X	
2. Offers control rather than eradication	X	
Uncertainties		
1. Rapid effectiveness	X	
2. Public attitudes	?	?

[a] An X indicates that the criterion is affected by the option; a question mark indicates an uncertain (but possibly small) impact.
[b] An *effective* program under either option would benefit consumers. In 1981 the aerial program was more effective.

alternative options. We have also proposed that a set of validation checks is needed to help evaluate the methodological integrity of comparative risk assessment studies, and to extract meaning from professional disputes relative to the procedures and/or findings of particular studies. Much remains to be done, however, before there is a professional consensus either as to how institutional considerations should be handled in analytical studies, or how validation checks should be applied. One difficulty is that two analysts with comparable credentials may reach diametrically opposite risk–cost–benefit conclusions concerning different options, while operating from the same information base.

Another area for research involves the problem that the analyst, on the one hand, and the decision maker and the citizen, on the other, seem, at times, headed along two different pathways. The analyst, in an effort to better understand a complex issue, will resort to a more sophisticated methodology. A frequent consequence of this more rigorous analysis is that an issue becomes more equivocal than initially perceived; the more sophisticated study has increased apparent uncertainty rather than reduced it. The decision maker and the public, on the other hand, tend to measure progress in terms of more lucid, less equivocal findings. Both funding agencies and scholars need to give more attention to bridging this communication gap.

Table 6. Hernia Surgical Repair Option Evaluation Recap

Criteria	Effects of decision options[a]			
	Traditional surgery	Newer surgery techniques		
		Mode 1	Mode 2	Mode 3
Benefits				
Likelihood of success	1	3	2	2
Recuperation period	1	3	3	2
Dry run: Future surgery	3	1	2	3
Response to surgery	1	3	3	3
Risks				
Family impact	3	1	1	3
Impact of complications	3	1	1	3
Length of hospital stay	1	2	3	2
Costs				
Personal financial cost	3	1	1	3
Adoption constraints				
Interface with surgeon	2	1	1	3
Location/convenience	3	1	1	3
Implementation				
Insurance complications	3	1	3	3
Uncertainties	3	2	2	1

[a] 3 = Most favorable effect, 1 = least favorable effect.

Proposed congressional risk analysis legislation noted the need for "facilitating public understanding" and placed this need on a par with that of resolving scientific uncertainty. Much research is needed on how this "facilitation" may best be achieved.

A related area that requires careful research involves the need to find better methods of placing risk in perspective for the public and decision makers.

A series of comprehensive comparative risk assessments is needed to develop further the general approach outlined herein, and to determine optimum methods for obtaining consideration of the results of CRA by potential users.

CONCLUSIONS

The need for improved methods of making decisions between technological alternatives of uncertain and possibly inequitable risks has become widely recognized. Comparative risk assessment (CRA) has been described herein as an approach to the analysis, balancing, and evaluation of risks, costs, and benefits in support of decision making under uncertainty, particularly public interest decisions involving multiple stakeholders.CRA should assist in comparing (1) the risks and costs posed by two or more technologies that meet the same human needs, i.e., provide similar important benefits; (2) the reduction in risks to health and the environment that may be achieved by one or more technology control options; (3) the risks, costs, and benefits of alternative technologies or technology controls, including both the inequity of their distribution among stakeholders and the net societal effects; and (4) a given risk with naturally occurring or familiar risks, enabling the decision makers and the public to place the risks, costs, and benefits of alternative technological choices into better perspective.

Comparative risk assessment methodology can be characterized as (1) a systematic but

flexible, nonmechanistic approach; (2) a realistic technosocial and institutional view of decision objectives, options, and implementability; (3) a comprehensive, long-range (life-cycle) view of risks, costs, and benefits; (4) a consistent treatment in the analysis of the technological alternatives and their consequences; (5) a multidimensional analysis of quite different consequences in summing up the trade-offs among risks, costs, and benefits, and in avoiding suboptimization; and (6) a presentation of results that is comprehensible and helpful to the nonexpert, but defensible by scientific standards; that makes matters simple, but not trivial; that provides perspective, but does not dictate the decision.

The present study reviewed important previous work related to the concept of CRA, surveyed institutional factors in decision making and implementation, and described a variety of methods and concepts used in forecasting, risk assessment, and decision making. We developed an eight-step generic approach for performing CRAs. These steps are:

1. Define the scope of the assessment.
2. Identify assumptions.
3. Define decision objectives and options.
4. Ascertain institutional factors.
5. Determine potential stakeholders.
6. Analyze benefits, costs, risks, and other impacts.
7. Compare alternative consequences, perceptions, and management options.
8. Summarize and report findings.

Guidelines for performing these steps are provided. A series of "validation checks" were also identified and described, which should be useful to a CRA project team in verifying the conceptual integrity of its proposed methodology or to a reviewer or potential user of a completed CRA in evaluating its quality.

The generic comparative risk assessment approach was applied in a series of case studies. These cases involved different risks to health and the environment by substantially different technologies, ranging from surgery to pest control. These cases also involved decisions made at several levels, including federal and state governments and the individual family. The report of findings in each case includes a summary or recapitulation sheet (CRA Recap), which compares the impacts in several important areas for each of the decision options under consideration.

Comparative risk assessment appears to be a useful aid for reaching optimal decisions in matters of technological choice, particularly for decisions involving the public interest and issues of risks to health and environment.

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REFERENCES

1. Lawless, Edward W., Martin V. Jones, and Richard M. Jones, Final report on: *Comparative Risk Assessment: Toward An Analytical Framework,* Midwest Research Institute under National Science Foundation Grant No. PRA-8018868, January 1984.

2. Jones, Martin V. *A Technology Assessment Methodology: Basic Propositions*. MITRE Corporation, 1971.
3. Coates, Joseph. "Some Methods and Techniques for Comprehensive Impact Assessment." *Technological Forecasting and Social Change, 6,* 341–357, 1974.
4. Lawless, Edward W. *Technology and Social Shock*. Rutgers University Press, New Brunswick, NJ, 1977.
5. Porter, A. L., F. A. Rossini, S. R. Carpenter, A. T. Roper, et al. *A Guidebook for Technology Assessment and Impact Analysis*. North Holland Publishing Co., New York, 1980.
6. Otway, H. J. and P. D. Pahner. "Risk Assessment." *Futures, 8,* 122–123, 1976.
7. Atomic Energy Commission. *Comparative Risk–Cost–Benefit Study of Alternative Sources of Electrical Energy*. Report WASH-1224. Washington, D.C., December 1974.
8. Kates, R. W. "Comparative Risk Assessment." Report of a Workshop on Environmental Hazards in an International Context, Woods Hole, Mass., March 31–April 4, 1975, for Scientific Committee on Problems of the Environment, International Council of Scientific Unions.
9. Rowe, W. D. *An Anatomy of Risk*. John Wiley & Sons, New York, 1977.
10. Covello, Vincent T. and Mark Abernathy. "Risk Analysis and Technological Hazards: A Policy-Related Bibliography." *Technological Risk Assessment*. P. Ricci, L. Sagan, and C. Whipple, eds. Sijthoff and Nordhoff, Winchester, Mass. 1983.
11. Lowrance, W. W. *Of Acceptable Risk: Science and the Determination of Safety*. William Kaufman, Inc., Los Angeles, 1976.
12. Wilson, R. "Analyzing the Daily Risks of Life." *Technology Review, 81,* 40–46, February 1979.
13. Cohen, B. L. and I. Sing Lee. "A Catalog of Risks." *Health Physics, 36,* 707–722, June 1979.
14. Crouch, E. A. C. and R. Wilson. *Risk/Benefit Analysis*. Ballinger Publishing Company, Cambridge, Mass., 1982.
15. Herrera, G., ed. "Assessment of R, D & D Resources, Health and Environmental Effects, O & M Costs and Other Social Costs for Conventional and Terrestrial Solar Electric Plants." Jet Propulsion Laboratory, Report 900-782. Pasadena, Calif., January 1977.
16. Caputo, R. "An Initial Comparative Assessment of Orbital and Terrestrial Solar Power Systems." Jet Propulsion Laboratory, Report 900-780. Pasadena, Calif., March 1977.
17. U.S. Nuclear Regulatory Commission, Atomic Energy Commission. *Reactor Safety Study: An Assessment of Accidental Risks in U.S. Commercial Nuclear Power Plants* (WASH-1400, NUREG 75/014). Washington, D.C., October 1975.
18. Inhaber, H. *Risk of Energy Production*. Atomic Energy Control Board Report AECB-1119, Ottawa, Canada, March 1978; Rev. 1, May 1978; Rev. 2, Nov. 1978. See also: *New Scientist, 78,* 444–446, May 18, 1978; *Science, 203,* 718–723, Feb. 23, 1979.
19. Holdren, J. P., K. Anderson, P. H. Gleick, I. Mintser, G. Morris, and K. R. Smith. "Risk of Renewable Energy Sources: A Critique of the Inhaber Report." Energy and Resources Group, Report ERG 79-3. University of California, Berkeley, Calif., June 1979. See also subsequent letters and papers by Holdren.
20. Cumming, R. B. "The Urge to Shout." (Editorial). *Risk Analysis, 1*(3), 165, 1981.
21. Cohen, B. L. "Long Term Consequences of the Linear No-Threshold Dose-Response Relationship for Chemical Carcinogens." *Risk Analysis, 1*(4), 267–275, 1981.
22. Moll, K. D. et al. "Hazardous Wastes: A Risk–Benefit Framework Applied to Cadmium and Asbestos." SRI International, Menlo Park, Calif., 1975; also Moll, K. D. and D. P. Tihansky. "Risk–Benefit Analysis for Industrial and Social Needs." *American Industrial Hygiene Association J., 38,* 153–161, 1977.
23. Graham, J. D. and J. W. Vaupel. "Value of Life: What Difference Does it Make?" *Risk Analysis, 1*(1), 89–91, March 1981.
24. Sage, A. P. and E. B. White. "Methodologies for Risk and Hazard Assessment: A Survey and Status Report." *IEEE Trans., Systems, Man and Cybernetics, 10*(8) 425–446, August 1980.

7

Comparative Analysis of Formal Decision-Making Approaches*

Miley W. Merkhofer

INTRODUCTION

In recent years, the public has become increasingly aware of and concerned about the risks associated with technology and has placed much of the responsibility for monitoring, controlling, and reducing these risks on government agencies. As a result, legislators and regulators are faced with complex, controversial decisions requiring the assessment and balancing of imperfectly known costs, risks, and benefits.

In an attempt to improve existing processes for dealing with such decisions, many agencies are beginning to use or are considering the use of quantitative decision-making approaches, such as variations of cost–benefit analysis (CBA), decision analysis (DA), and applied social welfare theory (SWT). Because these approaches differ, the value of analysis depends on the degree to which the selected approach matches the needs of the situation. To derive the greatest value, decision makers and analysts must understand the strengths and weaknesses of available approaches and select from the options an approach best suited to the problem at hand.

This chapter compares decision-making approaches and describes research designed to aid the selection of an approach for a given decision situation. The focus is on formal, quantitative, prescriptive approaches that may be applied to government decisions involving risks to health, safety, and the environment. Following a brief review of previous research, available approaches are described and distinguished. The conceptual framework for the comparative evaluation of approaches is then presented and used to evaluate the options. The chapter concludes with suggestions for further research and general observations and conclusions.

*Dr. Merkhofer provides an expanded discussion of this topic in *Decision Science and Social Risk Management: A Comparative Evaluation of Cost–Benefit Analysis, Decision Analysis, and Other Formal Decision-Aiding Approaches [96]*.

Miley W. Merkhofer • Applied Decision Analysis, Inc., Menlo Park, California 94025.

RELATED RESEARCH

The literature contains many descriptions of quantitative decision-making approaches. Unfortunately, there have been almost no objective, knowledgeable comparisons of these approaches.

One reason for the lack of objective comparative evaluations is that most approach descriptions are written by analysts who have an interest in promoting specific methodologies. As Cumming [1] notes much "jostling for position" is occurring because risk analysis is a new and rapidly expanding field. The need to establish one's credentials and the competition for research funds create strong incentives for analysts to overemphasize and exaggerate claims when comparing their methodological specializations with others.

Another reason that few comparisons of decision-making approaches have been attempted is the lack of consensus over methodology and terminology. Authors use a variety of different labels to describe their approaches. Furthermore, no consensus exists for the definitions or minimal requirements of even such commonly used labels as "decision analysis" or "cost–benefit analysis." What one researcher describes as a decision analysis, another may characterize as a cost–benefit analysis.

Because of these difficulties, there apparently have been only a few major studies that relate directly to the objective comparison of decision-making approaches. One such study was conducted by Hammond, McClelland, and Mumpower [2]. Its objective was not so much to distinguish or compare available approaches as it was to provide a "framework for integrating the concepts, methods, and procedures relevant to human judgment and decision-making." The study considers six decision-making theories: decision theory, behavioral decision theory, psychological decision theory, social judgment theory, information integration theory, and attribution theory. According to the authors' definitions, two of these theories (information integration theory and attribution theory) are not designed to serve as decision aids. The study provides a useful integration of several broad theories of decision making, but does not (nor was it meant to) supply much practical assistance for the selection of a specific prescriptive theory.

A recent effort by Fischhoff et al. [3] was designed to address more directly the problem of approach selection. The authors' objective was to "identify and characterize the variety of methods that have been proposed for resolving acceptable risk problems." They identify three broad categories of methods: professional judgment, bootstrapping (methods for identifying and continuing policies that have evolved over time), and formal analysis. Within the category of formal analysis, they distinguish decision analysis and cost–benefit analysis. Because of their broad scope, however, the main thrust of the comparative evaluation is whether or not to use formal analysis, not the choice of a specific approach to formal analysis. Thus, the work is useful for identifying situations in which formal analysis may be desirable, but it does not provide adequate discrimination among formal approaches to aid in selecting a specific approach.

Brown and Ulvila [4] provide a comparison of approaches that is explicitly designed to aid approach selection. Although their work considered only variations of decision analysis and concentrated on applications to military decision problems, it presented a perspective that is essential to an intelligent choice among approaches–different types of situations demand different types of analysis. This same perspective has been adopted here, where the comparison of approaches is conducted at a level that distinguishes the many variations of decision analysis and cost–benefit analysis as well as other types of formal decision-making approaches that are available.

DECISION-MAKING APPROACHES

This section begins the comparative evaluation of decision-making approaches with a description of available quantitative methods. Presented first is a discussion of the nature of decision-making approaches. Then, the principal normative theories for decision making are described. These theories provide the logical foundations for most approaches. Next, several popular types of approaches described in the literature are summarized and compared on the basis of their underlying rationales and procedures. Finally, a simple means is proposed for characterizing and distinguishing among approaches.

Nature of Decision-Making Approaches

A major difficulty in describing decision-making approaches is that in practice the development and application of an approach is largely a creative art. There are certainly scientific elements to this process—indeed the mathematics can become quite sophisticated. Establishment of specific steps associated with specific approaches is, however, neither practical nor useful. There are too many different problem situations and the responses of individuals engaged in the decision process are too unpredictable to characterize analysis as a hard-and-fast step-by-step process. The experienced analyst establishes as a goal a general idea of the information and structure that must be developed to apply some decision-making logic and then gradually modifies, clarifies, and realizes this goal through reliance on a variety of analytical procedures, experience, and ingenuity.*

Before attempting to clarify this characterization of decision-making approaches, it is necessary to clarify the focus and scope of the discussion. Therefore, the definition of a decision-making approach established for the purposes of this research is presented. The research scope was confined to normative, analytical, quantitative approaches that provide formal criteria for identifying a "best" alternative under situations of risk. Furthermore, only those approaches for which a body of practical applications literature exists were included.

Definition of a Decision-Making Approach. What is a normative, formal, analytical, quantitative decision-making approach for dealing with situations of risk? In the broadest sense, a decision-making approach is any orderly, systematic way of reaching a decision. Decision-making theory distinguished between descriptive theory (which is concerned with understanding and predicting how people actually reach decisions) and normative or prescriptive theory (which is concerned with how people ideally should reach them).† A normative decision-making approach is thus concerned with identifying which of a number of available alternatives is in some sense "best."

Conceptually, normative decision-making approaches can range from highly intuitive to very formal. Churchman [5], White [6], and others have defined formal approaches as those consisting of three identifiable phases: a problem formulation phase, an analysis phase,

* Recognition of the necessarily creative elements of decision-making approaches explains what might otherwise appear as a curious omission in the literature. Authors often provide good accounts of the historical foundations and theoretical justifications for an approach, but provide little or no discussion of the specific procedures to be used in its practical application. Conversely, the applications literature generally describes the technical procedures used without pointing out the logical justification for those procedures in terms of underlying methodological principles.

† Most normative approaches do, however, contain descriptive elements in the form of empirically observed or expressed values and beliefs. Behavior prescriptions are based on consistency requirements.

and a solution phase. Analytical approaches proceed through the development of a representation (model) of the decision problem based on mathematical or logical symbols. This analytical representation is used as the basis for simulating or otherwise estimating decision outcomes. Quantitative approaches develop numerical measures of decision outcomes and their valuation.

Risk may be addressed by an approach either directly through the development of quantitative measures of the likelihood of possible decision outcomes or indirectly, for example, through the use of sensitivity analysis to determine the range of possible outcomes. This research is focused primarily on approaches that develop probabilities to quantify uncertainty. The central concerns of such approaches are the proper way to develop measures for probabilities and values and the proper way to combine these measures into a figure of merit [7].

Characteristics Common to All Approaches Studied. Many of the arguments for, as well as criticisms of, decision-making approaches are intimately connected with features common to all approaches. Therefore, before distinguishing among the various approaches (decomposition, modeling, iteration, quantification), we present a more detailed discussion of their common characteristics.

Decision-making approaches are all based on the concept of divide and conquer. *Analysis,* according to Webster, has a Greek etymology (ana + lysis) and means a loosening or breaking up of any whole into its parts. In the context of decision making, this means that the critical components of a problem should be sorted out, identified, and analyzed separately to the extent possible, and then synthesized at the end. Typically, the application of such an approach entails the execution of several disaggregate tasks, including structuring the problem, determining probabilities of risky event outcomes, interpreting those outcomes in terms of impacts, and valuing those impacts [7].

Decomposition has several benefits. It provides a formal structure for collating expertise on different facets of a problem. If assessments of uncertainties are conducted separately from evaluation, it may be possible to tap the expertise of scientists without embroiling them in value-laden issues. Decomposition also makes explicit the rationale used in reasoning. The more one structures a problem and articulates the rationales for conclusions about component parts, the easier it is for others to criticize constructively the reasoning used—and to criticize it destructively as well.

The principle of decomposition is applied in decision-making approaches through the development of models. The model relates the identified alternative courses of action to the set of possible decision consequences. Reflecting the divide-and-conquer strategy, models generally decompose this relationship into more manageable parts; for example, submodels of physical processes, market behavior, and dose–response relationships. Although simplified, the model is meant to include all essential elements and their interrelationships—simplification occurs by omitting nonessentials. The model is thus a simplified representation of the important characteristics of the system that will be affected by the decision. Models used in decision-making approaches are generally composed of mathematical equations and procedures, but they need not necessarily be highly refined or complex. Anything that illuminates by simplifying and identifying key elements and their relationships is a legitimate model.

Strauch [8] describes the role of a model within a decision-making approach. The model is a proxy for the real-world problem. Rather than analyze the problem directly, the model is analyzed. Results derived from the model are interpreted as useful in formulating con-

clusions and developing a decision strategy for the problem itself. It is assumed, in effect, that the problem structure matches or comes very close to that of the model.

Strauch notes that when a decision problem involves risk, the relationship between the substantive problem and the model used to analyze it is generally more complex and tenuous than this simplified concept. The substantive problem is likely to differ considerably from the model. Generally, one or more layers of formulation, simplification, and redefinition must be inserted between problem and model, necessitating corresponding layers of interpretation between analytical results and substantive conclusions. Thus, application of an approach not only requires analysis of a model, it requires formulation of the model and interpretation of the results. Therefore, in applying a decision-making approach the analyst must function as a detective in ferreting out important issues, as a synthesizer of information, and as a facilitator of the decision process.

Iteration is a fundamental component of all of the decision-making approaches considered by this research. The decision model used in the application of an approach is constructed through a process of trial and error. The model is repeatedly compared with the real world. If decision makers or others serving as clients or sponsors of the analysis express dissatisfaction with the analysis, if statistical or logical evidence indicates that the model does not adequately describe the real situation, or if a previously unrecognized dimension of the problem is uncovered, then some or all of the steps in the decision-making approach may be repeated. Iteration is thus a crucial component in the formulation stage of analysis. It is also largely responsible for producing the credibility and improved problem understanding that are often the most important benefits derived from the application of a formal decision-making approach.

The decision-making approaches addressed in this research all rely on quantification: data are transformed into numeric scales of measurement prior to analysis. Risk is quantified through the development of numerical estimates of probability and consequence. Consequences are equated to a common unit (e.g., dollar value). Finally, all components of the analysis are integrated to produce a bottom-line number evaluating each alternative.

As quantification necessarily represents a specific language for expressing information, models based on quantification will have errors to the extent that holistic or qualitative elements of the problem are not captured by the quantitative model. Decision makers may respond to aspects of the problem not captured by variable transformed to quantitative scales. The analysis, however, is based solely on the transformed data.

Decision-Making Theories

To aid the characterization of decision-making approaches, this subsection describes three distinct, internally consistent theories of normative decision making: cost–benefit theory (CBT), decision theory (DT), and social choice theory (SCT).* Understanding the basic theories is important to developing an understanding of available decision-making approaches for three reasons. First, the theories serve as a source of (implicit) philosophical rationales for most decision-making approaches. Second, the procedures used in the various approaches are to a considerable extent natural derivations from the fundamental theories. Third, the criteria by which approaches are evaluated as "right" or "wrong" must stem directly from the philosophical judgment of the appropriateness and usefulness of the theories. As stated

* Other normative decision theories also exist. See, for example, Arrow [9]. This study restricts attention to the most widely used and familiar theories of decision making.

earlier, the basic decision-making theories play an important role in the framework proposed for distinguishing among approaches.

Cost–Benefit Theory. CBT is the basic theory underlying cost–benefit analysis. CBT emerged from applications of economic theory originally conducted in the late 19th century to evaluate proposals for the construction of wastewater disposal systems [10]. The intellectual father of CBT is often said to be the 19th-century French economist Jules Dupuit, who in 1844 wrote a frequently cited study, "On the Measure of Utility of Public Works" [11]. Even today, most authors of cost–benefit literature are economists.

The basic premise of CBT is that alternatives should be selected according to a systematic comparison of the advantages (benefits) and disadvantages (costs) that result from the estimated consequences of the choice. Thus, the theory does not involve the concept of a social decision maker with special responsibility for the decision. Individuals define the perspective for establishing ultimate consequences, and individuals are assumed to be the appropriate judges for valuing consequences. More specifically, CBT identifies a "best" alternative in terms of an "efficiency criterion" that specifies both how advantages and disadvantages to individuals should be measured and how they should be aggregated to obtain an overall measure of social good. To value consequences to individuals, the concept of willingness to pay is applied—that is, the individual's valuation of impacts is what he would be willing to sacrifice to incur or avoid them. To aggregate values to the social level, individuals' values—the values of all consequences, regardless of to whom they accrue—are summed up to obtain a measure of the total social utility of the alternative. Thus, CBT is concerned with the maximization of the aggregate value of goods and services consumed by individuals.

According to CBT, the adoption of the principle of willingness-to-pay implies the use of market values for valuing marketable commodities. Hirshleifer [12] justifies this through an "equimarginal principle":

> If a loaf of bread has a market value of one dollar, this means that it is valued (to a close approximation) at one dollar by everyone in the community. For, every consumer will have adjusted his rate of purchase of bread until the last loaf purchased is worth (has a marginal value) to him just equal to the worth to him of whatever else he could have purchased for one dollar. And similarly for production as well as consumption. Suppliers of bread will devote resources to its production only up to the point where the marginal value of a resource in bread-making is equal to its yield elsewhere. So market values are not arbitrary measurements. They are a kind of social consensus, approaching unanimity, as to the worth of increments or decrements of products and resources.

Although this argument is conceptually appealing, it has two major deficiencies. First, it applies only to people who purchase the commodity. The value of pork to a Moslem or bourbon to a Mormon may be less than market prices. Second, if the market for a commodity is distorted in any way, by taxes or externalities, for example, then prices may not equal individuals' willingness to pay. In any case, individuals' willingness to pay for impacts of importance that are not traded in the marketplace must be established in some other way.

CBT embodies a number of important assumptions. Most notably, the basing of social decisions on aggregate net benefits means that CBT considers only total societal welfare—it is insensitive to distribution of that welfare across people or groups within society. Thus, CBT could result in the redistribution of resources from the poor to the rich, so long as the rich gain more than the poor lose.

The efficiency criterion underlying CBT is sometimes referred to as a criterion of potential Pareto optimality.* Pareto optimality is an economic principle that states that a

* This has also been called the Kaldor–Hicks criterion [13].

decision is an improvement on the *status quo* if it makes one or more persons better off without at the same time making other persons worse off. The efficiency criterion is not as restrictive as Pareto optimality. The efficiency criterion states that a decision is an improvement if those who are better off could potentially share some of their gains with those who are worse off in such a way that everyone would be better off. It does not, however, require that such compensation actually be made.

Hirshleifer, Bergstrom, and Rappaport [13] have defended the efficiency criterion on several grounds. For one thing, application of the criterion will tend to increase the size of the total economic "pie." The redistribution of these returns can be a separate decision for policy makers. Another argument is that of the many projects to be evaluated, some may benefit the rich, but others are likely to benefit the poor. In the long run, as the argument goes, everyone will be made better off [14].

The efficiency criterion has important implications for the values that are reflected in decision making. The value perspective implied by CBT is that of society as a whole, rather than any particular person or group within it. The theory considers the benefits and costs that occur throughout the social system, and not merely the direct benefits to intended beneficiaries and direct expenditures by the implementing party. Furthermore, authority for value judgments (expressed through market prices, for example) is decentralized to all stakeholders in the decision. Thus, the specific preferences of the policy maker or the government agency responsible for the decision are not reflected by CBT. In addition, the focus of CBT on the consequences of a decision means that the process by which alternatives are generated or selected (e.g., the extent of participation of affected parties) is not considered.

Anderson et al. [15] summarize several additional assumptions embodied in CBT. Two have to do with the relationship between monetary value and welfare (utility). Implicitly, it is assumed that this relationship is linear (i.e., an individual will be twice as well off with twice the money) and that the relationship is the same for all persons (i.e., a given increment of money would provide all individuals with the same pleasure). CBT also implies a fundamentally materialistic view of individuals and society. On the individual level, CBT collapses multidimensional impacts into a single monetary equivalent, in effect assuming that "individuals can feel just as well off with greater command over marketable commodities but less of certain nonmarketable gratifications as in the reverse situation" [16]. In effect, individuals can be compensated with money for any impact. The same assumption holds true at the societal level—any adverse effect with a given monetary value can be offset by any favorable effect with the same value. Another inherent assumption is that the current societal distribution of income is equitable. This is implied because market prices and willingness to pay depend on individuals' wealth as well as on their preferences. Therefore, accepting existing market prices requires accepting the existing distribution of wealth because an individual's influence on prices is proportional to the individual's wealth.

Decision Theory. DT is a theory of how individuals should make decisions in the face of uncertainty. The origins of DT can be traced to the 18th-century mathematician Bernoulli, who held that choice logically depends on the probabilities of the various consequences of a decision and the utility (worth) of those consequences to the decision maker [17].

The criterion used by DT to identify a "best" alternative is largely a result of von Neumann's and Morgenstern's efforts "to find mathematically complete principles which define rational behavior" [18]. Their approach consisted of proposing a set of basic axioms of rationality. Most individuals find these axioms quite compelling. For example, one axiom

deals with transitivity of preferences. It states that if a decision has three outcomes, A, B, and C, and if the decision maker prefers A to B and B to C, then the decision maker must prefer A to C.*

The von Neumann–Morgenstern axioms of rationality can be expressed in a variety of ways [20, 21, 22]. Each statement of the axioms, however, leads to a proof of two results central to DT. The first is that a decision maker's preferences can be encoded in terms of his utility function. This utility function represents a scaling of the values assigned by the decision maker to decision outcomes that captures the decision maker's attitude toward accepting risk [16]. The second result is that a decision maker's preference for various alternatives may be measured by calculating expected utility (the sum of the utilities of possible outcomes weighted by their probabilities of occurrence). The preferred alternative will have the highest expected utility. The axioms themselves do not include a notion of expected utility. Rather, this criterion is a logical consequence of the axioms.

An important orientation of most modern decision theorists is that uncertainty is not an objective state of the world, but rather it exists in the mind of the decision maker. Thus, probabilities assessed by an individual are regarded as subjective and dependent on the information, experience, theories, etc., of that individual. Keeney and Raiffa [21] emphasize this view by arguing that the aim of DT is to elaborate the logical implications of subjective probability and utility theory and to extend them by means of mathematics.†

The criterion of modern DT can therefore be expressed as subjective expected utility—the sum of the utilities of an alternative's outcomes weighted by their subjective probability of occurrence [25]. The key to DT is the construction of the "decision set"—specifying the available alternative actions; defining a set of variables, the outcome vector, on which the outcome will be judged; assigning probabilities on the outcome vector given each alternative; and finally, establishing a utility function on the outcome vector. By the axioms of rational behavior, the preferred alternative is the one with the highest subjective expected utility [26]. The validity of DT is its mathematical logic. Once the decision set is developed, the theory stands as a logical structure for decision making—decision makers may use it to achieve logical consistency. Aiding decision makers to achieve consistency is thus a principal justification for DT.

DT implies a number of assumptions, most significantly that all possible events and all significant consequences can be enumerated in advance, that meaningful probability and utility values can be obtained and assigned to them, and that the often disparate outcomes of concern to the decision maker can be made comparable to one another.

The von Neumann–Morgenstern axioms of rationality can be shown under some problem specifications to imply decisions that are counter to common behavior, particularly in cases

* Other axioms (see Howard [19]) are:

Continuity—If A is preferred to B and B is preferred to C, then there must be some lottery between A and C (i.e., an uncertain situation in which either A or C will be received) for which the decision maker is indifferent between that lottery and B. (B is then referred to as the "certain equivalent" of the lottery.)

Substitutability—A lottery and its certain equivalent are in all situations interchangeable without affecting preferences.

Monotonicity—If A is preferred to B, then in all evaluations of lotteries involving only A and B, the decision maker must prefer those with the highest probability of yielding A.

Decomposability—The value assigned by a decision maker to a lottery should not depend on whether the uncertainty is resolved in stages or all at once, but only on the probabilities and possible outcomes.

† Both subjective probability theory and utility theory contain a number of directly relevant principles. For example, Bayes's Theorem specifies an optimal rule for revising subjective probabilities in the light of new evidence [23]. Multiattribute utility provides a theory for making multiple value dimensions commensurable in terms of a common scale of value [16, 21, 24].

where decision outcomes involve large amounts of money or when the probabilities or differences among the probabilities associated with the choices are small. Allais, among others, has constructed a number of examples of this type [27]. Decision theorists argue, however, that it is precisely because of the departure of actual decision making from the logical theory that the theory is useful [28]. The assumption is that once the axioms are carefully explained, any reasonable person would want to change his behavior accordingly.

One frequently cited implication of the axioms is that DT is results-oriented—the decision maker must be indifferent between two uncertain situations yielding the same outcomes with the same probabilities, even if the situations used quite different physical processes to generate these outcomes. This does not mean that process implications may not be included in outcome definitions. The decision maker may, for example, express a difference in preference over breaking a leg while skiing as opposed to tripping on the walk back to the car. All that is required is to incorporate into the outcome definitions important process characteristics.

Finally, it must be emphasized that DT is focused on individual decision making. Using DT as a basis for reaching social decisions requires answering a difficult question: How should individual decision making be extended to collective decision making?

Social Choice Theory. SCT takes the perspective that the appropriate criterion for social decisions is not the preferences of some single decision maker, but rather a rational synthesis of the preferences of all those individuals who will be affected by the decision. The theory is thus concerned with finding decision rules or procedures by which preferences specified by individuals may be incorporated into the decision process. It may be interpreted, therefore, as a "normative theory of elections and legislative choices" [29].

Research in SCT has taken two related directions. One line of investigation has been to derive ways of aggregating individual preferences into a social utility function that can then be used to extend individual decision-making theory to group decision theory. The second approach is the analysis of mechanisms by which group decisions may be reached directly through a process (such as voting) in which individuals encode and simultaneously incorporate their preferences in the decision-making process without explicitly developing a group utility function [30].

In developing social choice processes, researchers naturally have sought to minimize restrictive assumptions and difficult input requirements. A question central to the theory has been whether ordinal expressions of individual preferences are sufficient inputs to a rational process of social choice. Ordinal expressions of preference are limited to statements such as A is preferred or indifferent to B. Cardinal expressions, on the other hand, require statements of the strength of preferences—that is, the amount by which an individual prefers A to B must be measured. Procedures that require individuals to express the intensity of their preferences are particularly subject to subversion by the strategic misrepresentation by individuals of their true preferences [31].

The most significant results of SCT research to date have been disappointing—whenever a minimum set of seemingly reasonable conditions are imposed on the process of forming social choices from individual preferences, it can be demonstrated that no processes will always satisfy those conditions. The central result is Arrow's Impossibility Theorem [21, 32], which states that given only ordinal information on individual preferences over a set of alternatives, there is no collective ranking of those alternatives that does not contradict one of the following assumptions: (1) Complete domain—The procedure works for all possible preference orders for at least two individuals and three alternatives. (2) Positive association of social and individual orderings—If the group originally prefers A to B; and

if any change is, if anything, in favor of A, the group still prefers A to B. (3) Independence of irrelevant alternatives—If an alternative is eliminated from the possible set, the group ordering for remaining alternatives is unchanged. (4) Individual's sovereignty—For each pair of alternatives A and B, there is some set of individual ordering such that the group prefers A to B. (5) Nondictatorial—There is no individual with the property that whenever he prefers A to B, the group will also prefer A to B regardless of the others' preferences.

Arrow's theorem has been generalized by Sen [33], who proves that no procedure for quantifying a group's preference structure is consistent with the spirit of Arrow's assumptions and does not include interpersonal comparison of preferences. Green and Laffont [31] and Gibbard [34] extend this further by showing that no social choice mechanism exists that is nondictatorial and that can never be advantageously manipulated by some member of the group. Intuitively, this says that all nondictatorial social choice mechanisms will be subject to misrepresentation of preferences if these preferences are privately held pieces of information. Thus, even if some optimal social decision-making rule can be found, it is not clear that individuals would reveal their true tastes. Hence, such a decision process may find the optimal social choice for a distorted set of preferences and therefore result in allocations that are far from optimal [31].

Despite the difficulty associated with assessing cardinal preferences, the impossibility theorem has tended to force normative SCT research toward theories based on cardinal utilities. Keeney [35] shows that consistent group preferences may be obtained when individuals' strengths of preferences are included in Arrow's axiomatization. He shows that the group utility function that is implied must be a linear combination of the individual utility functions. Harsanyi [36] develops a similar group utility function based on a model of "impersonally situated" rational decision makers. An individual is said to be impersonally situated if he faces an equal chance of ending in the shoes of any of the citizens affected by a policy decision. Harsanyi shows that if an impersonally situated citizen is rational in the von Neumann–Morgenstern sense, it follows from the expected utility maximization theorem that he or she will select the policy that maximizes the sum of the utility functions associated with each individual. Harsanyi also arrives at a linear form for the social utility function by assuming that each individual subscribes to the von Neumann and Morgenstern axioms and by adopting a specific definition of "equity." The notion of equity assumes that if all individuals are indifferent between two alternatives defined by probability distributions over the consequences, then the group will be indifferent between them. Other forms for the social utility function may be obtained by adopting alternative rules of equity [37].

The most obvious difficulty associated with SCT is the need to assume utility functions for each individual affected by a social decision. Exhaustively identifying the individuals affected by a decision would itself likely be controversial. In any real application, participants might be tempted to alter their reported utilities rather than report their true preferences so as to influence the decision. If the preferences are hypothesized rather than directly assessed, any group not in agreement with the decision would likely argue that its preferences were misrepresented.

Another major difficulty is determining how individual utility functions should be aggregated to obtain a social utility function. If, for example, the social function is a weighted average, selecting the weights will be controversial. At a more fundamental level, SCT, like the other decision-making theories, requires interpersonal comparisons. Specifically, it allows the "benefits" to one group to be traded off against the "costs" to another. That SCT makes these interpersonal comparisons in a more or less explicit way suggests that the process is likely to be controversial.

Table 1. A Comparison of Decision-Making Theories

	CBT	DT	SCT
Intellectual roots	Engineering economics	Engineering, psychology, management science, economics	Welfare economics
Conceptual basis	Economic efficiency	Axioms of individual choice	Axioms of social choice
Decision criterion	Comparison of aggregate value of estimated consequences of alternative actions	Determination of logical implications of alternatives, information, and preferences of decision maker	Derivation of group decision from acceptable mechanisms for incorporating individual preferences
Perspective on value	Total monetary equivalent as determined by economic actors in free market	Responsibility of decision-maker, objective is consistency	Social preference derived from "equitable" synthesis of preferences of impacted parties
View of uncertainty	Objective characterization of environment	Subjective state of individual	Product of individual coping with erratic environment

Differences among Decision-Making Theories. Table 1 summarizes important differences among CBT, DT, and SCT. As illustrated, the theories differ not only in their respective criterion for defining a "best" decision but also in the perspective each adopts in its interpretation of probabilities, values, and information.

An interesting parallel may be drawn between the three identified decision-making theories and Linstone's [38] "multiple perspectives on technology assessment." Linstone distinguishes among three perspectives: technical, personal, and organizational. The technical perspective represents an impersonal worldview based on scientific objectivity. Its preferred modes of inquiry can be traced to the thinking of Locke (data-based), Leibniz (models), and Kant (data plus model- or multimodel-based). This may be associated with CBT, which takes a technical view of decision making in its aggregate measure of value and its objective view of information and uncertainty. Linstone's personal perspective focuses on the individual. It is subjective in its worldview—reality is the perception of the senses. This may be associated with DT, in which the decision-making unit is taken to be the individual and information, uncertainty, and values are all taken as subjective. Linstone's organizational perspective is concerned with organizational structure and the fundamental importance of social processes. This can be associated with SCT, where the focus is more on equity and the process by which individuals incorporate their preferences into decision-making than on the logic or efficiency of the end results.

Decision-Making Approaches

Decision-making approaches are distinguished both by the basic theory or theories on which they are based and by the specific procedures used in their execution. A wide variety of procedures exists for dealing with virtually every aspect of analysis, and the flexibility of most of these is such that a great many variations are possible. Essentially, therefore, procedures can be defined and combined in an infinite number of ways to produce approaches.

Because it is not feasible to describe all possible approaches exhaustively, consideration

is given instead to several basic "types" of approaches that appear in the literature. The types of approaches that are considered are cost–benefit analysis—Paretian approach, cost–benefit analysis—decision-making approach, decision analysis—supra-decision-maker approach, social decision analysis, multiattribute utility analysis, and applied social welfare theory. Brief overviews of each of these basic types of approaches are given below. As the descriptions are not detailed, the reader is referred to the cited literature for more complete discussions and applications.

Cost–Benefit Analysis Approaches. Cost–benefit analysis (CBA)* [39–46] represents the operationalization of CBT. Sugden and Williams [47] and Watson [48] recognize two distinct types of CBA—a "Paretian approach" and a "decision-making approach."

The Paretian approach to CBA is a relatively uncompromising application of CBT. To the extent possible, consequences of alternatives are estimated objectively and preferences are deduced from choices and prices in the marketplace. Some practitioners evaluate only those commodities and services that have a readily measurable market value (e.g., costs, sales, wages) while others extend the range of considerations assigned dollar value using indirect economic evaluation methods involving demand principles or shadow prices [49].

Because controversial assessments are avoided in the Paretian approach, the analysis is recognized as not being comprehensive. There is no introduction of noneconomic consequences to "confuse the analysis" or "obscure the purely economic facts" [48]. Results are regarded as providing only one of many necessary inputs to a public policy decision: namely, a measure of the economic efficiency of each option. The conclusion is thus, "an ethical prescription of a rather weak kind: such-and-such course of action ought to be taken, provided that it does not adversely affect social welfare in some dimension other than that of economic efficiency" [47].

The decision-making approach to CBA attempts a much more ambitious accounting of decision factors. In addition to including estimates of dollar values for decision outcomes that are not traded in the marketplace, this form of CBA may even include factors not addressed by CBT, for example, by including personal values of decision makers and measures of the equity of distributional impacts. While the Paretian approach is meant to produce an objective model of the environment, the decision-making approach settles for a quasiobjective representation [48].

Because the decision-making approach attempts to introduce explicitly all issues of importance into the analysis, including the decision maker's evaluations and judgments, it is viewed by practitioners as providing a close approximation to the decision problem. Speaking of this approach, Sugden and Williams say, "There is, then, no sense in which a decision maker could regard the outcome of a cost–benefit analysis as an independent piece of evidence on which to base a decision; it *is* his decision" [47].

In theory, the decision-making approach to CBA should rely on decision makers for the development of assumptions and the establishment of measures for costs and benefits. Applications, however, generally appear to be conducted without detailed participation of decision makers [50]. Examples of cost–benefit analyses include airport siting [46, 51], public construction [52], resource development and conservation [53, 54, 55], and regulation and standards setting [56, 57].

* Also referred to as benefit–cost analysis, risk–benefit analysis, and other similar permutations of "cost," "risk," and "benefit."

Decision Analysis Approaches. Decision analysis (DA) [26, 58–62] uses concepts and procedures from systems engineering to operationalize DT. Although the philosophical justification of DA thus rests on the assumption of a single decision maker, two basic schemes have been developed for applications to social problems.

Keeney and Raiffa [21] present a "supra-decision maker" model for applying DA in the social sector. With this model, a single individual (or group of individuals with coincident views) is regarded as having the responsibility and authority for making public decisions. Thus, the group decision problem is reduced to a single decision maker case, and the justification for DA follows from the same arguments that justify its use for personal decision-making. In some versions of supra-DA, it is assumed that the supra-decision maker will attempt to reflect in his preferences (through empathy) the preferences of his constituents, and mechanisms are provided to support this task [21].

The alternative approach to applying DA in the public sector is to base the analysis on group (rather than on a single individual's) judgments and preferences. Howard's "social decision analysis" [63] and a similar approach proposed by Edwards [64] advocate specific schemes for obtaining probabilities and utilities representing society as a whole. With social DA, the decision analyst creates an extrapersonal, explicit model of the decision under consideration. Information on possible alternatives, uncertain relationships, and preferences comes from different groups and is represented in the decision model, with the implication that the basis for the decision is apparent to all. Applications of social DA include evaluations of regulations for automotive pollution, hurricane seeding, and nuclear safety [63]. The most important distinction between the supra-decision maker approach and social DA is the source of authorization and verification of assumptions. Social DA tends to place greater reliance on normative arguments.

To obtain the information on which the analysis is based, decision analysts rely heavily on interviews conducted with decision makers and technical experts. An important characteristic of such interviews is the extensive posing of choice situations (frequently involving only two options) in which the subject must indicate either a preference or indifference among clearly defined alternatives. The process tends to be dynamic with subsequent questions determined from the subject's responses to earlier choices. A complete analysis using this method may require hundreds of judgments and decisions from a single individual. Howard et al. [65] and Keeney [66] provide examples of extensive DA interviews.

Applied Social Welfare Theory Approaches. Social welfare theory (SWT) approaches [67] reflect SCT in their focus on the development of a social welfare function for aggregating individual preferences to yield a preference rule for society as a whole. Because of the limitations of social welfare theories based on ordinal preferences, applications have tended to make use of cardinal preference representations based either on von Neumann and Morgenstern utility theory [21, 67, 68] or on measurable value functions [69].

Applications of SWT generally make use of multiattribute utility theory (MAUT) [15, 24]. MAUT is a procedure for evaluating objects; it consists first of identifying a set of attributes (or dimensions) for characterizing the objects and then evaluating each object on each dimension. These judgments are then aggregated by some formal algebraic rule that typically reflects the relative importance of each attribute so as to produce an overall evaluation (or utility) of each object. In applications of MAUT to SWT, the attributes selected for the study are typically the preferences of various interest groups, while the aggregation function reflects a judgment of the relative importance of the preferences of each group [68]. Examples of SWT and MAUT applications are provided in references 21, 70–72.

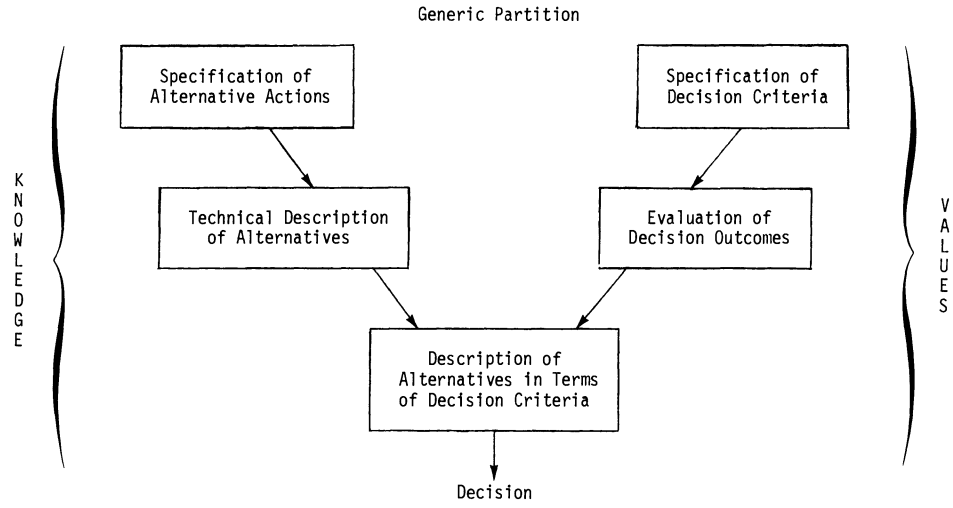

Figure 1. Generic partition of decision-making approach into basic elements useful for procedure identification.

A Comparison of the Procedures Used in Decision-Making Approaches

A review of the applications literature suggests that certain procedures tend to be associated with specific approach types. To some extent, the use of a particular procedure may be governed by a bias in the analyst's academic training or experience,*but in general the procedures used in the various approaches may be traced to the respective decision-making theories on which the approaches are based. For example, CBA approaches (following CBT) rely heavily on market arguments and procedures based on the aggregation of data. Probability is used sparingly—when probability is used, it is normally interpreted as a measure of relative frequency, and the procedures for manipulating probabilities are derived from classical statistics. On the other hand, DA approaches (following DT) emphasize interviewing procedures designed to minimize the influence of the analyst on the judgments expressed. Probabilities are regarded as expressions of states of knowledge or belief, and Bayes's Theorem is used to update probability assessments to account for new information. SWT approaches focus mainly on the representation of social preferences and emphasize procedures drawn from utility theory.

Although an approach's procedures tend to be associated with the decision-making theory on which the approach is primarily based, most approaches also use procedures that are closely related to the other theories. For example, the decision-making approach to CBA may use procedures derived from DT or SCT for representing preferences. Social DA generally uses willingness to pay and efficiency arguments from CBT to establish a social utility function. SWT and MAUT approaches often rely on procedures used in DA for encoding individuals' probabilities and utilities. This borrowing of procedures tends to blur the philosophical rationale underlying approaches and creates conflicts of perspective.

One way of categorizing the procedures used by decision-making approaches is according to the elements of analysis to which they relate. All approaches addressed in this

* For example, decision analysis is generally taught in the engineering and business schools, and cost–benefit analysis tends to be taught in the economics departments of universities. No doubt this contributes to the fact that decision analyses tend to use engineering and management science procedures, and cost–benefit analyses rely heavily on procedures from economic theory.

study involve the separate representation of the knowledge relevant to the decision and the values that permit decision outcomes to be evaluated. Knowledge is represented by (1) specifying alternative actions and (2) characterizing those alternatives in terms of technical descriptors. Values are represented by (3) defining a decision criterion and (4) specifying measures for evaluating decision outcomes according to this criterion. To complete an analysis requires (5) describing the alternatives in terms of the measures needed by the decision criterion.* The five basic elements identified in this generic partition of a decision-making approach are summarized in Figure 1.† The subsections below provide more detailed comments on the differences among the procedures typically used by various approaches within each of these basic elements of analysis.

Alternative Specification and Characterization. DA procedures for alternative generation and characterization tend to involve much more personal interaction between the analyst and participants in the decision process than do other approaches. Perhaps as a result, decision analyses generally evaluate a wider range of alternatives—for example, a range of project sizes or configurations—and may include as options contingency plans (policies for taking future actions as a function of anticipated information). Cost–benefit analyses, by comparison, typically evaluate a yes–no decision about one particular project (i.e., its costs either do or do not outweigh its benefits) [74].

Decision Criteria. The basic decision criterion function used in CBA is net present value; that is, an option is selected according to the rule: maximize the present value of all benefits less that of all costs. If, as is often the case, benefits and costs are estimated on an annual basis, then

$$\text{Net present value} = \sum_{t=0}^{T} \frac{B_t - C_t}{(1 + r)^t}$$

where B_t and C_t are the benefits and costs in year t, respectively, r is the discount or interest rate, and T is the time horizon for the evaluation [75]. Application of this rule generally involves a number of complications. For example, in the simplest case in which there are no budget constraints, only those projects with positive net present values would be recommended. If effective constraints on investment resources are assumed, then the criterion would be to allocate resources in such a way as to equalize the marginal (strictly positive)

* A recent decision analysis [73] conducted as part of a methodology development effort for the EPA provides an illustration of these five elements. Actions consisted of seven alternative national ambient carbon monoxide (CO) air quality standards. The method of characterizing the alternatives was in terms of assumed hourly average CO concentrations by exposure district resulting under each standard in each of the four cities (Chicago, Los Angeles, Philadelphia, and St. Louis). The selection criterion established by the analysts was defined to be the least stringent standard producing an expected health impact below some maximum "acceptable" level. The measure for assessing health impact level was the total number of "equivalent days of restricted activity (EDRAs)," defined as a weighted sum of specific health effects experienced by four sensitive populations. Associating health impacts with alternatives involved constructing models to simulate the impact of various levels of ambient concentrations on the incidence of the various health effects, encoding judgmental probabilities, and using decision trees to derive probability distributions over the total number of EDRAs.

† The procedures applied within an approach might be further characterized according to the tasks involved in developing each of the five elements. Each element requires the representation of data derived from some source in terms of numeric scales and mathematical relationships, followed by analysis. In general then, the process of developing these elements may involve steps directed at conditioning the sources of data, assessing the data, structuring those data, and analysis. Other partitions have also been proposed (e.g., Chapter 14 in Reference 2).

returns among opportunities [42]. Constraints may also be used to avoid the selection of projects with unacceptable distributional effects. Although risk is sometimes accounted for in the value selected for the discount rate r, cost–benefit analysts generally advocate associating probabilities with alternative net benefit (benefit minus cost) levels and then computing expected values (weighting net benefits by probabilities and adding) [14]. In this case the criterion function is expected net present value of benefits.

In DA and SWT approaches, the criterion function is expected utility. With the DA supra-decision-maker approach, this will be the subjective utility of the (supra) decision maker. In social DA, the social utility function is generally based on economic efficiency arguments, and a criterion function similar to the expected net present value criterion of CBA is used. SWT approaches generally use social utility functions that are either weighted sums or products of individuals' utilities.

Valuation of Outcomes. Procedures for identifying decision outcomes differ primarily in the emphasis on personal interaction and interviewing of decision makers. DA literature is fairly explicit in suggesting processes for working with decision makers to identify outcomes of relevance to the decision. For example, Keeney and Raiffa [21] and Merkhofer and Leaf [76] recommend that objectives be established through questioning decision makers and then organized into a hierarchy that distinguishes their relative importance and generality. Next, outcome variables are defined for quantifying the extent to which the decision results in objectives being achieved. Outcome variables are selected on a trial-and-error basis, with the analyst asking questions to assure that the variables are comprehensive, measurable, nonredundant, and minimal in number. CBA is less specific on how variables for quantifying benefits and costs should be defined, although a general rule that has been given is that benefits should consist of all effects producing an addition to real resources in the form of commodities (i.e., resources that, even if not traded on the market, have some commercial value) [41]. Similarly, the selection of cost items to be included in a cost–benefit calculation is governed by whether or not the decision results in consuming real resources. In practice, cost–benefit analysts generally arrive at a specification of variables for measuring costs and benefits through examination of relevant literature and discussions within the analysis team and with the sponsors of their analyses.

Procedures for valuing outcome variables also differ for the various approach types. CBA and social DA approaches almost always measure outcome value directly in monetary units. Market prices are the principal indicators used for establishing dollar values*; however, a variety of procedures are available for adjusting or augmenting market prices when they are distorted. A report [77] prepared by the National Academy of Sciences on the use of CBA concludes:

> In decisions that have a component that depends on human values, we propose the following: (i) The terms on both sides of the [cost–benefit balancing] equation should be given a monetary value based on the marketplace, public survey, or other appropriate means. . . . (ii) Weighting factors should be applied to those terms which may be undervalued by marketplace economics. . . . (iii) The values of the weighting factors have to be established by society in general, whether through the political process, public survey, or other means.

Several alternative procedures are used in CBA approaches for valuing outcomes for which no market exists (such as effects on the natural environment, human health, and aesthetic

* In situations where actions may produce substantial changes in the quantities of marketed goods, cost–benefit analyses and social decision analyses will sometimes estimate consumer's and producer's surplus as measures of values using a process that requires that demand and supply versus price curves for the goods be derived. For a discussion see Mishan [44] or Merkhofer [96].

values). The procedures generally followed by the Paretian approach to CBA is not to attempt the monetization of such effects, but to give a separate account of them in their respective units. One procedure for explicitly valuing intangible effects is to approximate them by surrogate, measurable ones; for example, approximating the costs of some effect by the costs incurred by individuals who take steps to avoid them. Another procedure is to derive an implicit evaluation from past social decisions—for example, estimating a value for clean air by looking at the costs imposed on industry for emissions controls. A third method is to poll consumers for their willingness to pay to avoid some effect or, alternatively, their willingness to be compensated to accept the effect.

Supra-DA and SWT approaches measure values of outcomes in a common unit (utility) that may or may not, depending on formulation, have a direct relationship with dollars. In some formulations, especially SWT approaches, the utility concept is devoid of risk, taking on a meaning more like that in conventional microeconomics where it measures strength of preference for multiattribute consequences known with certainty [78]. Another formulation, advocated for social DA approaches, explicitly incorporates risk aversion. The procedure usually consists of estimating risk aversion coefficients that are used to relate value to utility functions [26]. CBA approaches generally ignore risk aversion, although an ad hoc way to incorporate people's presumed aversion to risk is occasionally advocated that involves raising the number of lives lost in a single accident to some power (e.g., n^2) [79].*

The procedure for establishing an individual's utility function over a given outcome variable is conducted in an interview in which the analyst asks the decision maker to express preferences between pairs of alternatives, usually alternatives involving lotteries. For example, individuals are commonly asked to express their preference between two choices of the form "receive outcome x_C for certain or receive a lottery offering outcome x_1 with probability p or outcome x_2 with probability $1-p$." The purpose of these questions is to identify pairs toward which the decision maker is indifferent. Identification of such pairs permits construction of the subject's utility function.

In MAUT applications, the utility function would, in theory, have to be determined by varying each outcome variable one at a time so as to find indifference curves or surfaces. Because this is unmanageable if the number of outcome variables is very large, MAUT approaches typically use independence assumptions. Utility independence or dependence refers to whether the utility (desirability) of the levels of an attribute changes as a function of the levels of the other attribute variables. The presence or absence of utility independence is established by a series of questions involving paired comparisons. One common independence assumption permits the multiattribute utility function to be represented as a weighted sum of utility functions on single outcome variables. The procedure for specifying the utility function thus consists of determining a single-attribute utility function for each outcome variable and then determining appropriate weights to be used in the summation (for example, by setting the outcome variables at extreme values) [68].

Keeney and Raiffa [21] describe a procedure for obtaining a social welfare function that links multiattribute analysis with the supra-decision-maker concept. The assumption is that a (supra) decision maker would want to synthesize a social utility function from the preferences of individuals affected. The procedure begins by assessing a utility function for each of the affected parties and then requires that parameters for weighting the preferences of the various parties are obtained from the (supra) decision maker. Loosely speaking, the

* Alternatively, it has been argued that no explicit consideration of risk attitudes is needed with CBA because they are automatically incorporated into the market data—if people are risk-averse, they will pay more for safer goods, making those prices rise. The validity of this argument depends, of course, on the extent to which a free market exists and takes risk issues into account [3].

weights reflect the decision maker's view of the relative importance of the affected parties' preferences. Harsanyi [69] suggests that rather than attempt to actually assess a utility function for a spokesman from each interest group, the decision maker should use "imaginative empathy"; that is, imagine himself in each affected individual's shoes and hypothesize a utility function that might be expected to reflect the values of each group.

Because most government programs dealing with risk are designed primarily to protect and improve human health, it is useful to give special consideration to the procedures by which various approaches place a value on human life and health. Zeckhauser [80] and Linnerooth [81, 82] provide summaries of some of the available procedures.

Assigning a dollar value to loss of life would appear to be especially difficult for CBA because life has no market value—under nearly all conceivable situations, no sum of money would induce individuals to voluntarily give up their lives. Some of the procedures that were first used to rationalize finite values of life are now recognized as inappropriate. With the "human capital" calculation, for example, the dollar value assigned to the life of an individual is the present value of his or her projected earnings. In effect, the calculation views individuals as having worth only to the extent that they contribute to society. Another faulted procedure is to derive values of life from past public decisions that have saved lives or from the damages that juries have awarded in compensation for death. A problem with these is that widely varying values are obtained, depending on the awards or past decisions considered [83]. Furthermore, such procedures are inconsistent with CBT logic—they fail to account for the value of the life to the individual who has died and their implicit justification (the democratic or legal process created them) runs counter to the CBT logic of deriving values from independent economic criteria.

Valuation procedures based on individuals' willingness to pay for some statistical reduction in the risk of death are more easily defended. One popular procedure is to derive values from wage differentials in riskier than normal occupations. Another is to use questionnaires that ask the respondent to value a particular statistical reduction in morbidity or mortality. In that these fail to account for economic and psychic losses to survivors, additional procedures have been suggested that would augment individuals' willingness to pay with that of survivors.

Decision analysts and social welfare theorists have also devoted efforts to deriving procedures for valuing human life that are compatible with their respective approaches. Howard [84] derives a decision theoretic model for estimating the value to an individual of increasing or decreasing probabilities of death and shows that a small-risk value of life exists.* Keeney [85] describes a theory for evaluating mortality risks based on a social utility function describing group utility over probabilities of deaths experienced by group members and costs expended to reduce mortality risks.†

Despite the variety of different procedures and perspectives for estimating a value of life, decision-making approaches that assign dollar values have tended to arrive at a relatively small range of numbers. Typical values of life assigned by decision-making approaches range from about $200,000 to $4 million [3].

Virtually all decision-making approaches involve discounting the values assigned to future outcomes. Two reasons are cited for doing this. First, resources received early are

* Howard's model suggests that individuals may rationally place infinite values on their lives when the chances of dying are large (e.g., refusing a gamble involving a 0.5 chance of death for any amount of money) and yet willingly accept a finite amount of money in return for a small increase in the probability of death.

† Both Howard's and Keeney's procedures are somewhat difficult to apply in practice; as a result, DA and SWT approaches have tended to use the more standard procedures associated with CBA.

of greater value because they can be invested in productive areas to yield a return; that is, resources that are not consumed today can be invested to produce resources of greater value tomorrow. Second, irrespective of the existence of investment opportunities, individuals simply prefer to speed up the receipt of desirable outcomes and postpone undesirable ones—they demand compensation for reducing their consumption today in favor of consumption at a later date. Although there is little disagreement among the various approaches over the desirability of discounting, differences exist in the values used for discount rates.

CBA approaches generally rely on market arguments for selecting a discount rate. To some extent, resources used for an environmental project in the public sector will force displacement of private investments. Following the logic of CBT, such investments will be economically efficient only if the rate of return per dollar outlay in the public sector exceeds the opportunities foregone per dollar in the private sector. Thus, the CBT perspective suggests that benefits and costs of public programs be discounted by the opportunity costs of shifting productive resources out of the private sector. Unfortunately, it is generally not feasible to estimate where the money for a public investment will come from and what must, as a result, be given up. In theory, a solution is provided by the variety of private institutions that provide investment and borrowing opportunities. Because these institutions permit individuals to exchange commodities at one date for a larger or smaller volume at a later or earlier date, their market rates of return should, in theory, provide estimates of opportunity costs.

The difficulty for cost–benefit analysis in implementing this logic is the lack of a free-market rate of interest due to distortions produced by taxation, imperfect competition, disequilibrium, uncertainty, etc. A variety of procedures have been proposed for modifying market rates to account for such imperfections, but the lack of agreement over these procedures is evidenced by the differences among the rates actually used in applications.

DA and SCT approaches typically use discount rates meant to reflect social time preference rather than simply opportunity cost. For example, social welfare theorists may believe that individuals in the present generation would collectively agree to provide future generations with benefits in excess of what would be reflected by investments made in the private sector. With this view, some explicit (perhaps political) process is needed to determine overall rates of growth, investment, and discount for society. The decision-making approach to CBA also often makes use of a social time preference rate rather than a rate reflecting opportunity costs, although analysts have recognized the inconsistencies with CBT [86]. In practice, analysts who interpret the discount rate as appropriately being a reflection of social time preference will select more or less arbitrarily a discount rate in consultation with sponsors or decision makers.

Procedures for Relating Alternatives to Outcomes. Even a cursory review of the applications literature is sufficient to demonstrate that many different kinds of models are used in decision-making approaches to relate alternatives to outcomes. Although all approaches derive their modeling procedures from the general field of systems analysis, different modeling procedures tend to be associated with the different types of approaches. These differences may be largely traced to the different perspectives and roles adopted by analysts using the various approach types.

For example, as described above, CBA attempts to build an objective or quasi-objective representation of the decision situation. Most cost–benefit analyses are conducted by members of the academic community, which, as Quade [87] notes, often leads to "academic quality criteria" governing the development of such models:

> [M]odels are designed to be nontrivial (permitting inferences not perceivable by direct observation), powerful (offering a large number of nontrivial inferences), elegant (using a minimum of carefully selected analytic tools to produce a model of great power), cost effective (producing the answer with a minimal number of machine operations), valid (capable of reproducing results based on historical data), and so on.

Decision analysts, as a result of viewing their role as that of aiding the decision maker, tend to place greater emphasis on the model being relevant (inclusion of only those factors likely to influence the decision), acceptable (likely to reflect a view of the world acceptable to decision makers), and cost-effective (producing benefits that exceed the expense of their development). The greater reliance of CBA on data results in a greater use of empirical relationships, whereas DA relies to a considerable extent on dynamic models (especially decision trees) and causal logic for representing how actions interact with events.

A principal difference between approaches is their treatment of uncertainty. Most cost–benefit analysts recognize probabilities as being the appropriate way to account for uncertainties but make little use of probabilities. The problem lies with the CBT interpretation of probabilities as being relative frequencies. "Unfortunately, far from all project outcomes can be characterized by a well-defined probability distribution" [42]. Lacking objective measures of probability distributions, some cost–benefit analysts have argued that accounting for uncertainty may not be that essential:

> Provided that the government can be regarded as having a time horizon of several years during which it undertakes a large number of investment projects in many separate fields, these can be treated as essentially independent of one another. Hence we can anticipate that some projects will turn out worse and some better than expected. In fact, . . . we can expect that the negative and positive "surprises" would tend to cancel [30].

The most common way for CBA to deal with uncertainty is through sensitivity analysis. The calculations of costs and benefits are repeated, using alternative values within conceivable intervals. If each reanalysis produces the same relative preponderance of costs or benefits, then it is argued that these particular uncertainties do not matter [88]. When a full probabilistic analysis is undertaken in a CBA, probability distributions are generally calculated statistically from experience or predicted from models, for example, by using event tree or fault methods.* Various procedures for deriving a full distribution of project outcomes are described by Heggie [89]. The most common procedure is the Monte Carlo simulation—probability distributions of the relevant input variables are fed into a computer, and a simulation program selects values for each variable on the basis of their relative likelihood of occurrence. Through such a sample of simulations, the program estimates the distribution of outcomes for the decision.

DA approaches, conversely, place much emphasis on the explicit representation of subjective probabilities. The subjectivist view argues that probabilities represent an individual's degree of belief about the world, not a property of the world. Hence, the decision analyst feels as comfortable eliciting probabilities of unique events (e.g., a new drug being carcinogenic) as events for which frequency information is available (e.g., a valve failing

* Event trees and fault trees both represent the relationship among uncertain in a tree structure, but they are constructed in opposite directions. Event trees start from a particular undesired initiating event (for example, a component failure in a nuclear reactor) and project all possible outcomes of that event. Fault trees start from a particular undesired final event (for example, release of radioactivity) and work backwards to identify each sequence of enabling events and component failures that would be needed for that event to occur.

to close properly during the course of 10,000 operations).* Decision trees are normally used to display the sequence of decisions and the order in which uncertain information is anticipated to be revealed. Bayes's rule is used to specify the appropriate means for revising probabilities to reflect new information, and the dynamic programming algorithm is used for folding back decision trees.

Procedures for obtaining subjective probability estimates ordinarily involve lotteries or imaginary bets. In particular, the procedures for assessing subjective probabilities frequently involves the use of a "probability wheel." The wheel is constructed so that two colors can be adjusted to occupy varying amounts of area. The subject is asked whether he prefers a bet in which a prize is received if the spinner lands in the target color area or a bet in which the same prize is received if some event defined by the uncertainty occurs. The area of the target color is adjusted until the subject is indifferent between the two bets; the subjective probability estimate of the occurrence of the event is then assumed to be equivalent to the proportion of area covered by the target color. An interval probability encoding technique is also used. In the interval technique, the subject must specify values for the uncertain variables that define intervals over the range of possible values. The values are adjusted until the intervals are such that the subject thinks it equally likely for the actual value to lie in each. In both forms of the probability encoding procedures, steps in the elicitation process are designed to assist the decision analyst in identifying and compensating for any cognitive or motivational biases held by the subject.

Characterizing and Distinguishing Decision-Making Approaches

The method proposed for characterizing a decision-making approach consists of both a description of the procedures applied and a statement of its underlying philosophical rationale. Thus,

$$\text{Decision-making approach} = \text{Philosophical rationale} + \text{Procedures}$$

CBT, DT, and SCT provide the implicit rationales for most decision-making approaches; however, as noted above, a typical approach may not be entirely consistent with any single one of the theories. Instead, while based primarily on one of the three aforementioned theories, an approach will most likely incorporate some concepts and procedures that are the logical results of the other theories. If the space of philosophical rationales were represented as a triangle whose vertices correspond to the distinct decision-making theories, then conceptually, as shown in Figure 2, the rationale for any specific approach could be represented by a point located somewhere within the triangle (not necessarily at one of the extreme corners). What is gained in moving away from a single well-defined theory is an approach that (ideally) meets the situational needs of the specific application. What is lost is some consistency in underlying logic.

As described earlier, several different types of decision-making approaches provide a link between procedures and theory; these approaches rely on procedures to operationalize the decision-making theories, and although there is much variation from application to

* Indeed, probabilities are regarded by decision analysts as appropriately obtained only through elicitation—extrapolating from frequency counts to prediction requires judgment because to rely solely on past data implies the belief that the conditions surrounding the event are identical to those existing in the past.

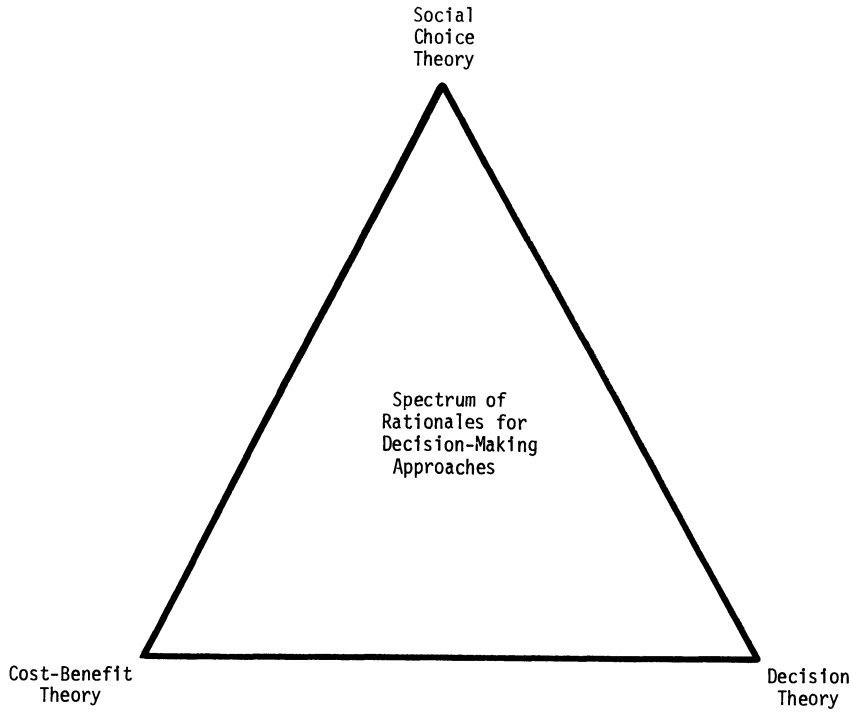

Figure 2. Implicit rationales for decision-making approaches represented as a space defined by mutually exclusive, internally consistent theories.

application, specific procedures may be generally associated with each type of approach. Figure 3 shows the various approach types discussed in this section as they might be represented in the space of philosophical rationales, taking into account the characteristics present in typical applications. Because of the association of procedures with various theories and the internal inconsistencies that result when an approach relies strongly on procedures consistent with different theories, the internal consistencies and conflict that are present are indicated by the location of the approach within the triangle.*

The triangle of Figure 3 may be used to help distinguish approaches—if the procedures applied or specified by an approach are first identified and used to locate the approach within the triangle, the philosophical rationale and internal consistency of the approach may be clarified. Locating an approach within the triangle requires that the approach be assessed along three dimensions: objective versus subjective, individual versus group, and efficiency versus equity. Objective versus subjective refers to the extent to which quantitative estimates

* The inconsistencies present in an approach represented by a point within the interior of the triangle will tend to be more a matter of perspective than computation because, despite the differences in underlying rationales for the theories (e.g., their axioms), they tend to imply decision criterion functions whose forms are compatible with each of the theories. For example, SWT approaches may be regarded as special cases of DT in which the decision maker adopts a utility function that is an aggregation of the utility functions of the affected individuals (i.e., the decision maker feels the criterion for choice should be the preferences of the individuals in society). CBA may be regarded as a special case of SCT with (1) a utilitarian assumption (the efficiency criterion), (2) an additive form for the social welfare functions in which each individual's utility is decomposed into costs and benefits, and where (3) a market value is imputed for all benefits and costs, (4) the assumption is made that each individual values benefits and costs at their market values, and (5) the value of each additional dollar is constant and equal among all individuals [68].

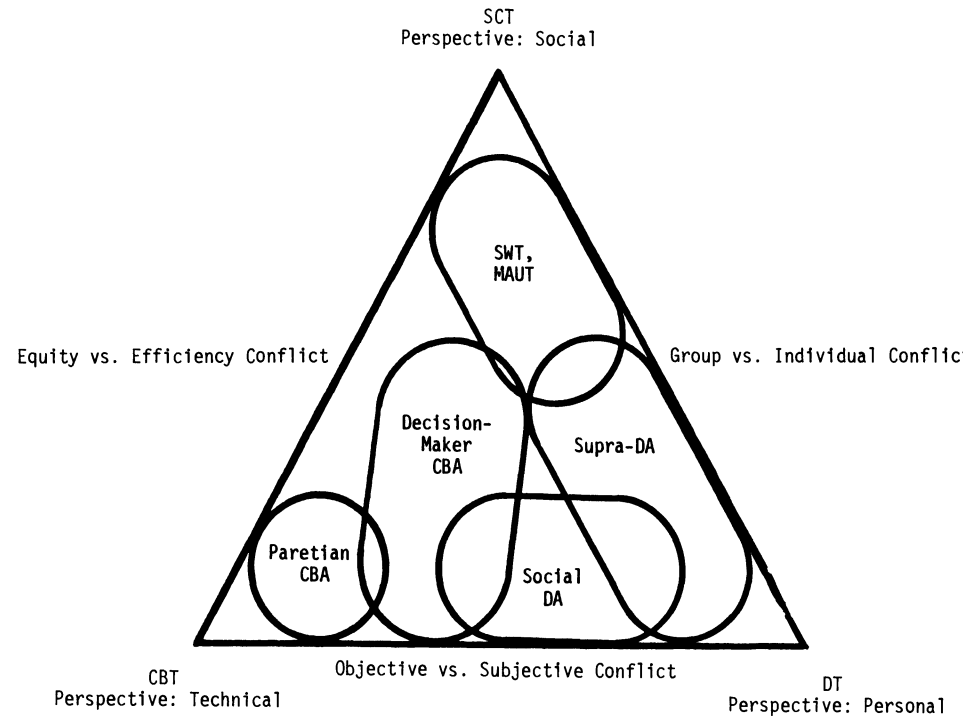

Figure 3. Implicit rationales and perspective conflicts inherent in various types of decision-making approaches as typically described in the literature.

are objectively or subjectively obtained in the approach.* Individual versus group reflects the extent to which information and values used within the approach are those of a specific decision maker or of society as a whole. Efficiency versus equity refers to the degree to which the decision criterion used in the approach reflects aggregate (summed) value versus attempts to represent distributional considerations.

Although the applications literature generally provides a detailed account of the procedures applied in a given approach, the underlying rationale for an approach is rarely made

* Rowe provides some useful benchmarks along this scale [90]. An objective measure of probability that an event will occur may be determined by direct measurement of repeated trials of the event. When the number of trials is large, the estimate of probability is properly considered objective because it represents an empirical estimation. On the other hand, if probability estimates are made on the basis of one or a few trials or by conjecture, then the probability estimate is subjective. This view is consistent with classical definitions of objective and subjective probability. Objective probability is a number between 0 and 1 assigned to an event based on a history of trials of similar events. Subjective probability is a number between 0 and 1 assigned to an event based on personal views as to whether or not the event will occur. Between these extremes lies another estimate that Rowe refers to as "synthesized probability." In this case, the probability of an event is not measured directly, but rather is extrapolated through simulation using models of causal systems that are expected to behave similarly.

A similar range between objective and subjective sources exists in estimating consequent value. An objective estimate of consequent value consists of a consequence that is directly measured along a value scale—for example, the medical costs borne by a particular population. Subjective consequence value, on the other hand, occurs when the consequence value to a particular risk agent depends completely on the risk agent's personal value system and situation—for example, the amount of money necessary to compensate (make indifferent) the victims of an accident. Between these two extremes is a value estimate, which Rowe terms "observable consequence value," in which the behavioral response of groups in society to risk consequences is ascertained and measured by studying actual behavior—for example, the amount of money people spend on safety.

explicit. Hence, a careful consideration along the lines described above may be necessary to identify the underlying rationale. Determining the theoretical rationale for an approach helps distinguish problems of poor application from inherent limitations. Furthermore, understanding the philosophical justification for an approach is important for approach evaluation because higher-order criticisms (i.e., those relating to philosophical, institutional, or ethical issues as opposed to operational issues) are directed primarily at the foundations of an approach. Criticisms leveled at an approach may be inappropriate if they misinterpret the underlying rationale.

COMPARATIVE EVALUATION

While it was not the intent of this study to identify a "best" approach, or even to recommend a specific approach for a given type of social risk decision, providing information and a rudimentary framework for evaluating and selecting among approaches was an objective. The proposed framework for an approach evaluation consists of three components: (1) an identification and characterization of essential features of a risk problem that may be relevant to the decision to apply a formal approach, (2) a means of characterizing and distinguishing among available approaches, and (3) criteria for evaluating the use of an approach in a given situation. This section discusses briefly criteria for evaluating decision-making approaches and then describes the conceptual framework proposed by this research for use in evaluating and selecting alternative approaches.

Criteria for Evaluating Decision-Making Approaches

Establishing evaluation criteria requires an understanding of the role or function of the thing being evaluated. For example, the criterion applied when selecting a pair of ski boots is very different from that used when purchasing hiking shoes, and someone who mistakenly thought ski boots were for hiking would have a very different opinion of their value than would a skier. Thus, identifying criteria for evaluating decision-making approaches requires first an understanding of the role of an approach within the decision process.

Role and Professed Value of Approaches

Many of the criticisms leveled at the use of formal decision-making approaches seem to assume that analysts view the approach as a rigid rule to supplant or replace the decision-making process. This is not the case. Promoters of analysis view decision-making approaches as an aid to decision making. "We believe that the basic function of formal analysis should be to help policymakers gain insight into complex issues" [91]. "The important element is not the bottom line, but the process of reaching it" [74]. "Even the most purported scientifically objective assessment is useful only as another input along with data from myriad other sources, interested and disinterested, informed and uninformed, rational and irrational" [92].

The tendency of critics of decision-making approaches to confuse the approach with the actual process of arriving at a decision may be partly due to terminology. As Majone and Quade [93] point out, the role of analysis in assisting choice is generally discussed in a language that obliterates the difference between analysis and decision making. "The same

categories—objectives, alternatives, prediction, control, optimization, and so on—are used in both cases, thus setting up a one-to-one correspondence between the stages of the decision process and the stages of the analytical process." In fact, analysis operates on a simplified model of the decision situation and not on the real-world problem itself. Expressing the results in terms of conclusions concerning the real decision situation requires interpretation. Should the model be confused with reality, then the outputs of analysis will be assigned a significance beyond that which is justified.

Hammond, McClelland, and Mumpower [2] provide a summary of specific claims made for the value of decision-making approaches. Most of the claims fall into the category "aids clear thinking." For example, theoretical and applications literature claim that formal approaches promote a policy focus that helps "shift the decision maker's attention from specific actions to the values these actions serve," "helps separate judgments of probabilities from those of values," "forces full consideration of all consequences of a given action," "identifies what is important for making decisions and what is not important," and so forth [2]. In addition, analysts argue that separating information from preference inputs "permits elected officials to function exclusively as policymakers and scientists to function exclusively as scientists," tends to produce insights that "aid in generating creative alternatives," and "improves communication" in such a way as to permit decision makers to "isolate and quantify differences of opinion among experts." It is also claimed that decision-making approaches can help individuals who have already made up their minds by supporting advocacy or defending a particular viewpoint. For example, analysis "helps the decision-maker defend and communicate his decision . . . makes the point that the decision was not frivolous and that all factors were considered" [2].

Viewing analysis as an aid to decision making rather than as a way to make decisions emphasizes the importance of the analyst. With this view, the analyst largely plays the role of a facilitator, and the overall objective of a formal approach may be regarded as that of providing a framework for investigation that is likely to produce information of useful value in the decision process.

Two important implications may be drawn from this perspective. First, the skill and capabilities of the analyst are of prime importance in determining the success achieved from the use of a formal approach. Although decision theories provide a logic for decision making, they offer only limited guidance to the analyst who must choose among various procedures, methods of analysis, assumptions, and data. Relying on an understanding of the decision problem, theory, and basic concepts of analysis (e.g., quantification, iteration, and modeling), the analyst must piece together an approach. Majone [93] likens analysis to craft and notes that in both cases successful performance depends on an intimate knowledge of materials, tools, and processes and on a highly personal relationship between agent and task.

The second implication of viewing analysis as an aid rather than a replacement for the decision process is the shift from evaluation by results to evaluation by process. Because the impact of a formal approach on the decision actually reached depends on a very complex, indirect, and poorly understood interaction, the process by which the approach is conducted is intrinsically important in determining success. Majone notes that this is typical of professional work. In the case of physicians, for example, "much, perhaps most, of what a physician does must be categorized as process, and process not even calculated to affect outcome" [93].

The more general view of the role of formal approaches as an aid rather than a way of making decisions argues for a pragmatic perspective in identifying evaluation criteria. This perspective is taken in what follows.

Evaluation Criteria. Following Majone and Quade [94], evaluation criteria may be categorized as internal or external. Internal criteria are generated within the disciplines of analysis (economics, mathematics, etc.) and reflect the logical and technical "correctness" of the approach. External criteria are imposed by considerations normally outside the disciplines of analysis and deal with the acceptability, effectiveness, and practicality of the approach. Although both categories of criteria are needed to evaluate an approach, one or the other often seems to be improperly elevated to primary importance. Analysts, for example, often assume that a high technical quality of an analysis is sufficient to guarantee its practical effectiveness. Examples of analyses of high technical quality that had no visible impact on policy demonstrate the error in this view. On the other hand, the sponsors of analyses tend to judge the value of the approach solely by the outcome of the process. Balanced criteria for evaluating an approach should include both types of considerations.

Internal criteria relate to what Ford, Keeney, and Kirkwood [95] have described as the "quality of the analysis." The major categories of internal criteria are logical soundness, completeness, and accuracy.

Logical soundness is determined by the inherent consistency of the approach (i.e., adherence to or violation of the principles of logic), whether differences in the quality or strength of evidence are properly reflected, the degree to which tests are undertaken to establish the credibility of the models used, and so forth. For an approach to be logically sound, conclusions must be derived via a defensible decision rule. Such a rule should be sensitive to the various aspects of the problem, reliable in that independent applications to the same problem would produce the same results, justifiable in terms of theoretical arguments or empirical evidence, and unbiased in its recommendations by not giving undue weight to any specific interest or consideration [3].

Completeness reflects the extent to which an approach permits a comprehensive problem definition. This would include both inherent inabilities of an approach to account for certain aspects of a problem and the extent to which it purposefully ignores relevant considerations or information because they are hard to accommodate. For example, this category would include the degree to which multiple concerns are accounted for (e.g., environmental "intangibles," distributional effects, and varying degrees of impacts), labile and conflicting social values are acknowledged, uncertainty in data and judgment are considered or assumed away, long-run impacts are represented, and the costs of irreversibility are reflected.

Accuracy of analysis includes biases, omissions, and inaccuracies due to errors of elicitation and estimation. Errors of elicitation can be the result of psychological factors such as fatigue, boredom, or inattention; errors of estimation are associated with theoretically imprecise procedures [2].

External criteria are imposed by the realities of the decision-making process, including the clients of the study, the public, and the objective limitations of time and resources. The major categories of external criteria are practicality and acceptability.

Practicality means that the analysis can be conducted in the real environment using the methods and procedure provided. Basically, this requires that a pool of expertise be available to implement the approach and that the costs, time, and effort required are appropriate and compatible with the constraints of the situation. People requirements can be significant—applying an approach is a labor-intensive exercise involving both substantive experts who understand the hazard and normative experts who specialize in the decision-making methodology. Also, depending on the approach, considerable time and information demands may be made on decision makers. The crisis atmosphere of most decision making and the reluctance of decision makers to spend funds for the uncertain benefits of good advice, which at best only increases one's chances of obtaining a favorable outcome, generally result

in analysts being provided with less time and fewer resources than they would like for the conduct of their analyses.

Acceptability largely relates to public perception of the approach, compatibility with existing institutions, and the desires of decision makers. Characteristics influencing public perception would include understandability (the degree to which concerns of the various participants in the process are responsibly and demonstrably addressed), and compatibility with social norms, such as the degree to which the approach is viewed as fair, legal, and rational. The extent to which value judgments are clear and the evaluation process is transparent will affect public perception in these areas. Although clarity may be essential for acceptability, if an approach produces clear but unwanted conclusions, the offended parties may choose to discredit the approach rather than contest the assumptions leading to the undesired conclusion [3]. Furthermore, some decision makers may prefer an approach that cloaks their decisions in ambiguity over one that is logically clear. They may feel uncomfortable with what others consider to be elements of a good approach, such as extended time horizons, explicitly acknowledged uncertainty, and extensive reliance on outsiders.

Notice that the various evaluation criteria are not independent. Weaknesses in some areas (e.g., logical soundness) are likely to preclude strengths in others (e.g., acceptability). Furthermore, some of the goals may be in conflict. For example, it may be easier to derive a logically sound decision rule by leaving out certain awkward issues and thereby sacrificing completeness. If no approach does, or even can, satisfy all of the criteria and if their respective strengths and weaknesses lie in different areas, then the choice of an approach will require trade-offs.

Comparative Evaluation

Various types of decision-making approaches were compared in the previous section in terms of their underlying rationales and standard procedures. A useful way of conceptualizing these comparisons is in the form of a matrix that evaluates the potential application of different types of approaches to different kinds of risk problems. For example, Table 2 shows a matrix in which risk problems with various characteristics are represented by rows and different categories of decision-making approaches are represented by columns. Because there is disagreement over the meaning of the various labels used to describe approaches (e.g., DA, social DA, supra-DA, CBA, Paretian CBA, etc.), clear definitions must be established for the approach categories used in such an evaluation scheme. Table 3 illustrates basic characteristics that might be associated with the labels used in Table 2. As shown in Figure 4, the approach categories might be regarded as providing a mutually exclusive, collectively exhaustive partition of the space of decision-making rationales. Comparing Figure 4 with Figure 3 shows that such attempts at defining and distinguishing approach categories are likely to produce some inconsistencies with the way in which the labels are currently used.

In Table 2, two conditions are defined for each of the 10 dimensions for characterizing risk problems, and there are six categories of approaches. Therefore, each of the 120 cells in the matrix represents the potential application of a specific sort of approach to a risk problem possessing certain characteristics. Although evaluating each combination of approach and risk problem characteristic according to each of the five evaluation criteria listed above would require 600 separate evaluations, it is straightforward to provide "first-cut" evaluations for any cell. To illustrate, the subsections below provide summary evaluations for the various approach categories (assuming definitions consistent with Table 3 and Figure 4).

Table 2. Conceptual Framework for Evaluating Approaches

Risk problem characteristics		Approach category[a]					
		CBA	Social DA	DA	Supra-DA	SWT	D-M CBA
Technical alternatives	Simple—e.g., go/no-go, ranking						
	Complex—e.g., contingencies, portfolios						
Structure	Simple—e.g., few variables simple relations						
	Complex—e.g., dynamic dependencies						
Uncertainty	Limited—e.g., no relevant data						
	Extensive—e.g., abundant data						
Outcomes	Measurable, easily valued						
	Intangible, distributional impacts		Evaluation 1. Logical soundness 2. Completeness 3. Accuracy 4. Practicality 5. Acceptability				
Process constraints	Not significant						
	Serious—e.g., time, resources, legal						
Decision maker	Favorable qualities—e.g., analytic, active						
	Unfavorable qualities—e.g., passive, qualitative						
Organization	Rational decision maker model						
	Organizational process model, bureaucratic politics model						
Environment sensitivity	Limited potential for creating public bias						
	Considerable potential for creating bias						
Controversy	No controversy						
	Considerable controversy						
Expectations	Limited—e.g., no pressure for government action						
	Well defined—e.g., powerful pressures						

[a]See Figure 4 and Table 3 for definition of approach categories.

Table 3. Typical Characteristics Distinguishing Approach Categories

<table>
<tr><th></th><th>CBA (cost–benefit analysis)</th><th>Decision-maker CBA (decision-maker cost–benefit analysis)</th><th>Social DA (social decision analysis)</th><th>Supra DA (supra-decision-maker decision analysis)</th><th>DA (decision analysis)</th><th>Applied SWT (applied social welfare theory)</th></tr>
<tr><td>Description</td><td>Uncompromising application of cost–benefit theory</td><td>Cost–benefit theory augmented to reflect decision maker's preferences</td><td>Decision analysis from a social perspective</td><td>Decision analysis based on decision maker's "imaginative empathy"</td><td>Uncompromising application of decision theory</td><td>Application of social welfare function based on multiattribute utility theory</td></tr>
<tr><td>Decision criterion</td><td>Maximization of economic efficiency</td><td>Maximization of decision maker's definition of equitable equivalent economic value</td><td>Maximization of social value</td><td>Maximization of subjective expected social utility</td><td>Maximization of decision maker's personal subjective expected utility</td><td>Maximization of social welfare</td></tr>
<tr><td>Typical characteristics and procedures</td><td colspan="2">Models based primarily on empirical relationships</td><td colspan="2">Models based primarily on experts' judgments of causal logic</td><td>Models based on decision maker's assessments</td><td>Models based on simple empirical or theoretical relationships</td></tr>
<tr><td></td><td colspan="3">Dollars generally used to value outcomes</td><td colspan="2">Outcomes generally measured on scale of utility</td><td></td></tr>
<tr><td></td><td>Outcome valuation based on market prices and willingness to pay</td><td colspan="2">Outcome valuation based on market values, willingness to pay, and decision maker's preferences</td><td>Outcome valuation based on interpersonal preference comparisons</td><td>Outcome valuation based on decision maker preferences</td><td>Outcome valuation based on interpersonal preference comparisons</td></tr>
<tr><td></td><td colspan="2">Limited consideration of uncertainties through frequency distributions and sensitivity analysis</td><td colspan="3">Explicit treatment of expert uncertainties through probability encoding</td><td>Limited consideration of uncertainties based on (subjective or objective) probabilities</td></tr>
</table>

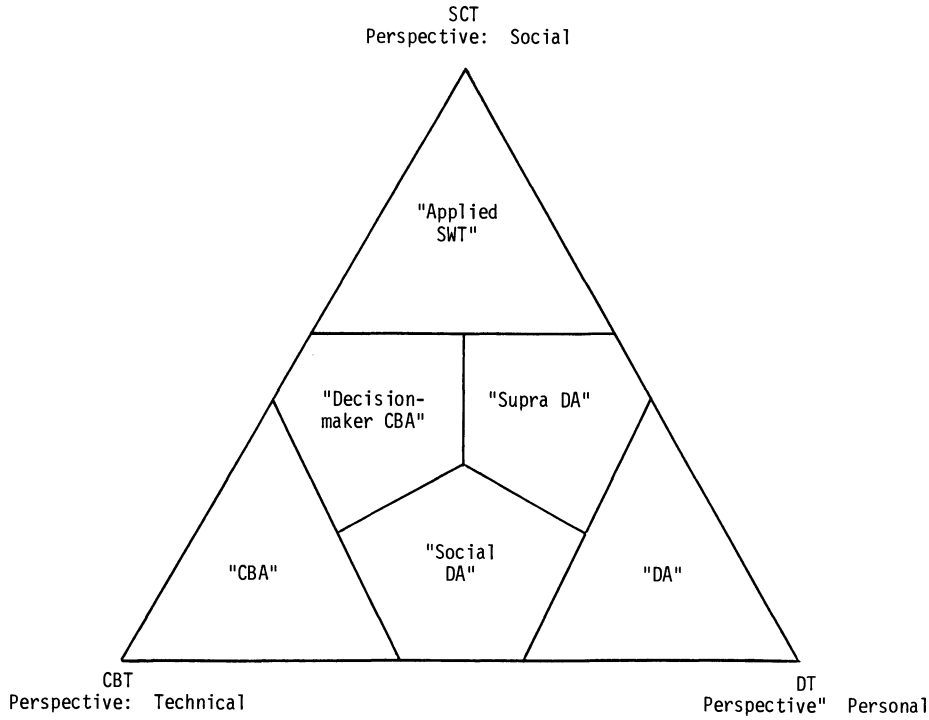

Figure 4. Categories of decision-making approaches defined in terms of their underlying theories and perspectives.

Logical Soundness. CBA, DA, and SWT represent the operationalization of CBT, DT, and SCT, respectively, and appeal, therefore, to these theories for their logical justification. As previously described, CBT, DT, and SCT are each coherent, consistent theories that describe how information and values should be integrated to identify alternatives that are in some sense "best." CBT is founded on the concept of economic efficiency and reflects a technical, objective worldview. DT is based on axioms of individual choice and reflects an individualistic, subjective worldview. SCT is based on the concept of a social welfare function and reflects a worldview centered around equity and process. Decision-maker CBA, social DA, and supra-DA are hybrid approaches that derive their perspectives and procedures from more than one of the decision-making theories. Decision-maker CBA appeals to both CBT and SCT for its rationale and as a result mixes both equity and effeciency criteria. Social DA is based on both CBT and DT and contains some subjective versus objective inconsistencies in its perspective. Supra-DA relies on both DT and SCT. Consequently, it tends to mix individual with group decision-making perspectives.

A critical determinant of the logical soundness attributed to the various approaches is the persuasiveness of their underlying behavioral assumptions. To the extent that market prices do not reflect preferences, people reject the axioms of decision theory, or equity assumptions cannot be justified, the logical appeal of the approaches is diminished. Thus, for example, CBA is less attractive for situations in which there are considerable differences in the quality of relevant information, DA is less useful if there is no decision maker willing to provide or delegate responsibility for providing subjective information and preference judgments, and SWT loses its appeal in situations where a comparison of the strengths of preferences of affected parties is not regarded as crucial to the decision. Because all ap-

proaches rely on decomposition, enumeration, and quantification, they are all subject to charges that information and values cannot be effectively separated, all possible consequences cannot be anticipated, and important factors cannot be quantified.

Completeness. Formal approaches embody few restrictive assumptions about how problems are to be defined. In each case, a decision model is constructed whose structure and content is largely determined by the substantive information provided to the analyst by the client, decision maker, or other "experts." The completeness of any analysis will thus be limited by the breadth and depth of vision possessed by those experts. Furthermore, because the sources and perspectives identified for providing information differ among the approaches, the nature of the omissions that occur is likely to depend on the approach that is applied.

Obviously, approaches are less effective in situations where the factors they tend to omit are crucial. Thus, CBA will be less effective in situations where little or no data are available for quantifying important uncertainties or where important outcomes exist which do not have immediate, tangible economic implications. DA will be less effective if decision makers are likely to define the problem in habitual ways that overlook options or overemphasize certain factors. Social DA, because of its development of an extrapersonal decision model through the participation of a large number of substantive experts, can be expected to provide a more complete accounting of available information. Similarly, supra-DA, with its assessment and integration of preferences of stakeholders, is likely to produce a more complete representation of social preferences. For situations where distributional equity is an important issue, decision maker CBA or another approach other than a standard CBA will permit explicit accounting of considerations beyond efficiency.

In general, DA approaches permit a more comprehensive accounting of factors than do CBA approaches. In principle, at least, any concept in the problem definition may be translated into operational terms under DA. Social DA approaches are especially flexible—they allow economic and statistical estimates to be used when they are available, while permitting subjective judgment as a source when they are not.

Accuracy. Inaccuracies in approach applications may result from a variety of sources, including omissions, the difficulty of measuring costs and benefits, biases, and manipulation. CBA approaches are likely to be less accurate in situations where there are significant market distortions (due to taxes or externalities) or when information or preferences are changing rapidly. DA approaches, because they rely heavily on the assessment of subjective judgments, may be expected to yield less accurate results in situations where respondents have difficulty providing the required assessments (for example, when experts do not have coherent, articulated views on a topic). SWT and supra-DA approaches which require measures of strengths of preferences of stakeholders will be subject to inaccuracies in situations where strong motivational biases exist for stakeholders to strategically misrepresent their preferences.

Iteration, as described earlier, is an important component of analysis. Since errors are to be expected in complex problems, it is important that analyses be subjected to peer review. Weaknesses should be corrected and improvements incorporated into the analysis. Too often, the relatively small additional resources required to correct the inaccuracies that a careful review reveals are not made available. Furthermore, there is a natural tendency for analysts and clients stubbornly to defend their assumptions against all attacks rather than for them to view critiques as indications that their approach has successfully illuminated the problem and focused debate.

Practicality. Despite their logical appeal, neither CBA, DA, nor SWT was specifically designed for application to social decisions involving risk. Consequently, each shows some strain (in the form of conceptual difficulties or in resorting to ad hoc procedures) when forced to accommodate aspects of risk problems that are unlike those of the traditional problems for which these approaches originally evolved. For example, CBA is best suited for go/no-go decisions with immediate consequences for which responsive markets exist and consumers are well informed. It will not work as well in situations where the only information available is subjective. DA presumes the existence of a decision maker empowered and willing to speak on behalf of society. Assuming such individuals can be found, considerable time and information demands may be placed on them. Although DA approaches are much more flexible in their ability to handle difficult measurement problems (e.g., value of a life), workable and validated procedures are not available for addressing all problem aspects (e.g., joint time–risk preferences, assessments of future values).

An important characteristic of formal approaches is their flexibility in level of detail and time and resource requirements. Full-blown approaches are expected to be the most complete and accurate. However, a full-blown approach can also be expensive and time-consuming. Fast, limited analyses not only place greater reliance and demands on experts, but are also likely to require the most highly skilled analysts.

Acceptability. Critical acceptability issues include transfer of decision-making power and the explicitness of formal approaches. Critics worry that formal approaches will place too much societal decision-making power in the hands of a technical elite composed of those who perform analyses and interact with the analyst. CBA provides the most constraining decision-making rule by requiring that decisions be based on a balancing of economic costs and benefits. Thus, CBA provides little opportunity for stakeholders to contribute to the analysis except, perhaps, in defining the problem (e.g., identifying alternatives). At the same time, however, CBA avoids the necessity of a decision maker providing subjective value judgments. CBA is thus likely to appeal to some regulators because it appears to them as a value-free guide to decision making. In reality, of course, CBA embodies strong value judgments.

DA and other approaches that permit subjective inputs are more amenable to public participation because anyone's perspective can be represented. On the other hand, DA, supra-DA, SWT, and decision-maker CBA all require explicit, potentially controversial value comparisons to be established. Social DA demands that equivalent dollar values be assigned to human health and other nonmonetary outcomes and requires unambiguous statements from experts regarding scientific uncertainties. It also highlights the risks and uncertainties associated with alternatives and therefore may appear less attractive in situations in which decision makers are reluctant to admit the subjectivity or uncertainty inherent in their decisions. Furthermore, such approaches may be more prone to raise suspicions that analysts are playing a sophisticated numbers game. DA will be most acceptable in situations as an aid to individual decision makers concerned with achieving rationality and consistency in decisions for which they have complete authority.

Formal approaches have already established a niche in most institutions. Regulatory agencies, industry, labor unions, professional organizations, and consumer groups have all found it useful to commission at least an occasional analysis. CBA seems to have achieved a slightly broader acceptance to date, although this may simply reflect its seniority to DA and other approaches.

Selecting a Decision-Making Approach

Although an evaluation of the various approach categories in terms of the five criteria may provide some idea of how well each currently does in practice from various perspectives, it does not tell us which to choose. None of the options appears to surpass the others in all respects. Thus, the criteria that are most important in a particular situation must be determined. The most appropriate approach for one problem might be rejected in another situation for which its particular strengths (e.g., completeness) are less essential and its weaknesses (e.g., political acceptability) more so.

With current practice, the analyst rarely treats the design of an approach for a specific risk problem as a strategic decision. Instead, analysts tend to select the approaches with which they are most familiar and then tactically modify the procedures and methods of analysis as required to meet the technical requirements of the problem. Clearly, a more deliberate consideration of the options available is needed. A conceptual framework for approach evaluation and selection such as that represented in Table 2 may be of value in this respect. Rather than selecting arbitrarily an approach type, the analyst should identify critical problem characteristics and then explicitly consider the strengths and weaknesses of various approaches in view of each of these characteristics, as they might be entered in the relevant rows of the matrix. Such explicit consideration in the design of an approach is likely to improve the quality of analysis for social risk decisions.

DIRECTIONS FOR FUTURE RESEARCH

Research designed to support the choice of a formal decision-making approach is just beginning. If, as is argued in this chapter, the selection of an approach requires consideration of the significance of the strengths and weaknesses of each available option in the context of the risk decision at hand, then additional research might usefully address the following sorts of questions:

- What are the fundamentally different kinds of risk decisions facing society? More specifically, what identifiable characteristics might suggest that a given risk decision might be most effectively dealt with by a particular decision-making approach?
- Might it be possible to provide analysts with useful aids to support the design of a decision-making approach? For example, would it be helpful to develop comprehensive catalogs of available analytical procedures?
- How can the value of applying a formal approach be increased? In particular, if no analysis can completely capture the decision problem, how can the logic and assumptions underlying an analysis be more effectively communicated to decision makers? The effective communication of analyses may well be the weak link in achieving the potential benefits that formal analysis has to offer.

CONCLUDING OBSERVATIONS AND COMMENTS

The metadecision problem of deciding among decision-making approaches is difficult because the options are not directly comparable—each approach embodies an alternative

concept of rational decision-making. If applied competently, each does best what it sets out to do. Rather than attempt to solve the question "What is the best definition of rationality?" we have chosen to ask, "Which approach best serves the needs of a specific problem?" To help in this respect, five evaluation criteria have been presented: logical soundness, completeness, accuracy, practicality, and acceptability. Determining the relative importance of these criteria in the context of a given social risk problem underlies the choice of a decision-making approach.

Although a decision-making approach is not appropriate for use as a formal device for making decisions, it can provide a valuable process for deepening understanding and clarifying issues. The complexity of social decisions involving risks demands that they be illuminated from all possible perspectives if those decisions are to be made in the best way possible. Formal approaches can provide an important, although sometimes uncomfortable, pragmatic perspective. For example, they force us to recognize that society's resources are limited, that above some level of expenditure additional programs designed to reduce risks to health and safety will be counterproductive because of economic and political effects, and that resources expended inefficiently result, at least in principle, in lower levels of health and safety than might otherwise be achieved.

Formal analysis thus has the potential but cannot be guaranteed to improve decision making. Analysis can clarify a decision; it can also obscure it in technical and mathematical abstraction. Analysis can also sometimes exacerbate controversy by enabling protagonists to understand fully that their interests are opposed to those of others and by making explicit the critical assumptions on which any decision is based. The positive value derived from using formal analysis can be significantly enhanced through the careful selection of the approach and the methods for presenting the results. Analysts need to become more aware of the options that are available and the importance of societal and institutional realities when choosing from among these options.

REFERENCES

1. R.B. Cumming, "The Urge to Shout," *Risk Analysis,* Vol. 1, No. 3, September 1981, p. 165.
2. K.R. Hammond, G.H. McClelland, and J. Mumpower, *Human Judgment and Decisionmaking*. New York: Praeger Publishers, 1980.
3. B. Fischhoff, S. Lichtenstein, P. Slovic, S.L. Derby, and R.L. Keeney, *Acceptable Risk*. New York: Cambridge University Press, 1981.
4. R.V. Brown and J.W. Ulvila, "Selecting Analytic Approaches for Decision Situations (Revised Edition), Volume I: An Overview of the Methodology," Technical Report TR-77-7-25, Decisions and Designs, Inc., McLean, Virginia, December 1977.
5. C. Churchman, *Prediction and Optimal Decision: Philosophical Issues of a Science of Values*. Englewood Cliffs, New Jersey: Prentice-Hall, 1961.
6. D.J. White, *Decision Methodology*. New York: John Wiley & Sons, 1975.
7. A.P. Sage and E.B. White, "Methodologies for Risk and Hazard Assessment: A Survey and Status Report," *IEEE Transactions on Systems, Man, and Cybernetics,* Vol. SMC-10, No. 8, August 1980.
8. R. Strauch, "Risk Assessment as a Subjective Process," P-6460, The Rand Corporation, Santa Monica, California, 1980.
9. K.J. Arrow, "Alternative Approaches to the Theory of Choice in Risk-Taking Situations," *Econometrics,* Vol. 19, No. 4, October 1951, pp. 404–437.
10. M. Baram et al., "Federal Energy Regulation and the Use of Cost-Benefit Analysis: Legal and Public Policy Considerations," Part I: *Adoption of Cost-Benefit Analysis by Government Agencies,* report to Environmental Policy Office, Brookhaven National Laboratory, 1977.
11. S. Ben-David, A.V. Kneese, and W.D. Schulze, "A Study of the Ethical Foundations of Benefit-Cost Analysis Techniques," working paper, University of New Mexico, Albuquerque, New Mexico, 1979.

12. J. Hirshleifer, "The Economic Approach to Risk–Benefit Analysis," in *Risk–Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22–26, 1975, Asilomar, California,* D. Okrent, ed. Los Angeles, California: UCLA, December 1975.
13. J. Hirshleifer, T. Bergstrom, and E. Rappaport, "Applying Cost–Benefit Concepts to Projects Which Alter Human Mortality," UCLA-ENG-7478, School of Engineering and Applied Science, University of California, Los Angeles, California, November 1974, p. 5.
14. B. Fischhoff, P. Slovic, and S. Lichtenstein, "Weighing the Risks," *Environment,* Vol. 21, No. 4, 1979, pp. 17–28.
15. B.F. Anderson, D.H. Deane, K.R. Hammond, G.H. McClelland, and J.C. Shanteau, *Concepts in Judgment and Decision Research.* New York: Praeger Publishers, 1981.
16. J. Rothenberg, "Cost–Benefit Analysis: A Methodological Exposition," in *Handbook of Evaluation Research,* Vol. 2, M. Guttentag and E. Streuning, eds. Beverly Hills, California: Sage Publications, 1975.
17. D. Bernoulli, "Exposition of a New Theory on the Measurement of Risk" (L. Sommer, trans.), *Econometrica,* Vol. 22, 1954, pp. 23–36.
18. J. von Neumann and O. Morgenstern, *Theories of Games and Economic Behavior.* Princeton, New Jersey: Princeton University Press, 1947.
19. R.A. Howard, "Risk Preference," in *Readings in Decision Analysis,* R.A. Howard, J.E. Matheson, and K.L. Miller, eds. Menlo Park, California: SRI International, 1976.
20. C.A. Hooker, J.J. Leach, and E.F. McClennen, eds., *Foundations and Applications of Decision Theory,* Vols. I and II. Boston, Massachusetts: D. Reidel, 1978.
21. R.L. Keeney and H. Raiffa, *Decisions with Multiple Objectives, Preferences and Value Tradeoffs.* New York: John Wiley & Sons, 1976.
22. P.J. Schoemaker, *Experiments on Decisions Under Risk, The Expected Utility Hypotheses.* Boston, Massachusetts: Martinus Nijhoff, 1980.
23. T. Bayes, "An Essay Towards Solving a Problem in the Doctrine of Chances," *Biometrik,* Vol. 45, 1958, pp. 296–315.
24. P.C. Gardiner and W. Edwards, "Public Values: Multiattribute Utility Measurement for Social Decision Making," in *Human Judgment and Decision Processes,* M.F. Kaplan and S. Schwartz, eds. New York: Academic Press, 1975.
25. W. Edwards, "The Theory of Decision Making," *Psychological Bulletin,* Vol. 51, No. 4, 1954, pp. 380–417.
26. R.A. Howard, "The Foundations of Decision Analysis," *IEEE Transactions on Systems Science and Cybernetics,* Vol. SSC-4, No. 3, September 1968.
27. M. Allais, "La Psychologie de l'Homme Rationale devant le Risque: Le Theories et l'Experience," *Journal of the Statistics Society,* Vol. 94, Paris, 1953, pp. 47–73.
28. R.A. Howard, "An Assessment of Decision Analysis," *Operations Research,* Vol. 28, January 1980, pp. 4–27.
29. K.J. Arrow, "Current Developments in the Theory of Social Choice," *Social Research,* Vol. 44, No. 4, Winter 1977, pp. 607–622.
30. R.C. Lind, "The Analysis of Benefit–Risk Relationships: Unresolved Issues and Areas for Further Research," in *Perspectives on Benefit–Risk Decision Making,* report of a colloquium conducted by the Committee on Public Engineering Policy, National Academy of Engineering, Washington, D.C., 1972, pp. 109–114.
31. J.R. Green and J.-J. Laffont, *Incentives in Public Decision Making.* New York: North-Holland, 1979.
32. K.J. Arrow, *Essays in the Theory of Risk Bearing.* New York: Elsevier, 1974.
33. A.K. Sen, *Collective Choice and Social Welfare.* San Francisco, California: Holden–Day, 1970.
34. G.S. Gibbard, *Analysis of Groups: Contributions to Theory, Research, and Practice.* San Francisco, California: Jossey-Bass, 1973.
35. R.L. Keeney, "A Group Preference Axiomatization with Cardinal Utility," *Management Science,* Vol. 23, No. 2, October 1976, pp. 140–145.
36. J.C. Harsanyi, "Mortality and the Theory of Rational Behavior," *Social Research,* Vol. 44, No. 4, Winter 1977, pp. 623–667.
37. R. Keeney and C. Kirkwood, "Group Decision Making Using Cardinal Social Welfare Functions," *Management Science,* Vol. 22, pp. 430–437.
38. H.A. Linstone, "The Multiple Perspective Concept, with Applications to Technology Assessment and Other Decision Areas," Report 81-1, Futures Research Institute, Portland State University, Portland, Oregon, September 1981.
39. A.R. Prest and R. Turvey, "Cost–Benefit Analysis: A Survey," *Economics Journal,* Vol. 75, 1975, pp. 683–735.
40. G.H. Peters, "Cost–Benefit Analysis and Public Expenditure," Eaton Paper 8, Second Edition, The Institute of Economic Affairs, 1968.

41. R. Layard, ed., *Cost–Benefit Analysis: Selected Readings*. Middlesex, England: Penguin Books, 1972.
42. P. Bohm, *Social Efficiency: A Concise Introduction to Welfare Economics*. Stockholm, Sweden: Macmillan Press, 1974.
43. R. Layard, *Cost–Benefit Analysis*. New York: Penguin, 1974.
44. E.J. Mishan, *Cost–Benefit Analysis*. New York: Praeger Publishers, 1976.
45. E. Stokey and R. Zeckhauser, *A Primer for Policy Analysis*. New York: Norton, 1978.
46. P. Abelson, *Cost–Benefit Analysis and Environmental Problems*. Westmead, England: Saxon House, 1979.
47. R. Sugden and A. Williams, "Practical Cost–Benefit Analysis," Oxford, England, 1978.
48. S.R. Watson, "Decision Analysis as a Replacement for Cost/Benefit Analysis," CUED/F-CAMS/TR197, University of Cambridge, Cambridge, England, 1979.
49. R.M. Parish, "The Scope of Benefit–Cost Analysis," *Journal of the Economic Society of Australia and New Zealand,* No. 52, 1976, pp. 302–314.
50. A.J. Van Horn and R. Wilson, "The Status of Risk–Benefit Analysis," discussion paper, Energy and Environmental Policy Center, Harvard University, Cambridge, Massachusetts, December 1976.
51. A.D.J. Flowerdes, "Choosing a Site for the Third London Airport: The Roskill Commission's Approach," in *Cost–Benefit Analysis,* R. Layard, ed. Middlesex, England: Penguin Books, 1972.
52. C.D. Foster and M.E. Beesely, "Estimating the Social Benefit of Constructing an Underground Railway in London," *Journal of the Royal Statistical Society,* Part I, 1963.
53. C.D. Throsby and P.W. Abelson, "Economic Evaluation of Net National Benefits from Sandmining on Moreton Island," in *Moreton Island Environmental Impact Study and Strategic Plan,* A.A. Health and Partners, 1976, pp. 2-148–2-177.
54. J. Krutilla and O. Eckstein, *Multiple Purpose River Development*. Baltimore, Maryland: Johns Hopkins, 1958.
55. "Report 9—Economic Evaluation of Eppalock Soil Conservation Study," Department of Environment, Housing and Community Development, Australian Government Publishing Service, 1978.
56. K.S. Moll, E. Baum, F. Capener, G. Dresch, and R. Wright, "Hazardous Wastes: A Risk–Benefit Framework Applied to Cadmium and Asbestos," SRI International, Menlo Park, California, 1975.
57. C. Jackson et al., "Benefit–Cost Analysis of Automotive Emission Reductions," General Motors Research Publication 2265, October 15, 1976.
58. H. Raiffa, *Decision Analysis: Introductory Lectures on Choices Under Uncertainty*. Reading, Massachusetts: Addison-Wesley, 1968.
59. R. Howard, "Decision Analysis: Applied Decision Theory," *Proceedings of the Fourth Conference on Operational Research*. New York: John Wiley & Sons, 1968.
60. R.O. Schlaifer, *Analysis of Decisions Under Uncertainty*. New York: McGraw-Hill, 1969.
61. R.V. Brown, A.S. Kahn, and C.R. Peterson, *Decision Analysis for the Manager*. New York: Holt, Rinehart & Winston, 1974.
62. C. Holloway, *Decision Making Under Uncertainty: Models and Choices*. New York: Prentice-Hall, 1979.
63. R.A. Howard, "Social Decision Analysis," *Proceedings of the IEEE,* Vol. 63, 1975, pp. 359–371.
64. W. Edwards, "How to Use Multi–Attribute Utility Measurement for Social Decision Making," *IEEE Transactions on Systems, Man, and Cybernetics,* Vol. SMC-7, 1977, pp. 326–339.
65. R.A. Howard, M.W. Merkhofer, A.C. Miller, and S.N. Tani, "A Preliminary Characterization of a Decision Structuring Process for the Task Force Commander and His Staff," Technical Report MSC-4030, SRI International, Menlo Park, California, December 1975.
66. R.L. Keeney, "The Art of Assessing Multiattribute Utility Functions," *Organizational Behavior and Human Performance,* Vol. 19, No. 2, 1977, pp. 267–310.
67. J.S. Dyer, "Applications of Decision Analysis to Occupational Health and Safety Problems," UCLA, Los Angeles, California, November 1978.
68. J. Dyer and R. Sarin, "Measurable Preference Aggregation Rules," Discussion Paper No. 71, Management Science Study Center, UCLA, Los Angeles, 1978.
69. J.C. Harsanyi, *Rational Behavior and Bargaining Equilibrium in Games and Social Situations*. Cambridge, England: Cambridge University Press, 1977.
70. J. Dyer and R. Miles, "An Actual Application of Collective Choice Theory to the Selection of Trajectories for the Mariner Jupiter/Saturn Project," *Operations Research,* Vol. 24, 1976, pp. 220–224.
71. J. Dyer and R. Miles, "Alternative Formulations for a Trajectory Selection Problem: The Mariner Jupiter/Saturn 1977 Project," in *Conflicting Objectives in Decisions,* D. Bell, R. Keeney, and H. Raiffa, eds. New York: John Wiley and Sons, 1977.
72. D.W. Fisher and D. von Winterfeldt, "Setting Standards for Chronic Oil Discharges in the North Sea," *Journal of Environmental Management,* Vol. 7, 1978, pp. 177–199.

73. A.E. Smith, P.C. McNamee, and M.W. Merkhofer, "Development of Decision Analysis Methodology for Health Risk Assessment: An Illustrative Application to Alternative Air Quality Standards for Carbon Monoxide," Final Report 3432, SRI International, Menlo Park, California, 1982.
74. K. Thomas, "Comparative Risk Perception: How the Public Perceives the Risks and Benefits of Energy Systems," in *The Assessment and Perception of Risk,* F. Warner and D.H. Slater, eds. London: The Royal Society, 1981.
75. Battelle Pacific Northwest Labs, "Review of Decision Methodologies for Evaluating Regulatory Actions Affecting Public Health and Safety," December 1976.
76. M.W. Merkhofer and E. Leaf, "A Computer–Aided Decision Structuring Process," Final Report, SRI International Menlo Park, California, June 1981.
77. National Academy of Sciences, "Considerations of Health Benefit–Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives," EPA 520/4-77-003, U.S. Environmental Protection Agency, 1977.
78. D.E. Bell and H. Raiffa, "Marginal Value and Intrinsic Risk Aversion," Harvard Business School Manuscripts, Harvard University, Cambridge, Massachusetts, June 1979.
79. R. Wilson, "Examples in Risk–Benefit Analysis," *Chemtech,* No. 6, October 1975, pp. 604–607.
80. R. Zeckhauser, "Procedures for Evaluating Lives," *Public Policy,* Vol. 23, 1975, pp. 419–464.
81. J. Linnerooth, "A Critique of Recent Modelling Efforts to Determine the Value of Human Life," Research Memorandum RM-75-67, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.
82. J. Linnerooth, "The Value of Human Life: A Review of the Models," *Economic Inquiry,* Vol. 17, 1979, pp. 52–74.
83. J.D. Graham and J.W. Vaupel, "Value of a Life: What Difference Does it Make?" *Risk Analysis,* Vol. 1, No. 2, March 1981, pp. 89–95.
84. R.A. Howard, "Life and Death Decision Analysis," in *Lawrence Symposium on Systems and Decision Sciences.* North Hollywood, California: Western Periodicals, 1979.
85. R.L. Keeney, "Evaluation of Mortality Risks from an Organizational Perspective," presented at the Conference on the Value of Life, Geneva, March 30–April 1, 1981.
86. Committee on Environmental Decision Making, "Decision Making in the Environmental Protection Agency," National Research Council, National Academy of Sciences, Washington, D.C., 1977.
87. E.S. Quade, "Pitfalls in Formulation and Modeling," in *Pitfalls of Analysis,* G. Majone and E.S. Quade, eds., International Institute for Applied Systems Analysis. Chichester, England: Wiley, 1980.
88. P. Slovic, B. Fischhoff, and S. Lichtenstein, "Risk Assessment: Technical and Behavioral Issues," Decision Research, Eugene, Oregon, prepared for the Congressional Forum on Risk/Benefit Analysis in the Legislative Process, Washington, D.C., July 25, 1979.
89. I.G. Heggie, *Transport Engineering Economics.* New York: McGraw-Hill Book Company, 1972.
90. W.D. Rowe, "Governmental Regulation of Societal Risks," *The George Washington Law Review,* Vol. 45, No. 5, August 1977, pp. 944–968.
91. H. Raiffa, W.B. Schwartz, and M.C. Weinstein, "Evaluating Health Effects of Societal Decisions and Programs," in *Volume IIb: Decision Making in the Environmental Protection Agency, Selected Working Papers,* National Research Council, National Academy of Sciences, Washington, D.C., 1977.
92. H.P. Green, "Statement of Harold P. Green, Attorney, Professor of Law, George Washington University, Washington, D.C.," in *Risk/Benefit Analysis in the Legislative Process,* U.S. Senate Printing Office, 1980.
93. G. Majone, "An Anatomy of Pitfalls," in *Pitfalls of Analysis,* G. Majone and E.S. Quade, eds., International Institute for Applied Systems Analysis. Chichester, England: Wiley, 1980.
94. G. Majone and E.S. Quade, "Introduction," in *Pitfalls of Analysis,* G. Majone and E.S. Quade, eds., International Institute for Applied Systems Analysis. Chichester, England: Wiley, 1980.
95. C. Ford, R.L. Keeney, and C.W. Kirkwood, "Evaluating Methodologies: A Procedure and Application to Nuclear Power Plant Siting Methodologies," *Management Science,* Vol. 25, No. 1, January 1979, pp. 1–10.
96. M.W. Merkhofer, *Decision Science and Social Risk Management: A Comparative Evaluation of Cost–Benefit Analysis, Decision Analysis, and other Formal Decision-Aiding Approaches,* Dordrecht, Netherlands: D. Reidel Publishing, 1985.

8

Measuring Risk Attitudes in Risk Analysis

James S. Dyer and Rakesh K. Sarin

INTRODUCTION

Approximately 50,000 people die every year in automobile accidents, but no life has yet been lost in the United States due to a nuclear accident. Despite these facts, many people show little concern for automobile safety issues, but oppose nuclear power because they believe it is unsafe. It is clear that an individual's attitudes toward the risks associated with different technologies will vary significantly from case to case. An understanding of the factors that influence these attitudes could be helpful to public policy makers, especially those who are managing the introduction of new technologies.

Many factors contribute to form the attitudes of individuals toward the risks to human life and health associated with new technologies. Among these are the perceived risks and benefits of the technology, the perceived equity associated with the distribution of these risks and benefits, and even secondary issues such as the perceived relationship between nuclear power and nuclear weapons. Before we can begin to understand the influences of these factors, we must clarify the concept of a risk attitude.

In this chapter, we focus on the concept of an individual's attitude toward risk, or his risk attitude. We provide a definition of a risk attitude that can be measured, and discuss some potential uses of this measure in risk analysis. Loosely speaking, this proposed measure separates an individual's feelings or strength of preference for outcomes from his attitude toward the probabilistic process that determines which outcome actually occurs. We will argue that this separation can significantly enhance our understanding of how risk attitudes are formed and how they might be influenced.

As an illustration, suppose we consider two technological options, A and B, which have the same benefits and costs so that they are considered equivalent on every dimension except risk. Option A is estimated to have a 0.0001 annual chance of causing a catastrophic accident that will kill 1000 persons, while option B has a 0.1 annual chance of killing 1 person. Assuming that one of these options must be selected by society, which one should

James S. Dyer • Management Department, The University of Texas, Austin, Texas 78712. *Rakesh K. Sarin* • Graduate School of Management, The University of California—Los Angeles, Los Angeles, California 90024.

it be? Even though the expected number of annual deaths is the same for each option (0.1), the society may select one over the other because of the risk attitudes of its individual members. Even though the possibility of an accident associated with option A is very small, the society may wish to avoid this possibility of a "catastrophe," and therefore prefer option B. In fact, option B might be the preferred choice even if the expected number of deaths associated with it were significantly larger.

A preference for avoiding catastrophes has been noted in several real world situations. For example, the Construction Industry Research and Information Association (CIRIA) of the United Kingdom provides historical data demonstrating that society has responded to the threat of large consequence failures in construction by spending disproportionate amounts to avoid them (CIRIA, 1977).

This type of behavior complicates the problem of determining whether the risks associated with a new technology will be acceptable to society, because the expected number of deaths is not a reliable basis for comparison. Several suggestions have appeared in the literature to deal with this problem. Farmer (1967) proposed a risk acceptance limit line to judge the acceptability of the risk of a nuclear power plant. The Farmer limit line is shown in Figure 1. The acceptable frequency of the occurrence of an accident falls off with an increasing rate as the consequences increase so that the expected contribution to risk (defined as frequency $\times$ consequence) is less for very large accidents than for smaller ones (a negative slope of -1.5 on a log-log plot.) Figure 2 shows a similar frequency/consequence curve proposed by Kinchin (1978) to determine limits on the aggregate social risks of immediate and delayed deaths due to nuclear accidents.

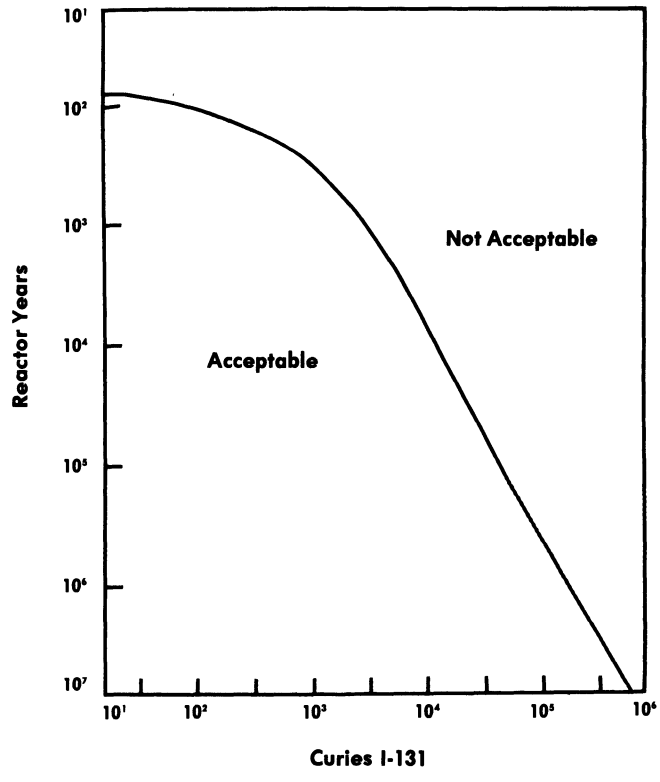

Figure 1. Farmer release frequency limit line (Farmer, 1967).

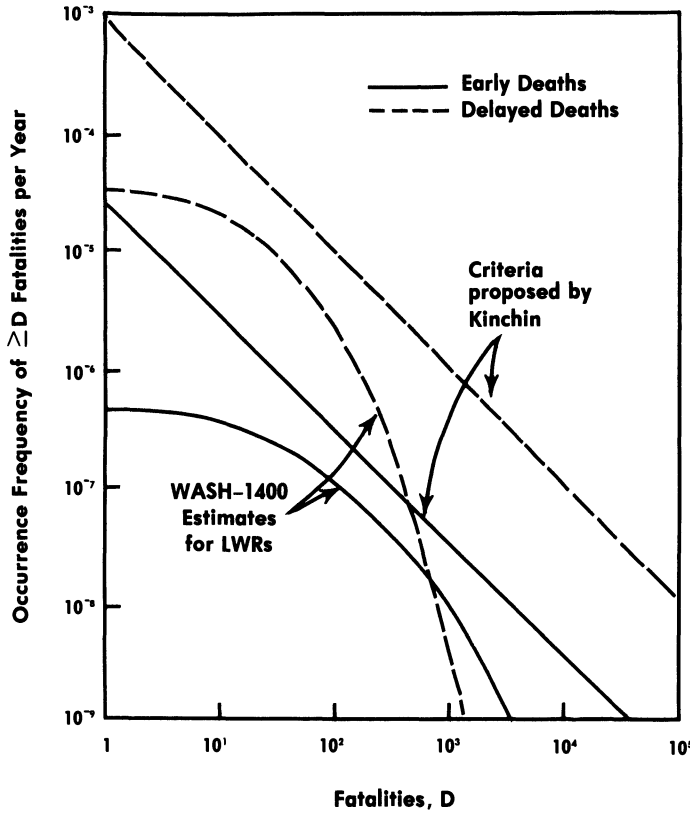

Figure 2. Criteria proposed by Kinchin (1978).

Assumptions about the risk attitudes of society and of the individuals in society are implicit in these risk acceptance curves. If the consequences from a technology are estimated to lie above a risk acceptance curve, then the technology is presumed to be unacceptable to society. This approach to determining the acceptable risk for a society has been criticized by Fischhoff et al. (1980). They argue that acceptable risk problems are really decision problems requiring a choice among alternatives. This choice depends on the alternatives, the values, and the beliefs that are considered. As a result, there is no single all-purpose number or curve that expresses the "acceptable risk" for a society.

We agree with this viewpoint, and suggest in the evaluation of new technologies that full facts should be developed regarding the risks, benefits, costs, and equity issues. A process should then be designed to ensure that these facts are considered, and that the final decisions are consistent with the preferences and the risk attitudes of the individuals in the society. In this chapter we focus our attention on the issue of the risk attitude, and discuss the insights that this concept can provide for the field of risk analysis.

PREVIOUS RESEARCH

The concept of a risk attitude was first rigorously interpreted and quantified by Arrow (1971) and Pratt (1964). These authors compared an individual's von Neumann and Morgenstern (1947) utility function to actuarial behavior to derive the measure of a risk attitude.

Simply stated, they define an individual as risk averse if he prefers the expected consequences of a gamble to the gamble itself; he is risk-prone if he prefers the gamble to the expected consequences; and he is risk neutral if he is indifferent between the two. If we denote an individual's von Neumann-Morgenstern utility function as u, then the Arrow-Pratt measure of a risk attitude for choices involving a consequence x (e.g., lives lost) is defined as

$$r(x) = -u''(x)/u'(x)$$

where u' is the first derivative and u'' is the second derivative of the utility function.

If an individual's preferences are monotonically increasing in x, then $r(x) > 0$ for the risk-averse individual, $r(x) < 0$ for the risk-prone individual, and $r(x) = 0$ for the risk-neutral individual. If the individual's preferences are monotonically decreasing in x, as is often the case in risk analysis, then these inequalities will be reversed. Since the traditional theory is presented based on the assumption of increasing preferences, we will adopt that convention here to avoid confusion.

One criticism of the use of the Arrow-Pratt theory as a measure of a risk attitude is that it simply compares preferences for lotteries to their actuarial values (or expected values) without consideration of the strength of preference that the individual feels for the consequences. Thus, this measure confounds his risk attitude with his strength of preference so that the actual effects of risk on his choices cannot be identified. This subtle point can best be illustrated with a simple example.

Suppose a policy maker is faced with a choice between two standards for a pollutant such as carbon monoxide. He can recommend standard A, which is estimated to cause a 20% decrease in the time to the onset of angina pain for angina patients. In other words, if an individual typically began to feel angina pain after 10 minutes of exercise prior to the adoption of this standard, then he would expect to feel the pain after only 8 minutes of exercise after its adoption. Notice that we are assuming that the situation is deteriorating, so that even with this new standard the pollution is worse. As an alternative, he could select standard B, whose impacts are much less certain. It is estimated that it will lead to a 10% decrease in the time to the onset of angina pain with a 0.5 probability, and a 30% decrease with a 0.5 probability. The 10% decrease would be a better result than the one associated with standard A, but the 30% decrease would be worse.

Suppose the decision maker prefers A to B. Then he would be classified as a risk-averse individual according to the classical Arrow–Pratt definition of a risk attitude. Loosely speaking, he would prefer to accept the 20% decrease for sure than to take the 0.5 chance of a 30% decrease even though the expected value of the outcomes associated with standard B is 20%; that is, the actuarial values of the two standards are identical.

Now suppose we probe the preferences of this policy maker more deeply. Suppose we find that he considers a decrease in the time to the onset of angina pain from 10% to 20% to be much less serious than the decrease from 20% to 30%. He may feel, for example, that the level of the pollutant that would cause this 30% decrease in the time to the onset of angina pain would have other serious health impacts as well. Then his preference for standard A can be explained by his concern about these health effects that are felt to be correlated with the larger decreases in the time to the onset of angina pain. The introduction of the risk in standard B in the form of the probabilities may have had no effect on his preference for this option. In fact, it may be that relative to the strength of preference that he feels for these outcomes, he is actually risk-neutral.

If the policy maker considers the negative health impacts from a decrease in the time to the onset of angina pain from 10 to 25% to be just as serious as the negative impacts of a decrease from 25 to 30% then his strength of preference is not a linear function of the

percentage decrease. Suppose he would be indifferent between standard B and a new option offering a sure 25% decrease in time. This choice can be explained as a result of the strength of preference that he feels for these outcomes and is not influenced by the probabilities, so it does seem appropriate to describe his behavior as being neutral to the introduction of risk.

In this example, we note that a more descriptive conclusion regarding the risk attitude of an individual is provided if his von Neumann–Morgenstern utility function is compared to his underlying strength of preference for the consequences rather than to the numerical levels of these consequences as in the Arrow–Pratt measure. This example should also have clarified that a measure of a risk attitude refers to the effects of the introduction of uncertainty into the problem in the form of a probability distribution rather than to a definition of risk in terms of the life and health impacts of the outcomes. We now show how a new measure of a risk attitude can be developed to overcome this problem of confounding the risk attitude with strength of preference.

RELATIVE RISK ATTITUDE

The concept of a relative risk attitude provides a more intuitively descriptive measure of the impacts of the introduction of risk in the form of a probability distribution on an individual's preferences. We introduce a new preference function $v(x)$, which we call a measurable value function [see Dyer and Sarin (1982)]. The measurable value function measures an individual's strength of preference for alternatives in the absence of probabilistic risk. This function can be assessed using difference questions. To illustrate with our example, since the policy maker considers the health impacts associated with the decrease in the time to the onset of angina pain from 10 to 25% to be equal to the decrease from 25 to 30% then we know that

$$v(10) - v(25) = v(25) - v(30)$$

The function $v(x)$ can also be assessed through direct rating questions. Throughout the remainder of this discussion, we will assume that both the von Neumann–Morgenstern utility function $u(x)$ and the measurable value function $v(x)$ are monotonically increasing in x, and that they are continuously twice differentiable.

We begin by defining the coefficient of value satiation for the measurable value function, $m(x) = -v''(x)/v'(x)$. This definition is analogous to the Arrow–Pratt measure of risk aversion. Loosely speaking, $m(x)$ is a local measure of the strength of preference of an individual at a level of a criterion x. It seems natural to say that $m(x) = 0$ indicates constant marginal value at x, $m(x) > 0$ indicates decreasing marginal value at x, and $m(x) < 0$ indicates increasing marginal value at x. Alternatively, we interpret these three conditions as an indication that the preference differences associated with additional units of the criterion at x are constant, decreasing, and increasing, respectively.

Now, if $v(x) = u(x)$ for all x, then the introduction of risk in the form of a probability distribution over the outcomes has no effect on an individual's preferences, so we say that he is relatively risk-neutral. In the example regarding standards for carbon monoxide, if we arbitrarily set $v(10) = 1.0$ and $v(30) = 0.0$, then $v(25) = 0.5$ since $v(10) - v(25) = v(25) - v(30)$. Similarly, if we set $u(10) = 1.0$ and $u(30) = 0.0$, then $u(25) = 0.5$ as inferred by the policy maker's indifference between a sure decrease in the time to angina pain of 25% and standard B. This was our reason for arguing that this policy maker was actually neutral to the introduction of risk in the form of the probabilities in standard B. More specifically, we now would say that he is relatively risk-neutral.

When $v(x) = u(x)$ for all x, then $m(x) = r(x)$ over this same interval. When $v(x) \geq u(x)$ we can use the relationship between m and r to define a local measure of relative risk aversion. At $x \in X$, an individual is relatively risk-averse if $m(x) < r(x)$, relatively risk-prone if $m(x) > r(x)$, and relatively risk-neutral if $m(x) = r(x)$.

Notice that if $r(x) > m(x)$ for all x, then both u and v are concave, but u is relatively "more concave" than v. An easier way to modify the Arrow–Pratt measure to isolate the effects of strength of preference from the effects of risk is to introduce the utility function $u_v(v(x)) = u(x)$ defined on the value function v. Although it is theoretically possible to assess u directly on v, it seems more appropriate to assume that it would be obtained from its equality relationship with $u(x)$. We can now define

$$r_v(v) = -u_v''(v(x))/u'((v)(x))$$

and obtain the following result: Theorem [Dyer and Sarin (1982)]. At $x \in X$, an individual is relatively risk-averse if and only if $r_v(v) > 0$, relatively risk-prone if and only if $r_v(v) < 0$, and relatively risk-neutral if and only if $r_v(v) = 0$.

An intuitive interpretation of this result is that if $v(x)$ is concave as in our carbon monoxide example, then $u(x)$ will be even more concave if an individual is relatively risk-averse. When this occurs, the utility function $u_v(v)$ defined on $v(x)$ will also be concave. Some examples of relative risk attitudes are shown in Figure 3.

IMPLICATIONS

The concept of a relative risk attitude has several important implications for the theory and practice of risk analysis. This notion addresses a fundamental question in this field: How do "risks" affect preferences? We first discuss how the notion of a relative risk attitude may help to increase our understanding of how the preferences of individuals are affected by the introduction of probabilistic risks into a decision. We then describe some extensions of this basic concept that may have even more significant effects on both the theory and practice of risk analysis.

Risk Attitudes and Risky Technologies

Society makes many implicit trade-offs between risks and benefits of alternative technologies that provide us with necessary goods and services. Requiring a utility company to install scrubbers for coal power plants increases the cost of electricity but reduces the likelihood of adverse health effects to the people living or working in the vicinity of the plant. The reactions of the public toward policies such as the building or siting of a nuclear power plant, the introduction of a new chemical or drug, the transportation of hazardous wastes, and so on, depend on many factors. These factors reflect the information that the public has available regarding the perceived risks and benefits of the proposed policies and their attitudes toward the risks involved.

The classic theory of risky decision making among alternatives involving outcomes that are known only probabilistically is based on the expected utility model of von Neumann and Morgenstern. This approach separates the problem of risky choice into two independent tasks: the assessment of beliefs about the future states of nature in terms of subjective probabilities, and the assessment of tastes or preferences in the form of a utility function u. The axiomatic basis for this development is compelling, but the recent literature is filled with articles attacking its viability on both theoretical and empirical grounds.

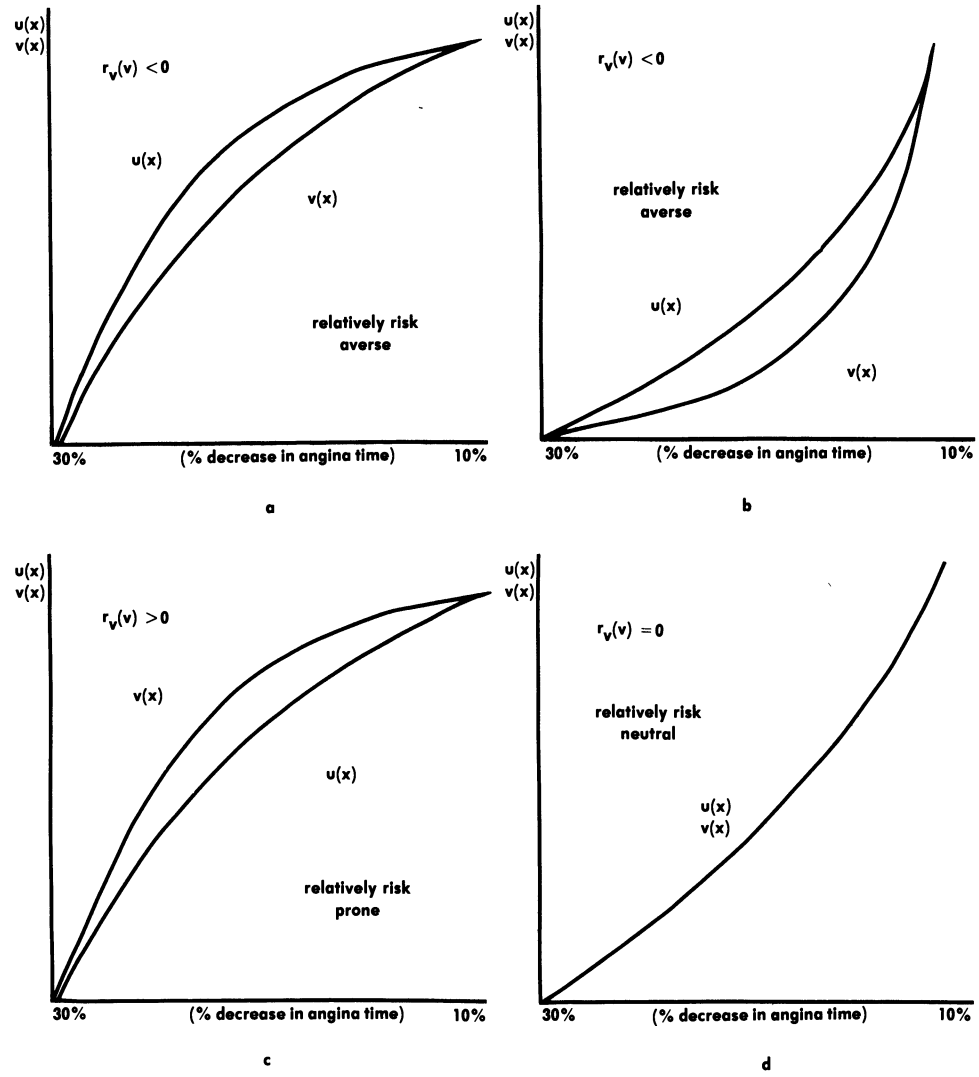

Figure 3. Examples of relative risk attitudes.

We now recognize that the problem of risky decision making is much more subtle and complex than previously thought. Several authors, including Arrow (1963), Baumol (1958), Ellsberg (1954), Fishburn (1970, 1976), and Luce and Raiffa (1957) have argued that, in general, a risky utility function does not measure strength of preference among consequences; that is, $u \neq v$. This observation was the inspiration for our development of the concept of a relative risk attitude. If $u \neq v$, we reasoned, then the difference between them must be attributed to the individual's reaction to the explicit introduction of risk into the preference assessment procedure. Thus, the second task in the classical approach to risky decision making, the assessment of preferences, may not be independent of the perception of the individual of the probabilistic risks inherent in the problem.

The concept of a relative risk attitude can help to isolate an individual's perception of the net benefits associated with a new technology from his attitude toward the probabilistic risks associated with it. It could help to clarify, for example, whether the differences in the opinions of "pronuke" and "antinuke" groups are due to the perceived values of the net

benefits associated with nuclear power, or whether they can be explained by differences in the relative risk attitudes of individuals in the two groups. It would be interesting to investigate the following hypothesis: An individual's relative risk attitude is correlated with his willingness to accept technological risks.

We are currently pursuing research on this issue. In a preliminary study, Anselmo (1982) investigated the risk attitudes of individuals and their attitudes toward the South Texas Nuclear Project. He divided his subjects into "pronuke" and "antinuke" groups according to their votes on the recent referendum in Austin, Texas on the project (the majority in Austin voted to sell the city's interest in the project). He found that the "antinuke" subjects were much more risk-averse using the traditional Arrow–Pratt measure for utility functions defined on fatalities. We would like to replicate this study with a larger sample to determine whether they were also more relatively risk-averse, or whether the explanation for these differences in the utility functions is in their strength of preference for the outcomes.

We do suspect that an individual's relative risk attitude will have a significant effect on his preferences regarding techological risks. Under conditions of certainty, a subject will often respond affirmatively to the proposition that each additional human life saved (or lost) has equal value. This would imply that the measureable value function defined over lives would be linear. However, von Neumann–Morgenstern utility functions assessed over the attribute "lives saved" are often highly nonlinear (see Keeney, 1980, for a discussion). Therefore, $u \neq v$ and the difference can be attributed to the introduction of probabilistic risk.

This argument can help to explain why the public seems willing to accept the risks of automobile accidents but not to accept the risks of nuclear power (or other new technologies). The outcome associated with automobile accidents is essentially known with certainty; we know that approximately 50,000 people will die this year. Thus, this outcome can be evaluated with a measurable value function v. However, the outcome from a new technology is not well known since there are no historical data to provide its estimate. The outcomes are only known probabilistically, and their estimation may be made even more difficult because of disagreements among the "experts." Thus, these outcomes will be evaluated by an individual in terms of his von Neumann–Moorgenstern utility function u, and because $u \neq v$, his decision may appear to be inconsistent with the preferences revealed by his decisions regarding well-established technologies such as the automobile. If he is relatively risk-averse, then this behavior will tend to penalize new technologies in comparison with established ones.

Effects of Perceived Risks on Preferences

Recent research efforts in the field of risk analysis have begun to clarify the public perceptions of the risks associated with new technologies and with other sources of risks to health and human lives. Subjects have been asked to rank these sources of risk, and have responded, for example, that nuclear power is a more "risky" technology than automobiles. This research has also been successful in identifying some of the underlying factors that explain these risk perceptions (e.g., see Slovic et al., 1980). In a related line of work, researchers have investigated the perceived riskiness of simple gambles defined by probability distributions over the outcomes. This latter research has led to the development of several models which can predict the ordering of these simple gambles on the basis of their perceived riskiness.

The concept of relative risk aversion can be used as a guide to further research in this emerging area of interest that attempts to integrate theories of preferences with theories of

perceived risk. In our previous discussion of relative risk aversion, we argued that an individual's preferences under conditions of certainty (represented by the measurable value function v) may not be identical to his preferences when probabilities are associated with the outcomes (represented by the von Neumann–Morgenstern utility function u). Implicitly, however, we assumed that u would be unchanged as a measure of this preferences for all probabilistic alternatives. We can now entertain the possibility that u itself is a function of the perceived riskiness of an alternative.

For simplicity, let us refer to alternatives involving probabilistic outcomes as lotteries. For example, we can view standard B in the carbon monoxide illustration as a lottery over levels of decrease in the time to angina pain. Further, suppose we have a measure of risk ρ that can be used to order lotteries on the basis of their perceived level of riskiness. What kinds of properties might this measure of risk have? As an example, if two lotteries have the same expected value, then the one with the larger variance would be ranked as more risky by ρ; if two lotteries have the same variance, then the one with the higher (or better) expected value would typically be less risky (for specific examples of alternative forms for ρ, see Luce, 1981; Fishburn, 1982).

If the preferences of an individual for a lottery are influenced by both the riskiness of the lottery, measured by ρ, and the strength of preference that he feels for the outcomes, measured by v, then we can write his utility function u as

$$u(x) = f(v(x), \rho)$$

The issues to be resolved include the actual form of f, which determines how v and ρ are to be combined, and the appropriate choice of ρ. The concept of relative risk aversion provides the basis for these extensions.

This development has the potential to explain many of the paradoxes of traditional utility theory that have been revealed by empirical tests. Consider, as an example, the paradox commonly known as the violation of the substitution principle in the context of a public risk decision. Suppose an individual is asked to choose between lotteries L1 and L2:

L1: 3000 people die with certainty.

L2: 4000 people die with a 0.8 probability, 0 people die with a 0.2 probability.

An individual may prefer L2 to L1 since it offers a 20% chance to avoid any fatalities. Now suppose he must choose between L3 and L4:

L3: 3000 people die with a 0.05 probability, 0 people die with a 0.95 probability.

L4: 4000 people die with a 0.04 probability, 0 people die with a 0.96 probability.

This time he may choose L3 over L4 because the probabilities of a catastrophe are almost the same but 1000 fewer people would die. However, it can easily be shown that the simultaneous choices of L2 and L3 are inconsistent with traditional von Neumann–Morgenstern utility theory. When we adopt the point of view that u is a function of both v and ρ, then by assuming a simple form for f, the combination rule for v and ρ, and by using a simple form for ρ such as the mean–variance measure of risk proposed by Pollatsek and Tversky (1970), then the simultaneous choices of L2 and L3 are consistent with this extended theory of risky choice.

Once again, this extension of the concept of the utility function u to include a measure of the riskiness of the lottery as an explicit criterion may offer several interesting insights to the field of risk analysis. For example, new technologies are generally considered more "risky" because their outcomes cannot be predicted based on historical data, and because experts do not always agree in their predictions. Even if a new technology has a smaller expected number of lives lost, the variance associated with predictions of its outcomes will typically be much larger than the variance associated with the outcomes of an existing

technology. If an individual uses the much more "risk-averse" utility function u to evaluate alternatives that are perceived as more risky (in terms of the measure ρ), then this would help to explain public reluctance to accept new technologies even when individuals are convinced that the expected number of annual deaths that would result from the technology is low. This point is consistant with the finding of Slovic et al. (1980) that individuals estimated the expected number of deaths that would result from accidents related to nuclear power to be low, but still rated that technology as very risky.

Multiple Experts

In the evaluation of many policies regarding public risk issues, many factors need to be considered simultaneously. For example, the evaluation of a policy to upgrade the structural integrity of older buildings to make them safer in an earthquake must consider the costs of the upgrading, the potential injuries and fatalities among the occupants of the buildings, the displacement of occupants, and other socioeconomic impacts. In a traditional risk analysis of an issue such as this one, the approach is based on the assessment of conditional von Neumann–Morgenstern utility functions from different experts and from the parties affected by the decisions. In this example, utility functions might be assessed from economists and social scientists regarding the socioeconomic impacts, from safety experts and policy makers regarding the levels of injury and of fatalities, and from representatives of the occupants of the buildings regarding changes in rent charges and levels of safety. The trade-offs among these criteria are then resolved by a group of experts or by another individual representing the policy makers. This allows these utility functions assessed from different individuals to be combined into a single multiattribute utility function (e.g., see Keeney and Raiffa, 1976).

The utility functions of the different experts are typically assessed using lottery questions that explicitly introduce risk in the form of probability distributions over the outcomes. As a result, these functions incorporate the relative risk attitudes of the experts as well as their judgments regarding the values of the outcomes. It may be more desirable to obtain only strength of preference information from the experts: that is, assess v rather than u from each expert. These measurable value functions can then be transformed coherently into utility functions using a single relative risk attitude obtained from the consensus of a group of experts or from the policy maker. (For a more extensive discussion of this point, see Dyer and Sarin, 1979).

SUMMARY

The concept of a relative risk attitude may seem rather elusive at first, but it has significant implications for the field of risk analysis. The idea is based on the observation that an individual's utility function appropriate for the evaluation of lotteries may not be identical to his measurable value function appropriate for the evaluation of strength of preference. The key insight in this development is to attribute the difference between these two functions, if it exists, to the introduction of risk in the form of probabilistic outcomes in the assessment procedures for the utility function.

This development is especially relevant for the field of risk analysis because problems in this area often involve catastrophic consequences that occur with extremely small probabilities. Several of our students have questioned the practical value of our research on a relative risk attitude by noting that the difference between u and v may not be large (intuitively

speaking), so there would be no significant differences in the rankings of lotteries generated by these subtle distinctions. More insightful students have noted, however, that this observation is likely to be true only for problems with relatively small ranges of outcome consequences and with relatively large probabilities of occurrence (say, 0.01 or larger), but the importance of the relative risk attitude concept dramatically increases when the probabilities become very small and are associated with high return or high loss outcomes.

Further, the concept of a relative risk attitude may be useful for an increased understanding of public attitudes toward risky technologies, for integrating theories of perceived risk with theories of preference, and in evaluating public risk issues using multiple experts. Research efforts currently under way should help to demonstrate these possibilities.

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REFERENCES

Anselmo, P., 1982. "The South Texas Nuclear Project: A Study of Risk Attitudes," MBA Professional Report, The University of Texas, Austin.

Arrow, K. J., 1963. *Social Choice and Individual Values,* 2nd ed., John Wiley and Sons, New York.

Arrow, K. J., 1971. *Essays in the Theory of Risk Bearing,* Markham, Chicago.

Baumol, W. J., 1958. "The Cardinal Utility Which Is Ordinal." *Economic Journal, 68,* 665–672.

CIRIA, 1977. *Rationalization of Safety and Serviceability Factor in Structural Codes,* London, Report 93.

Dyer, J. S. and Sarin, R. K., 1979. "Measurable Multiattribute Value Functions," *Operations Research, 27,* 4.

Dyer, J. S. and Sarin, R. K., 1982. "Relative Risk Aversion," *Management Science, 28,* 8.

Ellsberg, D., 1954. "Classic and Current Notions of "Measurable Utility,'" *Economic Journal, 64,* 528–556.

Farmer, F. R., 1967. "Siting Criteria—A New Approach," *Containment and Siting of Nuclear Power Plants,* Vienna, International Atomic Energy Agency, pp. 303–318.

Fischhoff, B., Lichtenstein, S., Slovic, P., Keeney, R., and Derby, S., 1980. *Approaches to Acceptable Risk: A Critical Guide,* Oak Ridge National Laboratory, Oak Ridge, Tenn.

Fishburn, P. C., 1970. *Utility Theory for Decision Making,* John Wiley and Sons, New York.

Fishburn, P. C., 1976. "Cardinal Utility: An Interpretive Essay," *Rivista Internazionale di Scienze Economiche e Commerciali, 13.*

Fishburn, P. C., 1982. "Foundations of Risk Management, I: Risk as Possible Loss," Bell Telephone Laboratories, Inc., Murray Hill, N.J.

Keeney, R. L., 1980. "Equity and Public Risk," *Operations Research, 18,* 527–534.

Keeney, R. L. and Raiffa, H., 1976, *Decisions with Multiple Objectives,* Wiley, New York.

Kinchin, G. H., 1978. "Assessments of Hazards in Engineering Work," *Proc. Instn. Civ. Engrs., 64,* 432–438.

Luce, R. D., 1981. "Several Possible Measures of Risk," *Theory and Decision, 12,* 217–228; Correction, *13,* 381.

Luce, R. D. and Raiffa, H., 1957. *Games and Decisions,* Wiley, New York.

Pollatsek, A. and A. Tversky, 1970. "A Theory of Risk," *Journal of Mathematical Psychology, 7.*

Pratt, J.W., 1964. "Risk Aversion in the Small and in the Large," *Econometrica, 32,* 122–136.

Slovic, P., Fischhoff, B., and Lichtenstein, S., 1980. "Perceived Risk," in R. C. Schwing and W. A. Albers, Jr. (Eds.), *Societal Risk Assessment: How Safe is Safe Enough?* Plenum Press, New York.

von Neumann, J. and Morgenstern, O., 1947. *Theory of Games and Economic Behavior,* Princeton University Press, Princeton, N.J.

9

The Analysis of Risks of Fatalities

Ralph L. Keeney

INTRODUCTION

Many important decision problems involve risks to the health and safety of members of the public. These risks include possible fatalities, sicknesses, and injuries, as well as psychological effects. For appraising alternatives in such contexts, decision makers need to address public risks in addition to other economic, social, and environmental consequences.

In some cases, it may be useful to analyze explicitly the alternatives in terms of their risks and other implications. To do this, one needs to quantify and evaluate the possible risks of each alternative. The focus of this chapter is on the evaluation of such risks. Specifically, it concentrates on the evaluation of risks that could end the life of individuals.

This chapter discusses why analysis of the evaluation of public risks is important and what the uses of such analysis should be; presents a short survey of previous work on the evaluation of public fatalities and outlines approaches that have been used for making such evaluations; focuses on recent results from analyses using von Neumann–Morgenstern utility theory; investigates different value assumptions and addresses implications of those assumptions; and outlines related important issues for further research.

The Importance of the Evaluation of Fatality Risks

Evaluating fatality risks is important for two reasons: (1) the problem is ubiquitous, and (2) the potential saving of even one life is significant. Many activities engaged in by individuals entail the possibility of fatality. Such activities include recreation such as skiing and swimming, transportation via any mode, and working in a mine, a factory, or the home. Also, many governmental or institutional decisions significantly affect public risks (for example, the licensing of drugs, use of existing technologies or the development of future ones, medical treatment and research, highway safety and maintenance, military programs, and building and operating power plants and other large facilities). Almost every activity

Ralph L. Keeney • Systems Science Department, University of Southern California, Los Angeles, California 90089.

in which members of society participate, by choice or because of external circumstances, results in some chance that the individual could lose his or her life. Such a chance is defined as a fatality risk in this paper.

To elaborate on one of these examples, consider the addition of a power plant to an electric power system. If one builds hydroelectric generating plants, there may be fatalities due to dam failures and floods; if one builds nuclear facilities, there may be fatalities due to plant accidents; if one builds coal-fired power plants, there may be fatalities due to mining and transportation of coal, as well as from air pollution; and if one avoids the need for a new power plant through conservation measures, there may be blackouts resulting in fatalities because of inoperable equipment (e.g., medical or heating equipment) or higher indoor air pollution resulting from better insulated buildings. Quite simply, alternatives free from the risk of potential fatalities do not exist.

The second reason why the evaluation of fatality risks is important needs no elaboration. Life is important.

It does not necessarily follow that analysis of a problem is important simply because the problem itself is important. However, I believe analysis of the evaluation of fatality risks is important for several reasons. First, problems are often characterized by complicated structures, interrelationships with political issues as well as ethical concerns, and significant uncertainties. Furthermore, because the evaluation of potential fatalities is by its very nature value-laden, different individuals and organizations may have divergent views about the appropriate way to evaluate fatalities. Thus, an analysis should help make explicit what value judgments are used, where and how they are used, and what the implications of this use are. It should clarify how uncertainty and other complexities are addressed in the evaluation process. For many fatality risk problems, it is simply too difficult to expect responsible appraisal of the alternatives without analysis. The problems are too tough for unaided intuition.

The fundamental purpose of any analysis of public risks is to provide insights for better decision making. In the long run, one would expect better decision making to result in fewer lives being lost, the quality of life being improved, and a lessening of the economic, social, and environmental degradation of the country. Analysis affects decision making primarily in the short run, but there is the presumption that better-informed decision making in the short run will, in fact, lead to better decisions in the long run.

There are different types of insights provided by analysis involving evaluation of fatality risks. On the one hand, there are problem-specific insights that are likely to result from the analysis of specific alternatives for a particular problem. For example, in analyzing the setting of a particular national ambient air quality standard, one might learn about the relationship between an appropriate standard and the value trade-offs between heart attacks, angina attacks, and economic costs. On the other hand, another type of analysis might be referred to as a "context-free" analysis. Such analysis might, for example, examine the compatibility of different types of basic value judgments for evaluating fatality risks. Insights from context-free analyses offer potential guidelines for the analyses of specific problems. This chapter focuses on the context-free analysis of the evaluation of fatality risks.

PREVIOUS WORK

In the recent past, numerous scholars, including Starr (1969), Mishan (1971), Zeckhauser (1975), and Lowrance (1976), have recognized the need and potential contributions of explicitly and systematically examining the issue of fatality risks. Several approaches

have been suggested in these papers and in others for evaluating potential fatalities (see, for example, Acton, 1973; Jones-Lee, 1974; Linnerooth, 1975; Howard, 1979; Keeney, 1980a). Zeckhauser (1975), Linnerooth (1979), and Jones-Lee (1982) provide surveys of much of this literature. Raiffa, Schwartz, and Weinstein (1978) present an excellent detailed summary of the numerous crucial value issues involved in evaluating public risks.

One thing is clear; there is no consensus on an appropriate approach for evaluating potential fatalities. A major reason for the lack of consensus is the complexity of the problem. Perhaps even more significant, many approaches that seem at first to be addressing the same problem, in fact, focus upon different problems. These problems might be differentiated in terms of the following dimensions: (1) prescriptive versus descriptive orientation; (2) evaluation before versus after fatalities occur; (3) one individual at risk versus many individuals simultaneously at risk; (4) whether contemplated actions affect the risk; (5) who is doing the evaluation; and (6) whose funds might be utilized to reduce risks. Regardless of the specific problem being addressed, value judgments must be made. The choice is whether to make them implicitly or explicitly.

In most, if not all, important decision problems involving potential fatalities, a value trade-off must be made between costs and potential fatalities in terms of a dollar amount. Hence, the term *value of life* is often given to this literature. Most of the approaches, including those based on the human capital of individuals, life insurance decisions, job choice and wage differentials, court awards, and governmental safety decisions, involve inferences about the "value of life" on the basis of actions taken. Such approaches are sometimes referred to as revealed preference approaches. The willingness-to-pay and utility analysis approaches address the value trade-off between costs and fatalities explicitly by requiring expressed preferences. Another important distinction between approaches is whether the trade-off between costs and individual fatalities is made first and then aggregated over multiple individuals, or whether the risk of multiple fatalities is first evaluated directly, then later combined with costs. In the remainder of this section, some of the major approaches to the value-of-life problem are briefly outlined.

Human Capital

With the human capital approach, one attempts to determine the net economic contribution of an individual to society over the remainder of his or her projected lifetime. That amount is then defined as the value of the individual. Numerous objections to such an approach have been raised. Perhaps the most important is that the computed value of an individual not earning money through his or her labor is very low and that numerous intangible or secondary effects (e.g., impact on family and friends) are not taken into account by human capital approaches.

Life Insurance

To attempt to infer the value of an individual from his or her decisions about life insurance has similar problems to those of the human capital approach. Any inferences must, of course, make assumptions about the individual's risk attitudes, available alternatives, and perceived risks. Individuals who are otherwise identical, except for their insurance, can thus be evaluated differently. Moreover, decisions about whether or not to insure and how much insurance to purchase are not necessarily made with the degree of logic that even the individual decision maker would ideally prefer.

Job Choice

To infer the value of life based on wage differentials and job choice, one utilizes data concerning the likelihood of fatality in various professions and the average salary paid to individuals in those professions. Thaler and Rosen (1976) found that on the average workers were paid approximately $200 per year more for a differential of 0.001 in the annual risk of fatality. Although such numbers can be used in the appraisal of different alternatives involving risks to individuals, it may not be justifiable to assume that individuals selecting jobs actually know the differential risks, or that alternative job choices are available to workers in various professions.

Court Awards

A slightly different approach for evaluating the value of a life involves the use of court awards. Inference in this case is different from the life insurance and job choice approaches in that the decisions in court awards are made by those other than individuals at risk. Also, court awards are made after individuals have become fatalities. Trying to determine the "appropriate compensation for a fatality" may be significantly different from trying to determine an appropriate value of life for use in analyses focusing on the prevention of fatalities (i.e., reducing risk of fatality).

Governmental Safety Decisions

Another approach for estimating implicitly the value of life relies on the use of governmental safety decisions made with the stated purpose of saving lives. Examples include highway safety decisions and numerous regulatory decisions. The basic line of reasoning is that if a decision is made which costs $100 million to implement, and if it is estimated that implementation would save 50 lives, then the value of a single life is $2 million. Use of such numbers in further analysis requires the assumption that the initial decision was made in a responsible and logically consistent manner. In this regard, Graham and Vaupel (1981) demonstrated that the value of life implied by a number of governmental decisions ranges from a few thousands of dollars to more than $100 million dollars per fatality avoided.

Willingness to Pay

One relatively common approach for determining explicitly the value of life (see Acton, 1973) involves questioning individuals about their willingness to pay their own money to reduce their risks of becoming a fatality. Individuals are asked how much they would be willing to pay to reduce a particular fatality risk by amount x. If the response is y dollars, this is extrapolated linearly to imply that y/x dollars is an appropriate value for life for the respondent when evaluating small risks. One shortcoming often cited for the usual assessment procedures is that the reasonableness of the derived value of life is not investigated. Experience indicates that it is difficult to respond consistently to questions involving small changes in one's fatality risks. An additional problem is finding an appropriate manner to aggregate individual responses. Such aggregation is necessary for an institutional evaluation of fatality risks for multiple individuals. Because responses about willingness to pay are keyed to the individual at risk (and his or her private funds), extrapolation of information from this approach to decision problems where public funds are utilized requires important additional assumptions.

Utility Analysis

A second explicit approach for evaluating potential fatalities involves the use of utility analysis to address directly the value judgments inherent in evaluating the risks of loss of life. Howard (1979) and Keeney (1980a) both develop utility functions for such evaluations that are consistent with the von Neumann–Morgenstern (1947) assumptions. Howard's approach is to examine the utility function that may be appropriate for an individual, whereas the utility functions utilized by Keeney address the problem from an institutional perspective. This approach will be elaborated in the next section.

CURRENT RESEARCH

The ultimate intent of the research reported here is to assist in identifying appropriate actions given the risks and costs of various alternatives. Thus, the orientation is prescriptive and specifically concerned with analysis of the relative desirability of spending different amounts of funds to reduce (directly or indirectly) fatality risks. This analysis requires an index of costs and an index of risks as arguments. To structure such indices, the process necessarily involves value judgments. I proceed by postulating various reasonable value judgments and then deriving their implications for the resulting indices. Examining the implications of different basic values provides interesting insights about the evaluation of possible fatalities. Rather than using a formal theorem-and-proof format, I will simply state results, and reference details to other works.

Notation

We wish to evaluate fatality risks before any fatalities have occurred and where there will be numerous individuals potentially at risk. Also, initially, our sole interest in fatality risks is because of the resultant fatalities that may occur. Hence, the problem can be characterized by a profile $p = (p_1,p_2, \ldots ,p_n)$ where p_i is the risk to individual I_i and n is the total number of individuals at risk. Specifically, p_i will be the probability that individual I_i will be a fatality in the time period of concern due to the cause of concern. This probability is independent of all the other probabilities in the risk profile. To describe circumstances involving dependent risks to individuals, lotteries over risk profiles may be utilized. For instance, suppose there was a 0.2 chance of an accident occurring which would result in the risk profile (0.4, 0.4) for a two-person society. If no accident occurred, the risk profile from "normal operations" would be (0.01, 0.01). This circumstance would be represented as a lottery yielding a 0.2 chance at (0.4, 0.4) and a 0.8 chance at (0.01, 0.01). An appropriate manner to measure the desirability of lotteries is a utility function assessed in accordance with assumptions postulated alternatively by von Neumann and Morgenstern (1947) or Savage (1954).

A risk profile characterizes a situation before the time period in which fatalities could occur. At the end of the period, each individual will either be or not be a fatality due to the cause of concern. Thus, we will define attribute X_i to take on levels x_i equal to 0 or 1 depending on whether I_i was not or was a fatality. Then a fatality profile can be represented by $x = (x_1, x_2, \ldots , x_n)$. At times, it may be appropriate to summarize the information about how many fatalities occur. We define the attribute F to be the number of fatalities and f to be a specific level of F. Then clearly $f = x_1 + x_2 + \ldots + x_n$.

The cost that one might be willing to expend to reduce fatality risks will be denoted

as c. Thus, a consequence characterizing a situation would be the vector $(p;c) = (p_1,p_2, \ldots ,p_n;c)$. A basic problem for evaluating fatality risks is then to determine an appropriate utility function u which assigns the utility $u(p;c)$ to each possible consequence $(p;c)$. Based on the assumptions of utility theory, consequences with higher utilities should be preferred to those with lower utilities, and when uncertainty is involved, situations corresponding to higher expected utilities should be preferred.

The observations in this section are appropriate for any separable utility function $u(p;c) = g[u_R(p),u_C(c)]$, where g is any function, u_R is the utility function for fatality risks, and u_C is the utility function for costs. However, for simplicity, we will assume that an appropriate utility function for risks and costs is an additive one,

$$u(p;c) = u_R(p) + \lambda u_C(c) \tag{1}$$

where λ is a scaling constant to assure that u_R and u_C are consistently scaled. For convenience, we will set the origin of all the utility functions by

$$u(0;0) = u_R(0) = u_C(0) = 0 \tag{2}$$

and establish a scale for each of the utility functions by

$$u(1,0, \ldots ,0;0) = u_R\,(1,0, \ldots ,0) = u_C(1) = -1 \tag{3}$$

where c is evaluated in millions of dollars.

The Utility Function u_R

To determine the utility function u_R, we can consider utility functions over each component p_i and the integration of these utility functions. Concerning the former problem, it may be reasonable to assume that an organization should evaluate an individual's risks as the individual would want to evaluate them. Assuming that the individual wants to minimize his or her risks, such a utility function should be linear in p_i. This linearity condition also follows from a consistency argument which assumes that the relative utility of fatality risk profiles must equal the expected utility of the implied set of fatality profiles (see Keeney, 1980c). If the individual has a different value structure, one would need to use a nonlinear utility function $u_i(p_i)$. Since we concentrate on the evaluation of simultaneous individual risks, we employ the linear case for u_i for simplicity. Similar developments are possible for nonlinear cases. We also make the assumption that risks to each individual should be evaluated identically. Furthermore, it may be appropriate to evaluate risks to any subset of individuals in the same manner regardless of fixed risks to those individuals not in the subset. In technical terms, these assumptions are equivalent to the following:

Basic Model Assumptions. The attributes measured by the individual risks are utility-independent, all subsets of attributes are preferentially independent, and the utility function for each of these single attributes is linear (namely, minus p_i for individual I_i).

As shown in Keeney (1980c), the utility function u_R consistent with the basic model assumptions must either be the additive form

$$u_R(p) = -\sum_{i=1}^{n} p_i \tag{4}$$

or the multiplicative form

$$u_R(p) = -1/k \left[\prod_{i=1}^{n} (1 + kp_i) - 1 \right] \tag{5}$$

where k is a scaling constant. We will now examine further implications on the form of u_R given the basic assumptions above for each of three different objectives: that we want to minimize the expected number of fatalities, that we prefer equitable ex-post distributions of risk, and that we wish to avoid catastrophes. As we will see, these desires are mutually inconsistent.

Minimizing Expected Fatalities. Given specific funds to reduce the risks to individuals, a reasonable guideline might be to minimize the resulting total expected fatalities to save as many lives as possible. Fewer expected fatalities are always preferred to more expected fatalities. The following result directly follows from the fact that the sum of the p_is is equal to the expected number of fatalities with any fatality risk profile.

Result 1: Given the basic model assumptions and the minimum fatality risk assumption, the utility function for fatality risks must be the additive form (4).

Recall that f is the number of fatalities resulting from any particular risk situation. To be consistent with the additive u_R, a utility function u_F for fatalities is

$$u_F(f) = -f. \tag{6}$$

An Equitable Distribution of Risk. We will define consequence $(p_1, \ldots, p_i, \ldots, p_j, \ldots p_n)$, for any i and j, to be a more equitable distribution of risk than $(p_1, \ldots, p_i + \varepsilon, \ldots, p_j - \varepsilon, \ldots p_n)$ if the difference between p_i and p_j is less than the difference between $p_i + \varepsilon$ and $p_j - \varepsilon$. Note that all p_h, $h \neq i, j$ are held fixed in this definition. This definition merely says that if all risks but two are fixed, the better balanced these two are, the more equitable the risk. We will define our risk equity assumption to mean that a more equitable distribution of risk is preferred to a less equitable distribution.

Result 2: Given the basic model assumptions and the risk equity assumption, the utility function for fatality risks must be the multiplicative form (5) where $0 < k < -1$.

As shown in Keeney (1980c), the utility function for fatalities consistent with this preference for risk equity is

$$u_F(f) = -1/k[(1 + k)^f - 1] \tag{7}$$

which is risk-prone for the allowable values of parameter k.

With a risk-prone utility function for fatalities, a lottery with f' expected fatalities would be preferred to f' fatalities for sure. In simple terms, one would gamble in an attempt to save more than the average possible fatalities. Thus, a risk-prone utility function would not always result in evaluating alternatives in the manner to save the most expected fatalities. It follows that to have the original risks more equitably spread among the individuals at risk, one must be willing to allow a few more expected fatalities. Whenever there is a preference for an aspect of risk other than the minimization of fatalities, it may be necessary to give up something in terms of expected fatalities to better achieve the other objective.

Catastrophe Avoidance. A number of papers, such as Ferreira and Slesin (1976) and Slovic, Fischhoff, and Lichtenstein (1977), suggest that a small probability of a cata-

strophic loss of life is worse than a larger probability of a smaller loss of life, given the expected number of fatalities are the same for each case. To be precise, we will define the following.

Catastrophe Avoidance Assumption. A probability π of having f fatalities is preferred to a probability π' of having f' fatalities for any f less than f' given that $\pi f = \pi' f'$. Given this assumption, the following is proven using results in Keeney (1980b, c).

Result 3: Given the basic model assumptions and the catastrophe avoidance assumption, the utility function for fatality risks must be the multiplicative form (5) where $k > 0$.

The corresponding utility function for fatalities is (7) where $k > 0$. As can easily be demonstrated, this utility function is risk-averse, which is consistent with a preference for f' fatalities for sure to any lottery with f' expected fatalities. With this preference to avoid a large loss of life (i.e., a catastrophe), one must be willing to accept more expected fatalities.

Identifiable versus Expected Fatalities

Now we will examine the value trade-off between costs and fatalities. Specifically, suppose we find a consequence $(0, \ldots, 0; c^*)$ indifferent to consequence $(1,0, \ldots, 0;0)$. Then because the first consequence involves no risks and a cost of c^*, and the second consequence involves a risk of 1 to one individual and no costs, one could define c^* to be the "value of life." The life at risk is clearly identifiable; it is individual I_1's life. Such a circumstance is referred to as an identifiable fatality. Hence, it might be more appropriate to refer to c^* as the value of an identifiable life.

Now suppose we determine that $(1/n, \ldots, 1/n;0)$ and $(0, \ldots, 0;c')$ are indifferent, which gives us another possible value of life. To interpret this, recall that with the first consequence there are n individuals at risk. At the time the evaluation must be made, it is clear that each individual has an equal $1/n$ chance of being a fatality, but it is not possible to identify who will be fatalities (in fact, there could be zero, one, or more than one fatality). The expected number of fatalities resulting from the risks is 1, so we could say that 1 expected fatality and no costs is indifferent to 0 expected fatalities and the cost of c'. Thus, c' could be referred to as the value of an expected life. Many people feel that the risk $(1,0, \ldots, 0)$ is worse than $(1/n, 1/n, \ldots, 1/n)$ because the former consequence is so unevenly distributed and at least the risk in the latter case is "somewhat equitable." If this is the case, the value c' should be less than the value c^*.

In essentially all situations involving an evaluation of fatality risks, we would expect to be dealing with only small risks to each individual. These risks should certainly be much less than 10^{-2} for each person and would much more likely be in the range of 10^{-4} and smaller. However, we could certainly have situations where 20% of the individuals had a risk of $5/n$ each and the other 80% had a 0 risk. The expected fatalities corresponding to this risk would also be 1, although the risk in some sense would not be as equitable as the situation where each individual has a $1/n$ risk. In any case, it should be obvious that there is no unique definition for the term *value of life*. Also, use of the term *value of life* can be misinterpreted to imply that the value of two lives is equal to twice the value of one life. This may be the case but it requires additional value judgments.

Combining the cost utility function in (1) with the utility functions for fatality risks in Results 1 through 3 leads to the following interesting result.

Result 4: Given the basic model assumptions and (1), the value of an identifiable life equals the value of an expected life if and only if there is a preference to minimize expected fatalities; the value of an identifiable life is greater than the value of an expected life if and

only if there is a preference for risk equity; and the value of an expected life is greater than the value of an identifiable life if and only if there is a preference for catastrophe avoidance.

Many individuals might feel that more funds should be expended to eliminate an identifiable risk $(1,0, \ldots ,0)$ than an expected risk $(1/n,1/n, \ldots ,1/n)$. It follows that the preference for risk equity and the risk-prone utility function for fatalities are appropriate, given the basic model assumptions.

*Equity of the Process**

Broome (1982) recently invoked an objection of Diamond (1967) to Result 2 concerning risk equity. Specifically, he pointed out that a utility function incorporating an equity concern for risk profiles (p_1,p_2) would assume indifference between a 50–50 lottery yielding either $(p_1 = 1, p_2 = 0)$ or $(p_1 = 0, p_2 = 1)$ and the sure consequence $(p_1 = 0, p_2 = 1)$ for a two-person society. Indeed, the consequences in either situation result in one fatality. However, Broome mentions that a preference for equity must lead one to prefer the lottery to the sure consequence. Such a preference may be reasonable, but it concerns a different type of equity. The preference for the lottery over the sure consequence indicates a preference concerning the equity of the process by which the consequences are distributed, not just a preference concerning the equity of the consequences *per se*.

To illustrate, we will introduce the concept of marginal risk equity using a two-person society with risk profiles $p = (p_1, p_2)$. Consider the following four lotteries: (1) a 0.5 chance at $p = (1, 1)$ and a 0.5 chance at $p = (0, 0)$; (2) $p = (0.5, 0.5)$; (3) a 0.5 chance at $p = (1, 0)$ and a 0.5 chance at $p = (0, 1)$; (4) $p = (0, 1)$.

Using the risk equity assumption, one should prefer Lotteries 1 to 2 and 2 to 3. Broome (1982) suggests that a desire for equity should also lead one to prefer Lottery 3 to 4. However, because the risk equity assumption implies that consequences can be characterized by risk profiles, the models discussed in Results 1 through 4 imply indifference between 3 and 4.

This example suggests that risk profiles (or equivalently the number of fatalities) may not always be an adequate representation of fatality risks. Hence, additional attributes will be needed. This can be addressed by defining a marginal risk profile of marginal risk probabilities $q = (q_1, q_2, \ldots , q_n)$, where q_i represents the marginal probability that individual I_i will be a fatality. Note that q differs from p in that probabilistic independence of the possible fatalities is not assumed.

For Lotteries, 1, 2, and 3, the marginal risk profile is $q = (0.5, 0.5)$, whereas for Lottery 4, the marginal risk profile is $q = (0, 1)$. A desire for equity in terms of marginal risk profiles q would lead one to prefer Lottery 3 to Lottery 4. This notion of marginal risk equity is characterized formally in the following definition. The marginal risk profile $(q_1, \ldots , q_i, \ldots , q_j, \ldots , q_n)$, for any i and j, will be called a more equitable distribution of marginal risk than $(q_1, \ldots , q_i+\varepsilon, \ldots , q_j-\varepsilon, \ldots , q_n)$ if the absolute difference between q_i and q_j is less than the absolute difference between $q_i+\varepsilon$, and $q_j-\varepsilon$.

It is obvious that marginal risk equity captures aspects of equity different from those captured by the (nonmarginal) risk equity. For example, Lottery 3 is perfectly equitable in a marginal sense but highly inequitable in a nonmarginal sense. However, the two types of risk equity are by no means incompatible. Note that Lottery 1 is perfectly equitable with respect to both types of equity, and Lottery 4 is totally inequitable in both senses. In general,

*The material in this section is condensed from Keeney and Winkler (1985). A related development is found in Sarin (1982).

if a situation is not perfectly equitable marginally, then it cannot be perfectly equitable in a nonmarginal sense, although some of the possible risk profiles p may be equitable.

To further clarify the distinction between the two types of equity, note that a risk profile p has a clear relationship to the eventual fatality profiles since it implies a certain lottery over such fatality profiles. As a result, the risk equity in Result 2 can be though of as ex-post risk equity, or consequence equity. In contrast, a marginal risk profile indicates the ex-ante probabilities of death for the individuals of concern, and as such it represents a characteristic of the process generating the risks. Thus, marginal risk equity can be defined to address ex-ante risk equity or process equity. A more equitable distribution of marginal risk is preferred to a less equitable distribution.

Fishburn (1982) recently proved that there is no utility function over marginal risk profiles for evaluating potential fatalities consistent with such an assumption. However, as shown in Sarin (1982), there are value functions $v_Q(q)$ over marginal risk profiles which rank preferences of those profiles. For a given q_i, v_Q must be highest for an equal division of q_i in order to satisfy the marginal risk equity assumption. Furthermore, purely in an equity sense, the marginal risk profiles (0, . . . , 0), (1, . . . , 1), (0.5, . . . , 0.5), and so on, might be considered to have equivalent marginal risk equity because all individuals have the same marginal risk in each of these profiles. Thus, excluding any impact of expected fatalities from v_Q, we might set $v_Q(q) = 0$ for all equal divisions of q regardless of the value of q_i.

Result 5: A value function v_Q consistent with the marginal risk equity assumption is

$$v_Q(q) = -(q_i - \bar{q})^2$$

where $\bar{q} = \Sigma q_i/n$.

This function yields $v_Q(q) = 0$ for Lotteries 1–3 and $v_Q(1) = -1/2$ for Lottery 4 for the two-person society.

Identifiable versus Statistical Fatalities

A general issue related to marginal risk equity has been discussed in the public risk literature for some time. It addresses the distinction between an identifiable and a statistical fatality. Recall that an identifiable fatality can be characterized by the risk profile $p = (1,0, \ldots, 0)$, so the value of an identifiable life c^* can be defined by two indifferent consequences $(1,0, \ldots, 0;0)$ and $(0,0, \ldots, 0; c^*)$. A statistical fatality results from a situation where it is known that exactly one individual will be a fatality, but the identity is not known. In terms of risk profiles, a statistical fatality can be represented by a lottery with a $1/n$ chance of each of the following risk profiles: $(1,0, \ldots,0)$, $(0,1,0, \ldots,0)$, . . . , $(0, \ldots,0,1)$. If the consequence $(0,0, \ldots,0;c^+)$ is indifferent to the lottery over risk profiles and costs with a $1/n$ chance at each of $(1,0, \ldots,0;0)$, $(0,1,0, \ldots,0;0)$, . . . , $(0, \ldots,0,1;0)$, we could define c^+ to be the value of a statistical life.

Descriptively, many individuals feel that the value of an identifiable life should be greater than the value of a statistical life. If so, more funds should be utilized to avoid an identifiable fatality than a statistical fatality. To relate the value of identifiable and statistical fatalities to marginal risk equity, we have the following.

Result 6: If the value of an identifiable life equals the value of a statistical life, the marginal risk equity assumption does not hold; if the value of identifiable fatality is greater than the value of a statistical fatality, the marginal risk equity assumption does hold.

No one has proposed a preference for the reverse of marginal risk equity, meaning for instance $q = (1,0, \ldots,0)$ preferred to $q = (1/n,1/n, \ldots,1/n)$. Such a preference might correspond to a situation where the psychological fear of dying was proportionally greater for smaller marginal risks and the overall objective was to minimize psychological fear. This preference would be consistent with the value of an identifiable life being less than the value of a statistical life.

IMPORTANT ISSUES FOR FUTURE RESEARCH

Numerous problems for future research have been suggested by the research to date concerning the evaluation of fatality risks. One might categorize them into methodological issues, implementation issues, and policy issues.

Methodological Issues

One of the fundamental methodological issues concerning fatality risks is to clearly articulate a set of appropriate indices for measuring such risks. As carefully argued in Raiffa et al. (1978), it is crucial that we have a meticulous accounting of the possible consequences that might be categorized as public health risks. This would include aspects of mortality and morbidity as well as issues related to the process of public risks such as ex-ante equity. A period of pain or morbidity resulting in a fatality may be evaluated as worse than an immediate fatality. The difference between immediate and lingering deaths can be characterized by the undesirability of pain or morbidity, which can be explicitly included in the evaluation process as another factor in addition to the fatality. We need to examine the appropriate role that various factors such as the age or existing health of an individual should play when assessing the relative importance of additional health impacts or deaths to those individuals. In simple terms, is the death of a 90-year-old with numerous debilitating diseases equivalent to the death of a healthy 15-year-old? If not, or even if sometimes not, then the meticulous accounting system must take into account the age and health of the individuals along with other information. Numerous other characteristics associated with risks, such as the degree of voluntariness, and the perceived benefits of the process creating the risks, have been discussed in the literature (see, for example, Slovic et al., 1980) as potentially important in the evaluation of risks. It would be desirable to identify a comprehensive list of measures appropriate for most public risk problems and guidelines for selecting among those measures for specific public risk problems.

A key research issue related to the issue of risk measures concerns appropriate manners for characterizing morbidity. The difficulty is that morbidity comes in so many shapes and sizes. How should we determine when one type of morbidity is worse than another? Even for a particular type of morbidity, such as burns, there are many degrees and different effects. Krischer (1976) discusses indices for categorizing the relative severity of different health effects. This issue, along with the issue of aggregating or combining the health effects to multiple individuals, must simultaneously be addressed in developing morbidity indices.

A third research issue, which concerns circumstances that induce a disease or an event that causes a fatality, involves attributable risks. If an individual dies as a result of a clearly identified circumstance, one can readily attribute the death to that circumstance. In many cases, however, it is not known for certain what induced the cause of death, although the evidence might suggest that one circumstance is more likely than others. A contemporary

example concerns the cancer cases which are allegedly induced by the atomic bomb testing in Nevada in the 1950s. One cannot be certain that any given cancer was the result of the testing, but some evidence suggests that the incidence of cancer has increased as a result of the exposure. If perfect information were available, one could identify which of the cancers were, in fact, a result of the exposure to testing. However, perfect information is not available. What can be determined or inferred is only the probability that a given cancer was a result of the testing. Such a risk is referred to as an attributable risk. There are numerous questions surrounding attributable risks: how to measure them, how to utilize information about them to reduce risks in the future, and how to appropriately compensate "victims" in cases for which the probabilistic risks have been assessed but no further resolution of the actual circumstances is possible.

Implementation Issues

We will suggest two important problems concerning the implementation of methodology. The first concerns how to obtain reasonable estimates for the parameters necessary to utilize models and the second concerns the possibility of involving the public in a responsible manner.

There are two general approaches to determining the parameters (i.e., the value judgments) which are necessary for and which become a part of public risk evaluation models. One approach is to directly assess the values of various individuals and the other is to infer appropriate values based on actions that individuals or society do take or could take. With the direct assessment procedures, the technical problems are similar to assessing any utility function (see Keeney and Raiffa, 1976). Educating respondees to be able to responsibly think about value trade-offs between costs and lives, however, is a difficult task. Although such trade-offs are implicit in virtually every major decision made, many individuals find it distasteful to explicitly face that value trade-off.

Another opportunity for interesting research would involve attempts to estimate appropriate value judgments for the models on the basis of actions society does or could select. It may not be possible for such research to provide precise estimates of the parameters, but even to bound the value parameters would be potentially very useful. The approach that I feel might be particularly interesting would be to approximate appropriate value trade-offs between costs and health effects by relying upon estimates of the indirect health effects of the various potential levels of cost. For example, it is essentially always possible to spend more money to reduce the amount of air pollution, which results in fewer fatalities due to air pollution. However, fatalities can result from constructing and operating the pollution control equipment. As Black and Niehaus (1980) indicated, such fatalities could be greater than the number eliminated by reducing pollution. Also, the cost of that pollution control equipment must be passed on to members of our society. With less disposable income in society, health effects will be induced because less money will be available for health care, appropriate nutrition, and so forth. In addition, if the costs are large, jobs may be lost which could lead to suicides, broken families, alcoholism, and so forth which, in turn, have their associated health effects. One could examine such decision problems in this broader context and attempt to identify the level of pollution control which would minimize the "total" number of fatalities. This approach would, in some sense, avoid the issue of trading off costs versus lives, because to spend either more or less money would both result in more fatalities.

Alternatively, one might examine how members in society could use the resulting extra disposable income if no pollution equipment or less pollution equipment were utilized. If

individual actions were identified that could avoid more health impacts for the same cost than would be avoided by the utilization of the pollution control equipment, then maybe the alternative of less pollution control would be appropriate. One might argue that with each of these indirect approaches, the uncertainties about the health effects induced by the economic costs would be large. However, we need to keep in mind that the cause-and-effect relationships relating pollution to morbidity and mortality also have large uncertainties.

In the last decade, many members of the public have been deeply involved in debates on public risks. There is broad public concern about these issues. However, mechanisms have not yet been developed to make use of public input in as effective or constructive a manner as might be desirable, nor have mechanisms been developed to allow individuals to easily enter the "public risk debate." Hence, involved citizens tend to have a highly specific agenda in mind and the "average" citizen is excluded. It would appear that the technical aspects of risk problems are not where most members of the public would have the strongest contribution to make. Rather, value-related aspects of risk questions are where the public's input could be most helpful and appropriate. It would, therefore, seem particularly desirable to develop mechanisms for providing concerned citizens with a role and a means for incorporating their values toward public risks into policy deliberations. One mechanism for this might be to constitute special committees of "average citizens" to provide some insights about reasonable guidelines for evaluation of public risks. With appropriate design, and the improvements that one might expect to come with experience, the value judgments provided by these committees might come to have some influence on the thinking of individuals in our state and federal legislatures and regulatory agencies.

Policy Issues

Let us briefly describe two important policy issues related to research and analysis of fatality risks. The first involves communicating the insights of analysis to those individuals who influence policy. The mechanisms normally used for such communication include written papers, news briefs, books, and oral presentations. Research examining potential improvements to this process could be very useful. In this respect, a key role might be played by a committee of, or organization including, governmental risk analysts, or a committee of the Society for Risk Analysis.

The issue of developing policy is, perhaps, even more difficult. It might be desirable to establish a special committee of "wise risk analysts" who would develop a set of policy guidelines for dealing with the evaluation of risk problems in legislative bodies and regulatory agencies. As above, perhaps a committee of the Society for Risk Analysis or one appointed by the National Academy of Sciences could play a helpful role.

CONCLUSIONS

A general comment sometimes heard about the "value of life" literature is "Does anybody ever expect to use that?" From a prescriptive viewpoint, the answer is most certainly yes. However, one must be careful about the meaning of "use."

Numerous programs are aimed directly at reducing fatality risks. Other programs are concerned with fatality risks as they are associated with otherwise beneficial actions. To responsibly evaluate decisions on such programs, it is essential to evaluate the various fatality risk profiles. The evaluation might not be conducted in a formal manner, but one must have some concept of what these risk profiles are and make value judgments to appraise them.

The choice is whether to make the value judgments formally or informally. Given the complexity of the problem, I think it is appropriate to use both approaches. The formal approach can be used as a device to assist one in understanding and examining various value judgments and their appropriateness for institutional policy regarding fatality risks. But, the purpose of the models and the methodology is to provide critical insights and guidance for action. They should not be a substitute for the decision makers.

Use of the models requires the careful consideration of several value judgments. First, one must consider the general structure of the problem. There are implicit value judgments built into this structure as they are built into any problem structure. Second, one needs to appraise the value judgments necessary to structure the utility function u. For illustration in this paper, we assumed by (1) that the utility function for fatality risks and costs is additive. This assumption could easily be relaxed and all the ideas in the paper would still be valid. The assumptions leading to functional forms for the fatality risk utility function or the ex-ante equity value function need to be appraised for any specific use. Finally, even if a particular functional form is found to be appropriate, parameters for that utility function or value function must be assessed. This requires the decision makers to make a few problem-specific value judgments to identify pairs of indifferent consequences. For such difficult judgments, it is best to ask redundant questions from different perspectives. Inconsistencies will no doubt be observed. However, part of the motivation for the assessment process is to identify such inconsistencies and bring about an internal reconciliation after decision makers understand where and why these inconsistencies occurred. In Keeney (1980a), the assessment of some parameters for utility functions involving public risks is illustrated.

There are many approaches which have been suggested for evaluating risks to life. One explanation for the large number of approaches is the large number of distinct generic problems associated with risks to life. It seems as if different approaches to evaluating such risks would be appropriate for the different problems.

In this paper, the risk problem was structured using explicit value judgments and the implications of these judgments for the evaluation of fatality risks was examined. It is evident from the results of our analysis that seemingly reasonable assumptions can lead to incompatible utility functions for fatality risks. It was shown that a preference to minimize the expected number of fatalities leads to a linear utility function for fatalities; a preference for risk equity leads to a risk-prone utility function for fatalities; and a preference for catastrophe avoidance leads to a risk-averse utility function for fatalities.

The important implication of these results is that three desirable objectives are to some degree mutually inconsistent. One might ask whether this inconsistency is due to the formalization of the problem using lotteries over fatality risk profiles $(p_1, p_2, \ldots, p_n)$ or to the specific definitions of equity and catastrophe avoidance. Unless one concludes that this formulation and these definitions are completely irrelevant to the problem of evaluating fatality risks, the answer is no; the inconsistency holds. If additional attributes are added for characterizing fatality risks or if additional assumptions such as ex-ante risk equity seem reasonable, the degree (but not the fact) of the inconsistency may diminish.

We should not, however, mistakenly assume that the inconsistencies among these objectives are unfortunate or wrong. Whenever there is more than one objective in a problem, there will necessarily be some inconsistency in achieving those objectives. If there is no inconsistency, they are *de facto* one and the same objective. It does not seem unreasonable that for some cases, one may have, among others, the following four objectives: to minimize lives lost, to avoid catastrophes, to maximize ex-post equity, and to maximize ex-ante equity. A four-attribute utility function could be constructed to reflect concern for each of these objectives. Among the individual components there would be inconsistencies, but collectively

the resultant utility function could represent our overall values and include the appropriate value trade-offs to address the inconsistencies. This is indeed one of the major motivations for and advantages of multiattribute utility.

The insights in this paper, while interesting, are in no way a solution to the general problem. The insights, however, do indicate the value of pursuing similar research to determine reasonable evaluation structures for fatality risks. The search for such evaluation schemes is currently being pursued actively by U.S. governmental organizations, such as the Advisory Committee on Reactor Safeguards (1980). In Salem et al. (1980), several different risk regulation policies are defined in terms of different goals which appear to characterize the aims of different government agencies. It is then shown that the different policies can result in significantly different evaluations of alternative energy technologies. The arguments for a systematic approach to assist with the evaluation of fatality risks are compelling (see, for instance, Okrent, 1980). With better allocation of the available funds, we can likely reduce the risks to the public in a manner felt to be more appropriate and responsive to the problem.

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REFERENCES

Acton, J.P., 1973. Evaluating public program to save lives: the case of heart attacks. Santa Monica, Calif.: Rand Corporation Report R-950-RC.

Advisory Committee on Reactor Safeguards, 1980. An approach to quantitative safety goals for nuclear power plants. Washington, D.C.: U.S. Nuclear Regulatory Commission, NUREG-0739.

Black, S.C. and F. Niehaus, 1980. How safe is "too" safe? *International Atomic Energy Agency Bulletin, 22,* pp. 40–51.

Broome, J., 1982. Equity in risk bearing. *Operations Research, 30,* pp. 412–414.

Diamond, P.A., 1967. Cardinal welfare, individualistic ethics, and interpersonal comparisons of utility: comment. *Journal of Political Economy, 75,* pp. 765–766.

Ferreira, J., Jr. and L. Slesin, 1976. Observations on the social impact of large accidents. Cambridge, Mass.: Operations Research Center, Massachusetts Institute of Technology, Technical Report No. 122.

Fishburn, P.C., 1982. Equity axioms for public risk. Murray Hill, N.J.: Bell Laboratories.

Graham, J.D. and J. W. Vaupel, 1981. Value of life: what difference does it make? *Risk Analysis, 1,* pp. 89–95.

Howard, R.A., 1979. Life and death analysis. In, *Lawrence Symposium on Systems and Decision Sciences.* North Hollywood, Calif.: Western Periodicals.

Jones-Lee, M.W., 1974. The value of changes in the probability of death or injury. *Journal of Political Economy, 99,* pp. 835–849.

Jones-Lee, M.W., 1982. *The Value of Life and Safety.* Amsterdam: North-Holland Publishing Company.

Keeney, R.L., 1980a. Evaluating alternatives involving potential fatalities. *Operations Research, 28,* pp. 188–205.

Keeney, R.L., 1980b. Equity and public risk. *Operations Research, 28,* pp. 527–534.

Keeney, R.L., 1980c. Utility functions for equity and public risk. *Management Science, 26,* pp. 345–353.

Keeney, R.L., 1982. Evaluating mortality risks from an organizational perspective. In M.W. Jones-Lee (ed.), *The Value of Life and Safety.* Amsterdam: North-Holland Publishing Company.

Keeney, R.L. and H. Raiffa, 1976. *Decisions with Multiple Objectives.* New York: Wiley.

Keeney, R.L. and R.L. Winkler, 1985. Evaluating decision strategies for equity of public risks. *Operations Research* (in press).

Krischer, J.P., 1976. Indexes of severity: underlying concepts. *Health Services Research, 11,* pp. 143–147.

Linnerooth, J., 1975. A critique of recent modeling efforts to determine the value of human life. Laxenburg, Austria: International Institute for Applied Systems Analysis, Research Memorandum RM-75-67.

Linnerooth, J., 1979. The value of human life: a review of the models. *Economic Inquiry, 17,* pp. 52–74.

Lowrance, W.W., 1976. *Of Acceptable Risk.* Los Altos, Calif.: Kaufmann.

Mishan, E.J., 1971. Evaluation of life and limb: a theoretical approach. *Journal of Political Economy, 79,* pp. 687–705.

Okrent, D., 1980. Comment on societal risk. *Science, 208,* pp. 372–375.

Raiffa, H., Schwartz, W., and M. Weinstein, 1978. Evaluating Health Effects of Social Decisions and Programs. In *EPA Decisionmaking.* Washington, D.C.: National Academy of Sciences.

Salem, S.L., Solomon, K.A., and M.S. Yesley, 1980. Issues and problems in inferring a level of acceptable risk. Santa Monica, Calif.: Rand Corporation Report R-2561-DOE.

Sarin, R.K., 1982. Measuring equity in public risk. Los Angeles: Graduate School of Management, University of California.

Savage, L.J., 1954. *The Foundations of Statistics.* New York: Wiley.

Slovic, P., Fischhoff, B., and S. Lichtenstein, 1977. Risk assessment: basic issues. In R.W. Kates (ed.), *Managing Technological Hazard: Research Needs and Opportunities.* Boulder, Colo.: Institute of Behavioral Science, University of Colorado.

Slovic, P., Fischhoff, B., and S. Lichtenstein, 1980. Facts and fears: understanding perceived risk. In R.C. Schwing and W. A. Albers, Jr. (eds.), *Societal Risk Assessment: How Safe is Safe Enough?* New York: Plenum Press.

Starr, C., 1969. Social benefits versus technological risk. *Science, 165,* pp. 1232–1238.

Thaler, R. and S. Rosen, 1976. The value of saving a life: evidence from the labor market. In N.E. Terleckyj (ed.), *Household Production and Consumption.* New York: National Bureau of Economic Research, Columbia University.

von Neumann, J. and O. Morgenstern, 1947. *Theory of Games and Economic Behavior.* Princeton, N.J.: Princeton University Press, 2nd ed.

Zeckhauser, R., 1975. Procedures for evaluating lives. *Public Policy, 23,* pp. 419–464.

10

Methods for Analyzing and Comparing Technological Hazards

C. Hohenemser, R. Goble, J. X. Kasperson, R. E. Kasperson, R. W. Kates, P. Collins, A. Goldman, P. Slovic, B. Fischhoff, S. Lichtenstein, and M. Layman

INTRODUCTION

Each year an estimated 17–31% of the U.S. mortality rate is associated with undesired side effects of technology (Harriss, Hohenemser, and Kates 1978). The productivity loss from technology-related illness, death, and pollution is equivalent to 3–6% of the gross national product (GNP). When combined with the cost of private and public sector efforts to prevent and mitigate such losses, the undesired side effects of technology amount to 7–12% of the GNP (Tuller 1985). Even so, these estimates of the societal burden of technological hazards are incomplete, and do not include, for example, a number of newly recognized hazards.

Despite the large burden imposed by the undesired side effects of technology and the intensity of society's concern with specific hazards, there has been relatively little systematic and comparative study of these threats. In this paper we establish a framework for conceptualizing technological threats, provide a brief review of comparative work by others, and present a classification scheme, with suggested applications. Aspects of our own work have been presented in earlier publications (Hohenemser, Kasperson, and Kates 1982; Hohenemser, Kates, and Slovic 1983).

APPROACHES TO COMPARING AND CLASSIFYING HAZARDS

"Hazard" and "risk" in the English language are often used interchangeably, but we find it useful to distinguish between them. We define hazards as threats to humans and the things they value and note that the full description of such threats requires knowledge of

C. Hohenemser, R. Goble, J. X. Kasperson, R. E. Kasperson, R. W. Kates, P. Collins, and A. Goldman • Clark University, Worcester, Massachusetts 01610. *P. Slovic, B. Fischhoff, S. Lichtenstein, and M. Layman* • Decision Research, a branch of Perceptronics, Eugene, Oregon 97401.

the causal sequence of events that link early stages, such as human needs and wants, with eventual experience of human harm in the form of death or injury. We define risks as quantitative measures of human harm, most frequently expressed in the scientific literature as conditional probabilities for experiencing harm. Thus, we think of automobile usage as a hazard and say that the fatality risk is 1 in 4000 per year in the United States.

Comparing and classifying hazards begins with a basic language problem. A sampling of the literature on technological hazard and risk shows that there is no universally agreed upon nomenclature for describing hazards. Technological hazards are labeled in terms of their releases (automotive emissions), technology function (diagnostic X rays), exposed populations (asbestos workers), environmental pathways (air pollution), or varied consequences (cancer). Which label is chosen is a function of historical or professional choice or regulatory organization. Any given hazard usually falls into several categories. For example, a specific chemical may be a toxic substance, a consumer product, an air or land pollutant, a threat to worker health, or a prescription drug. Indeed, a major recent achievement has been the cross-listing of several of these domains of hazardous substances by their environmental pathways (Greenwood, Kingsbury, and Cleland 1979). With the limitations of inconsistent nomenclature, a number of workers have proposed ways of comparing and classifying hazards. For example, Lawless and colleagues, after reviewing a variety of methods, have proposed an analytic structure for comparative risk assessment (Lawless, Jones, and Jones 1984).

Risk Comparisons

The earliest approach to comparing hazards consists of various efforts to "count the bodies." For example, the National Safety Council for decades has compiled mortality rates due to various causes, particularly accidents (National Safety Council 1982). Similarly, public health agencies have classified mortality by "causes of death" (World Health Organization 1976). Recently, risk analysts such as Wilson (1979) and Cohen and Lee (1979) have adapted these sources and others to compile mortality risks for specific technological hazards. Such lists have served to put the newer technological hazards into perspective, and to argue for particular thresholds of tolerable risk. This is done by noting which common hazards are already tolerated; by implication, lesser-known technological hazards of equivalent risk should then also be tolerable. A well-known example of this is the frequently repeated comparison between experienced auto fatality rates and the hypothetical risks of nuclear reactor accidents (Nuclear Regulatory Commission 1975).

Risk–Benefit Comparison

One obvious difficulty with simple risk comparison is that it fails to account for related benefits, which may be large or small in any given case. Starr (1969) dealt with this problem by plotting experienced mortality risk versus benefit, measuring the latter in economic terms. He also distinguished between voluntary and involuntary hazards. Starr found that voluntary hazards exhibit higher experienced risk than involuntary hazards at a given benefit level and that for each category of hazards risk increases with the cube of the benefit. Starr argued that the results revealed society's preference with regard to risk: that is, society willingly tolerates higher risks for higher benefits and distinguishes in its behavior between voluntary and involuntary hazards. Though Starr's analysis has served as an important stimulus, Otway and Cohen (1975), using a similar approach, were unable to replicate Starr's findings.

Multiple Characteristic Risk Comparisons

A possible reason for the difficulty encountered by Otway and Cohen is that hazards do not universally fall into just two categories, voluntary and involuntary, but must be divided according to several characteristics before simple, empirical risk–benefit relations are obtained. To this end, among other purposes, nine additional categorical distinctions were proposed by Lowrance (1976), including "immediate/delayed," "known/not known," and "common/dread hazard."

Rowe (1977) provides a semiquantitative framework for evaluating risks in different categories. He defines "risk conversion factors" that relate mortality risk in one category to equivalent mortality risks in another. As in Starr's work (1969), Rowe bases differences in risk evaluation on differences in mortality rates in various risk categories. Rowe, however, provides a more complex model for acceptable risk decision than the original paper by Starr. Recently, in an extension of Rowe's analysis, Litai, Lanning, and Rasmussen (1981) have described how risk conversion factors for eight risk categories are derived from existing mortality rates.

Hazard Perception

Whereas Starr's approach and subsequent elaborations of it may or may not yield a self-consistent classification of hazards, the work is subject to a fundamental critique: it is not necessarily appropriate to measure the threat to humans and what they value by the probability of dying, and the benefit of technology by purely economic variables such as market value. This is demonstrated most effectively by psychometric studies designed to elicit subjective ratings of risks and benefits from lay subjects. The earliest of these studies was done by Fischhoff et al. (1978) and involved rating 30 hazards in terms of nine characteristics (drawn largely from Lowrance 1976) and a global variable termed "perceived risk." Subsequent, related work was reported by Slovic, Fischhoff, and Lichtenstein (1979, 1980) and Vlek and Stallen (1981). The central conclusion of this work is that perceived risk must be explained by a combination of hazard characteristics, of which mortality is only one (Table 1). One must conclude, therefore, that if hazard classifiction is to be consistent with the judgments expressed by lay people, it must be based on a considerably

Table 1. Hazard Characteristics Used in Perception Studies by Slovic, Fischhoff, and Lichtenstein (1980)

1. Voluntariness of risk	10. Control over risk[d]
2. Immediacy of effect	11. Number of people exposed
3. Knowledge about risk[a]	12. Equitability of exposure
4. Knowledge about risk[b]	13. Effect on future generations
5. Control over risk[c]	14. Degree of personal exposure
6. Newness of the hazard	15. Global catastrophic character
7. Chronic versus catastrophic	16. Degree of observability
8. Dread	17. Changing level of risk[e]
9. Severity of consequences	18. Ease of reduction of risk

[a] Among those exposed to the risk.
[b] Among scientists.
[c] Control in the sense that mishaps can be prevented.
[d] Control in the sense that the severity of a mishap can be reduced after it occurs.
[e] Degree to which risks are increasing or decreasing.

broader measure of hazardousness than the traditional mortality-based definition that has been adopted by most risk analysts.

In undertaking our own hazard classification effort, we were mindful of the limited measure of hazardousness afforded by mortality risk and cognizant of the central conclusion of the risk perception work. On the other hand, we recognized the imprecise nature of psychometric scales and the variables that they measure. Therefore, we set ourselves the goal of expanding the measure of hazard beyond mortality risk while retaining the scientific quality that is usually associated with mortality estimates.

In the analysis that follows, we (1) conceptualize all technological hazards as involving potentially harmful releases of energy and materials; (2) characterize the stages of hazard causation via 12 physical, biological, and social descriptors measured on quantitatively expressed scales; (3) score 93 technological hazards on these scales and analyze them in terms of their correlative structure; and (4) consider the implications of hazards structure for understanding hazards, their perception, and their management.

We believe that our most significant finding is that "hazardousness," as defined by causal sequence descriptors, can be systematically codified, and that in this way it is possible to capture at least five independent qualities of hazards. Only one of these corresponds to the usual definition of risk as probability of dying. Our conceptualizaton, therefore, significantly extends the most common measure of hazard in current use and provides a relatively well-defined, objective method of doing so.

MEASURES OF HAZARDOUSNESS

Hazard Structure

We model hazards via a six-stage causal sequence (Figure 1) employed earlier to describe hazard management and control (Hohenemser, Kasperson, and Kates 1982). The sequence runs successively from human needs, to human wants, to choice of technology, to possible releases of materials and energy, to subsequent human exposure, and eventual harmful human consequences. In its logic the model is related to the partition of natural hazards into "events" and "consequences" (Burton, Kates, and White 1978). It can also be thought of as a simplified fault tree and is structurally similar to methods used in analysis of nuclear reactor safety (Nuclear Regulatory Commission 1975), in classification of auto safety options (Haddon 1975), and in assessment of consumer product hazards (Bick and Kasperson 1978).

The focal point of the model is the "release" stage, defined as the loss of control over flows of energy and materials. Such flows are essential to properly functioning technology and can strongly affect the biological well-being and survival of living organisms. Energy and materials releases are defined as hazardous to the extent that they exceed levels with which actual and potential target organisms can cope.

For most technologies several hazard releases occur. For example, the entire cycle of coal-fueled electric power involves at least five distinctive releases, each with its own set of consequences. Thus, air pollutants produce health effects in the public; coal dust leads to black lung disease in miners; thermal pollution damages aquatic ecosystems; emitted carbon dioxide may trigger climate change; and kinetic and electrical energy in mining, maintenance, and power distribution can produce a range of accidental injury and death. As illustrated in Figure 2, the "topology" of the hazard "coal-fueled electric power" resembles a pitchfork, with a handle and several tines. The point of junction is the stage "choice of

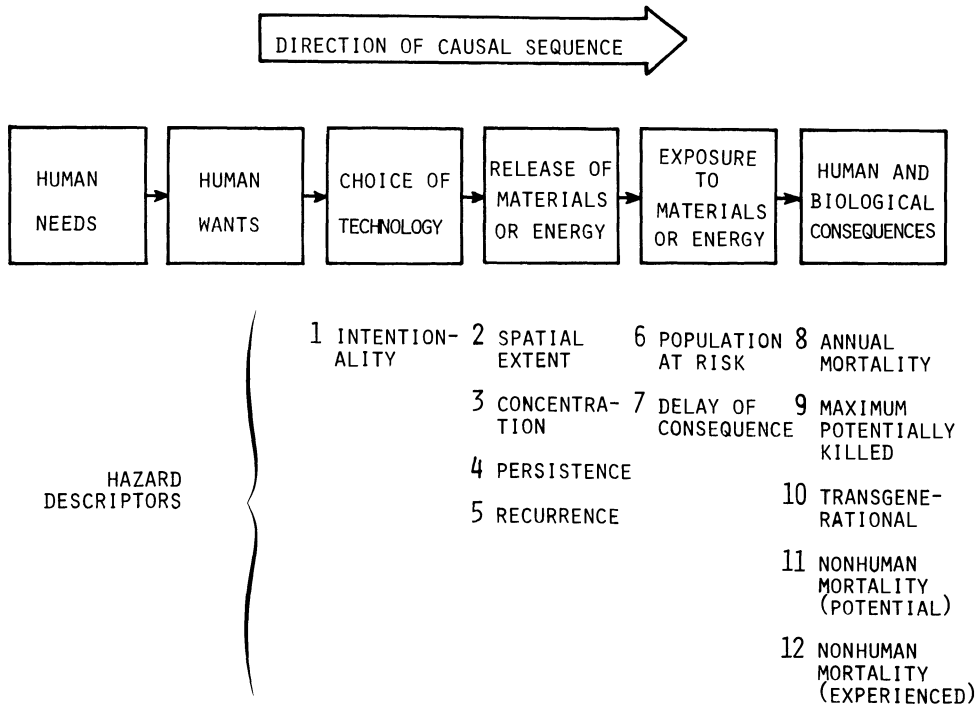

Figure 1. Causal structure of technological hazards illustrated via a simplified causal sequence. Note the arrow defining the direction of the sequence, from human needs and wants, via choice of technology, to human and biological consequences. Hazard descriptors used in our classification of hazards are shown below the stage to which they apply.

technology," and each tine is characterized by a specific release category and associated consequences.

In the following, we consider each tine of the multihazard as a separate and distinct hazard and employ a nomenclature whereby hazards are labeled by technology name and a subsequent release or consequence. Thus, we refer to "coal burning—SO pollution" as a hazard, and distinguish it from "coal mining—black lung disease," even though both are involved in the multihazard "coal-fueled electric power." To a large extent this eliminates the inconsistency of nomenclature referred to earlier.

Hazard Descriptors

With the causal sequence of hazards as a template, we define appropriate quantitative measures to describe individual hazards at each stage of the causal chain. In selecting descriptors we choose qualities that are universally applicable across the spectrum of technological hazards and that may be scaled using common physical units or distinctions. We also intend our descriptors to be comprehensible to ordinary people and to reflect a large fraction of their concern with hazards. We were, therefore, guided to some extent by previously proposed hazard characteristics (Lowrance 1976; Fischhoff et al. 1978).

As indicated in Figure 1, we have identified 12 measures of hazardousness. One variable describes the degree to which hazardousness is intentional in design, 4 characterize the release of energy and materials in physical terms, 2 deal with exposure, and 5 are measures

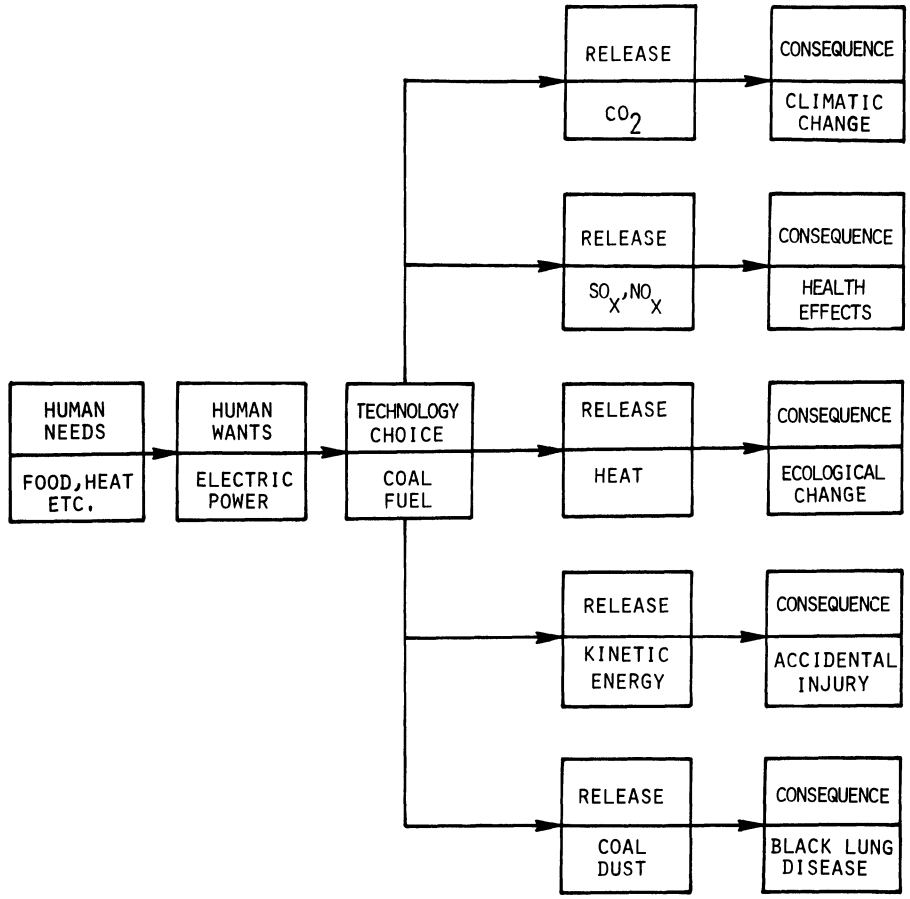

Figure 2. The "pitchfork" topology of technological hazards, illustrated for the case of coal-fired electric power. Associated with this single technology are several distinct hazard sequences, each with its own release of energy and materials and subsequent consequences.

of consequences. Only 1 descriptor, human mortality (annual), is closely related to the traditional concept of risk as the probability of dying. The others considerably expand and delineate the concept of hazardousness. Definitions of the 12 descriptors, including scales to score them, appear in Table 2. (See also Hohenemser et al. 1983.)

As indicated in Table 2, 8 of the 12 scales are quantitatively defined; the other 4 are qualitative and involve categorical distinctions. For the quantitatively defined descriptors we used logarithmic scales. These are practical in a situation in which successive occurrences may range over a factor of 10 or more in magnitude and in which estimation errors may easily differ by the same amount. Compared to linear scales, logarithmic scales may also be better matched to human perception, as seen by the success of the decibel scale for sound intensity and the Richter scale for earthquake intensity.

Hazard Selection and Scoring

Our initial base for hazard selection was the Clark University collection of case studies and the hazard list employed in early risk perception work by Fischhoff et al. (1978). The Clark collection included the case histories of technological concern prepared by Lawless

Table 2. Hazard Descriptor Definitions

Technology descriptor

1. Intentionality. Measures the degree to which technology is intended to harm using a categorical scale: 3—not intended to harm living organisms; 6—intended to harm nonhuman living organisms; 9—intended to harm humans.

Release descriptors

2. Spatial extent. Measures the maximum distance over which a single event has significant impact, using a logarithmic scale, $1 < s < 9$, where $s = \log_{10} d + 1$ rounded to the nearest positive integer, and d is the distance in meters.
3. Concentration. Measures the concentration of released energy or materials relative to natural background using a logarithmic scale, $1 < s < 8$.

   For materials and nonthermal radiation $s = \log_{10} R + 2$ rounded to the nearest positive integer, and R is the average concentration of release divided by the background concentration.

   For mechanical energy, $s = \log_2 a + 0.68$ rounded to the nearest positive integer, and a is the acceleration to which individuals are exposed measured in units of the acceleration of gravity.

   For thermal energy, $s = \log_2 f + 0.68$ rounded to the nearest positive integer, and f is the thermal flux expressed in units of the solar flux.
4. Persistence. Measures the time over which a release remains a significant threat to humans using a logarithmic scale, $1 < s < 9$, where $s = \log_{10} t + 1$ rounded to the nearest positive integer, and t is the time measured in minutes.
5. Recurrence. Measures the mean time interval between releases above a minimum significant level, using a logarithmic scale identical to that used for persistence.

Exposure descriptors

6. Population at risk. Measures the number of people in the U.S. potentially exposed to the hazard, using a logarithmic scale $1 < s < 9$, where $s = \log_{10} P$ rounded to the nearest integer, and P is the population.
7. Delay. Measures the delay time between exposure to the hazard release and the occurrence of consequences, using the logarithmic scale defined for persistence.

Consequence descriptors

8. Human mortality (annual). Measures average annual deaths in the U.S. due to the hazard in question, using the logarithmic scale defined for population at risk.
9. Human mortality (maximum). Measures the maximum credible number of deaths in a single event, using the logarithmic scale defined for population at risk.
10. Transgenerational. Measures the number of future generations which are at risk for the hazard in question, using a categorical scale: 3—hazard affects the exposed generation only; 6—hazard affects children of the exposed generation, no others; 9—hazard affects more than one future generation.
11. Nonhuman mortality (potential). Measures the maximum potential nonhuman mortality, using a categorical scale: 3—no potential nonhuman mortality; 6—significant potential nonhuman mortality; 9—potential species extinction.
12. Nonhuman mortality (experienced). Measures nonhuman mortality that has actually been experienced on a categorical scale: 3—no experienced nonhuman mortality; 6—significant experienced nonhuman mortality; 9—experienced species extinction.

(1977), as well as studies garnered from a review of relevant medical and scientific literature. Thus, the initial set of 66 hazards selected for scoring on the 12 scales defined in Table 2 included many of the hazards that have received public and scientific attention over the past decade.

After scoring the initial 66 hazards, we plotted their distribution on each of 12 scales, noted the extent of imbalances, and selected additional hazards to round out the sample. Our final sample of 93 hazards, given in Table 3 along with their scores, is therefore reasonably well distributed on most scales. As can be seen in Figure 3, several variables, such as "human mortality (maximum)," have strongly skewed distributions. This is because there are few hazards with large catastrophic potential and many with the potential to kill

Table 3. Descriptor and Factor Codes for Ninety-Three Hazards[a]

Hazard	Descriptor code	Factor code
Energy hazards		
1. Appliances—fire	333-333-42-3-95-2	00000
2. Appliances—shock	333-113-21-3-95-1	00000
3. Auto—crashes	333-113-11-5-96-2	00010
4. Aviation, commercial—crashes	333-113-63-3-97-4	00100
5. Aviation, commercial—noise	333-213-11-1-85-5	00000
6. Aviation, private—crashes	333-113-32-4-97-4	00010
7. Aviation—SST noise	333-313-41-1-76-5	00000
8. Bicycles—crashes	333-113-11-3-84-2	00000
9. Bridges—collapse	333-113-53-1-95-3	00000
10. Chainsaws—accidents	666-113-11-1-74-2	10000
11. Coal mining—accidents	333-233-53-3-64-3	00000
12. Dams—failure	693-423-74-2-85-5	10100*
13. Downhill skiing—falls	333-113-21-2-63-1	00000
14. Dynamite blasts—accidents	333-113-32-2-65-3	00000
15. Elevators—falls	333-113-52-2-96-2	00000
16. Fireworks—accidents	333-113-31-1-83-2	00000
17. Handguns—shootings	369-113-41-4-96-1	10010*
18. High construction—falls	333-113-71-1-28-2	00000
19. High voltage wires—electric fields	333-173-11-1-74-3	00000
20. LNG—explosions	363-213-85-1-86-5	00100
21. Medical X rays—radiation	333-189-11-4-92-2	00011*
22. Microwave ovens—radiation	333-173-11-1-84-2	00000
23. Motorcycles—accidents	333-113-11-4-76-2	00010
24. Motor vehicles—noise	333-213-11-1-83-3	00000
25. Motor vehicles—racing crashes	333-113-52-2-67-2	00000
26. Nuclear war—blast	699-213-87-4-98-6	10110*
27. Power mowers—accidents	333-113-21-2-73-2	00000
28. Skateboards—falls	333-113-11-3-73-1	00000
29. Skydiving—accidents	333-113-51-2-48-1	00000
30. Skyscrapers—fire	333-423-53-3-85-4	00000
31. Smoking—fires	333-433-32-3-85-1	00000
32. Snowmobiles—collisions	333-113-41-2-73-2	00000
33. Space vehicles—crashes	333-313-84-1-98-5	00100
34. Tractors—accidents	333-113-41-2-74-2	00000
35. Trains—crashes	333-213-53-3-84-3	00000
36. Trampolines—falls	333-113-51-1-74-2	00000
Materials hazards		
37. Alcohol—accidents	333-313-11-4-95-2	00010
38. Alcohol—chronic effects	333-486-11-5-85-1	00010
39. Antibiotics—bacterial resistance	666-563-11-3-97-1	10000
40. Asbestos insulation—toxic effects	333-583-11-3-56-3	00000
41. Asbestos spray—toxic effects	333-583-11-1-83-3	00000
42. Aspirin—overdose	333-456-11-3-97-1	00000
43. Auto—CO pollution	333-346-11-2-94-4	00000
44. Auto—lead pollution	663-976-11-2-95-5	01000
45. Cadmium—toxic effects	663-986-11-2-74-6	01000
46. Caffeine—chronic effects	333-566-11-1-95-1	00000
47. Coal burning—NO_x pollution	693-566-11-3-95-7	10000
48. Coal burning—SO_2 pollution	693-563-11-4-94-7	10010*
49. Coal mining—black lung	333-483-11-4-64-3	00010
50. Contraceptive IUDs—side effects	333-763-11-2-67-1	00000
51. Contraceptive pills—side effects	333-586-11-3-74-1	00000
52. Darvon—overdose	333-556-11-4-77-1	00010

(*continued*)

Table 3. (continued)

Hazard	Descriptor code	Factor code
53. DDT—toxic effects	996-886-32-1-87-5	11000*
54. Deforestation—CO_2 release	696-993-11-1-91-9	10001*
55. DES, animal feed—human toxicity	333-586-11-1-93-1	00001
56. Fertilizer—NO_x pollution	393-686-11-1-93-9	00001
57. Fluorocarbons—ozone depletion	393-883-11-1-97-9	00000
58. Fossil fuels—CO_2 release	393-993-11-1-92-9	00001
59. Hair dyes—coal tar exposure	333-286-11-1-87-1	00000
60. Hexachlorophene—toxic effects	666-363-11-2-87-1	10000
61. Home pools—drowning	333-223-41-3-83-1	00000
62. Laetrile—toxic effects	333-553-11-1-55-1	00000
63. Lead paint—human toxicity	333-773-11-3-75-2	00000
64. Mercury—toxic effects	663-986-13-2-85-5	01000
65. Mirex pesticide—toxic effects	696-886-22-1-67-5	11000*
66. Nerve gas—accidents	669-836-73-1-77-5	10100*
67. Nerve gas—war use	699-836-87-3-97-7	10100*
68. Nitrite preservative—toxic effects	336-786-11-1-91-1	00001
69. Nuclear reactor—radiation release	363-969-86-1-96-7	01100*
70. Nuclear tests—fallout	663-989-73-3-91-9	01101*
71. Nuclear war—radiation effects	699-989-88-4-97-9	11110*
72. Nuclear waste—radiation effects	363-989-15-1-82-6	01001*
73. Oil tankers—spills	663-763-61-1-15-6	00000
74. PCBs—toxic effects	663-976-13-1-97-6	01000
75. Pesticides—human toxicity	996-886-12-2-97-5	11000*
76. PVC—human toxicity	333-486-11-2-77-4	00000
77. Recombinant DNA—harmful release	393-869-97-1-97-9	01100*
78. Recreational boating—drowning	333-223-51-4-83-2	00010
79. Rubber manufacture—toxic exposure	333-986-11-3-57-4	01000
80. Saccharin—cancer	333-486-11-1-87-1	00000
81. Smoking—chronic effects	333-486-11-6-85-1	00010
82. SST—ozone depletion	393-893-11-1-93-9	00001
83. Taconite mining—water pollution	663-983-11-1-67-6	00000
84. Thalidomide—side effects	333-456-51-1-17-1	00000
85. Trichloroethylene—toxic effects	333-983-11-1-87-4	00000
86. 2,4,5-T herbicide—toxic effects	696-886-22-1-77-5	11000*
87. Underwater construction—accidents	333-223-61-1-44-3	00000
88. Uranium mining—radiation	333-989-12-2-64-5	01000
89. Vaccines—side effects	696-556-11-2-84-1	10000
90. Valium—misuse	333-566-11-3-87-1	00000
91. Warfarin—human toxicity	666-653-11-1-87-1	10000
92. Water chlorination—toxic effects	666-583-11-1-97-5	10000
93. Water fluoridation—toxic effects	333-786-11-1-82-5	00001

[a] The descriptor code for each hazard consists of a digit for each descriptor, and represents scores on the scales defined in Table 2. To help visualize the factor structure, descriptors have been grouped by factor in the order defined in Table 4. The factor code consists of a single digit for each factor, identifies extreme scores by 1 and nonextreme scores by 0, and also follows the order defined in Table 4. Hazards with two or more extreme factors are identified with *.

people individually. Definitions of the 93 hazards appear in an extended version of this paper (Hohenemser et al. 1983).

Most hazards were scored through reference to the scientific literature by two or more individuals from our interdisciplinary group. Many cases were discussed by a larger group or referred to specialists in order to clarify the meaning of the available literature. A subsequent series of checks led to alteration of 8% of the scores by 1–2 scale points and less

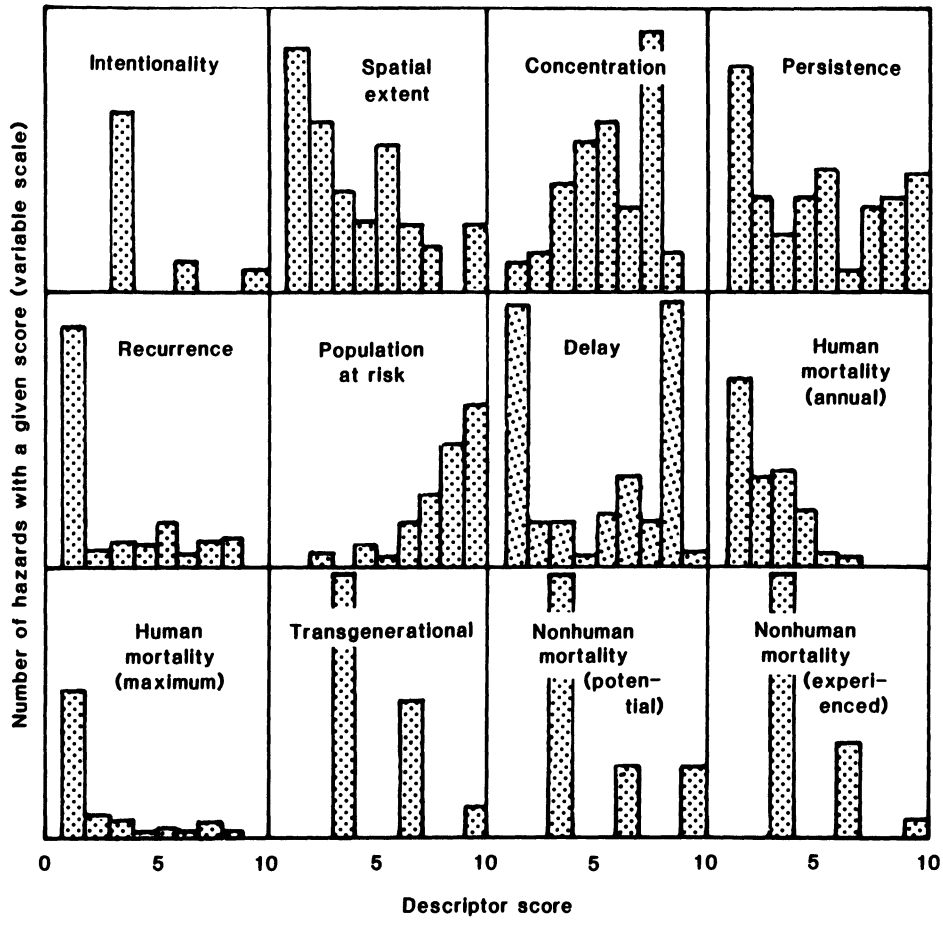

Figure 3. Descriptor frequency distribution for 93 hazards. The vertical scales are arbitrary and have been adjusted to fit the space available.

than 1% by 3 scale points or more. In a typical case these changes involved inconsistent use of scales; in some cases they corrected blunders such as inadvertent scale inversion by the first scorer. We believe the replicability of our scoring to be +1 scale point in most cases. In a few cases, especially for hazards undergoing current evaluation (such as recombinant DNA technology), we expect that judgments of readers might differ significantly.

Given the set of 93 scored hazards, we are prepared to explore methods of classification by noting how hazards group and cluster in our 12-dimensional "descriptor space."

HAZARD CLASSIFICATION

Energy versus Materials Hazards

One of the simplest, yet significant, classifications that can be derived from our data divides hazards into those that involve energy or materials releases. We have organized Table 3 accordingly. With a few exceptions, energy hazards are distinguished by releases

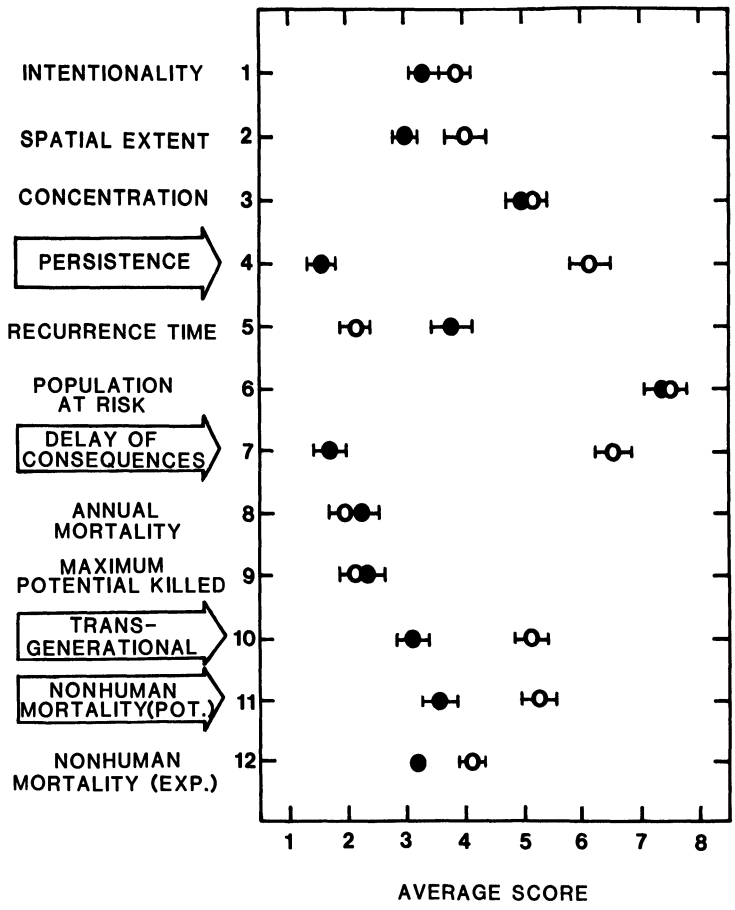

Figure 4. Average scores for energy hazards (solid circles) and materials hazards (open circles) on 12 descriptor scales. Significant differences (more than 3 standard deviations) are indicated by arrow symbols on the vertical axis. Error bars indicate the standard deviation of the mean.

of kinetic energy on a macroscopic scale, whereas materials hazards generally affect organisms on a molecular level.*

Marked differences in causal structure for energy and materials hazards are illustrated in Figure 4, which provides average scores for the two sets. From this we see that (1) energy hazards have releases with short persistence times, averaging less than one minute; materials releases have long persistence times, averaging a week or more; (2) energy hazards have immediate consequences, with average exposure-consequence delays of less than one minute; materials have delayed consequences, with exposure-consequence delays averaging one month; (3) energy hazards have only minor transgenerational effects, with consequences restricted almost wholly to the exposed generation; materials hazards affect on the average

* There is a major epistemological difference in the understanding of energy and materials hazards. By and large, the causal structure of energy hazards is well understood. In contrast, the links between exposure and consequences for many materials hazards are at best correlational, and true causal understanding awaits explanation of such important consequences as cancer or arteriosclerosis. We suspect that the difference between energy and materials hazards is fundamental and related to the levels of biological organization, but the differences may be an artifact of unequal knowledge.

one future generation; and (4) energy hazards have little potential effect on nonhuman mortality; materials hazards have significant potential effects on nonhuman mortality.

In addition, there are other less striking differences. Energy hazards involve less spatial extent, longer recurrence times between significant events, and fewer experiences of nonhuman mortality. The two categories of hazards are similar in intentionality, concentration, population at risk, annual mortality, and maximum potential killed.

We believe that the significant causal structure differences in energy and materials hazards are themselves a useful starting point in formulating and understanding hazard management options and indeed have been recognized in the existing regulatory structure. For example, auto transportation energy hazards (auto accidents) are handled by one agency (Department of Transportation), whereas materials hazards (pollution) are handled by another agency (EPA). Detailed consideration of this point is, however, beyond the scope of this paper.

Reducing the Number of Dimensions

Beyond simple division of hazards by release class, it is of interest to explore grouping or clustering of hazards according to causal structure. Because any grouping is aided by a reduction in the number of independent dimensions, we have employed principal component factor analysis to determine the minimum number of orthogonal dimensions needed to describe the data.* This process leads to five composite dimensions (or factors) which "explain" 81% of the variance of the sample. For practical purposes this means that the causal structure of each of the 93 hazards, and probably others to be scored in the future, can be described by 5 variables rather than 12.

The relation of the derived factors to the original set of descriptors is summarized in Table 4. The names given to the factors—Biocidal, Delay, Catastrophic, Mortality, and Global—are intended to aid the intuition and are related to the descriptors that define each factor.

The factor Biocidal combines hazards with a high level of nonhuman mortality and technologies that are purposefully designed to harm humans or other living organisms. The factor Delay combines persistence in the environment with long delay between exposure and consequences. The factor Catastrophic includes both rarity of occurrence and large human mortality in one event.The factor Mortality represents the single descriptor annual human mortality. Finally, the factor Global combines hazards with widespread exposure and a concentration of release that is modest with respect to background.

Several tests indicate that the factor structure does not change significantly when hazards are added and deleted from the sample, or when scoring changes comparable to the estimated scoring errors are made. Thus, the original 66 hazards yielded essentially the same factor structure as the final 93; changing 10% of the score by 1–3 scale points had no significant effect and removing 24 hazards with the most extreme factor scores produced only minor changes in factor structure. Particularly the last finding is remarkable and quite unexpected, since extreme scores often dominate a factor solution. Details of the factor analysis and tests of its robustness are summarized in the extended version of this paper (Hohenemser et al. 1983).

* Factor analysis was done using the package Biomedical Computer Program, Program BMDP:P4M, developed by the Health Sciences Computing Facility, U.C.L.A., available in *BMDP, P-series, 1979*, W.J. Dixon and M.B. Brown, eds. (University of California Press, Los Angeles, 1979). Orthogonal rotation was performed according to the varimax criterion, which maximizes the variance of the squared factor loadings.

Table 4. Factor Structure

Factor			Hazard descriptors	
No.	Name	Variance explained[a] (%)	Name	Factor loading[b]
1.	Biocidal	33	Nonhuman mortality (experienced)	0.87
			Nonhuman mortality (potential)	0.79
			Intentionality	0.81
2.	Delay	19	Persistence	0.81
			Delay	0.85
			Transgenerational effects	0.84
3.	Catastrophic	11	Recurrence	0.91
			Human mortality (maximum)	0.89
4.	Mortality	11	Human mortality (annual)	0.85
5.	Global	9	Population at risk	0.73
			Concentration	−0.73
	Residual		Spatial extent	

[a] The percentages given for "variance explained" differ somewhat from those in previous work (Hohenemser, Kates, and Slovic 1983, p. 380), which was subject to erroneous reading of the computer output.
[b] Factor loadings are the result of varimax rotation.

To help in visualizing the factor structure, Table 3 has been organized so that individual descriptor scores are grouped by factor into a 12-digit "descriptor code," and extreme scores on each factor are identified through a 5-digit "factor code." (See Table 3 for code sequence definitions.) The group into which a particular hazard falls depends, of course, on the cutoff for the designation "extreme." Although the location of the cutoff is ultimately a policy question, our preliminary method for defining it is arbitrary: we simply made a cut in the truncated factor scores at 1.2–1.5 standard deviations above the mean, the exact value depending on the location of a natural break.

In identifying extreme scores on each factor, we might have used exact factor scores generated by the factor analysis. These, however, include significant off-diagonal contributions, so that two hazards with identical descriptors on a given factor may have significantly different factor scores. Because we believe that the significance of factor analysis lies in descriptor grouping, and not in the mathematical abstraction called a "factor," we used truncated factor scores (consisting of sums of descriptors belonging to a given factor) to generate the extreme scoring hazards designated in Table 3.*

* Using raw descriptor scores D_{ik} for the ith descriptor and the kth hazard, we obtained truncated factor scores

$$F^t_{jk} = \sum_i D_{ik}$$

where i runs over just the salient descriptors belonging to the jth factor. This suppresses contributions from descriptors that load weakly on the jth factor. In contrast, the factor analysis program obtains exact standardized factor scores through the 12-term sum

$$F_{jk} = \sum_i d_{ik} f_{ij}$$

where the d_{ik} are standardized descriptor scores belonging to the ith descriptor and the kth hazard, and f_{ik} is the 12 × 5 factor score coefficient matrix, given in Table 13. In a statistical sense, there is little difference between the two methods: the correlation coefficients between F^t_{jk} and F_{jk} are (0.94, 0.96, 0.97, 0.85, and 0.96) for j = (1,2,3,4,5), respectively.

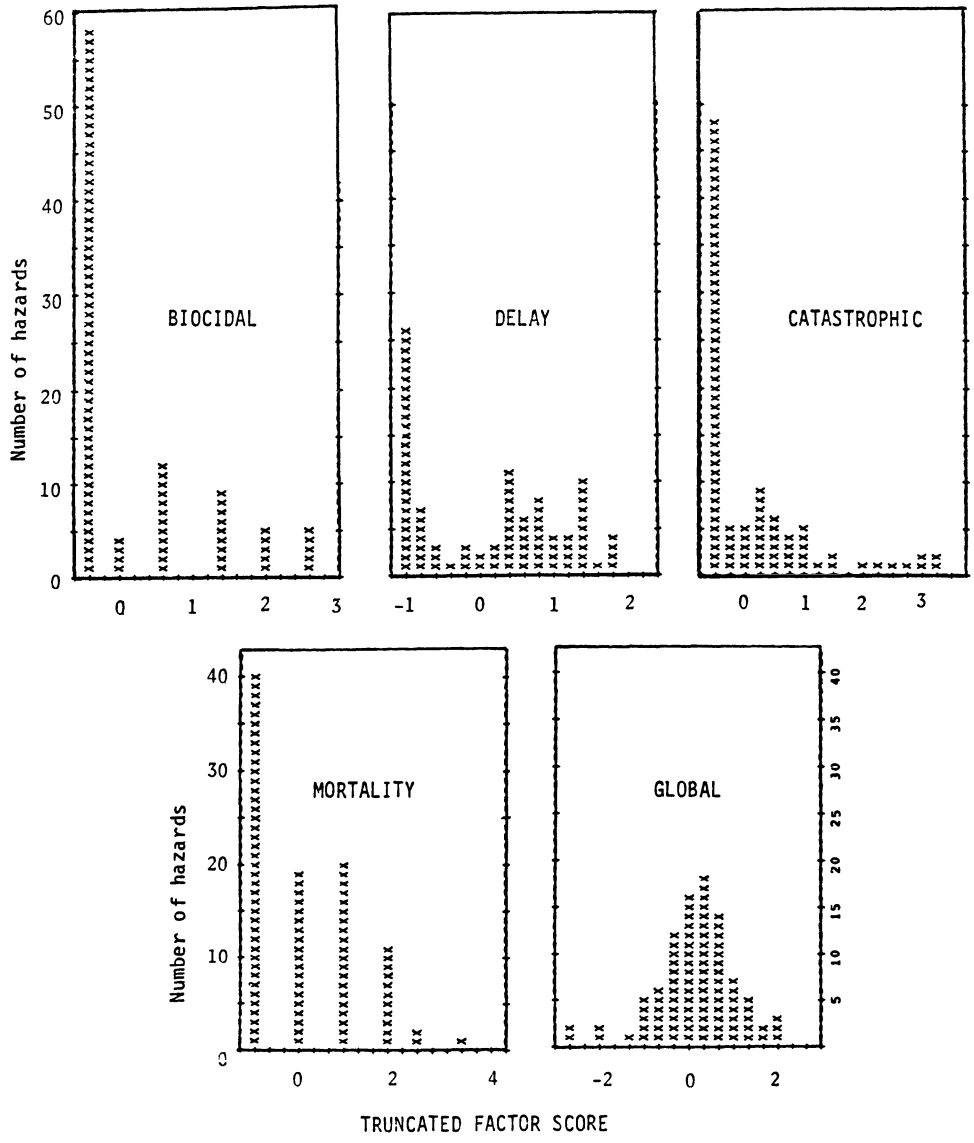

Figure 5. Ninety-three hazards: Distribution of truncated factor scores.

As expected, truncated factor scores correlate strongly with exact factor scores ($0.84 < r < 0.97$). Distributions of truncated factor scores over the 93 hazards are shown in Figure 5. This indicates, further, that with the exception of the factor Global, the designation "extreme" is unambiguous. For the factor Global one must decide which side of the symmetric distribution is to be regarded as extreme. As already indicated, we have chosen the side of low concentration and large population at risk. Truncated factor scores and correlation plots for truncated versus exact factor scores are given in the extended version of this paper (Hohenemser et al. 1983).

Inspection of Table 3 permits quick identification of dimensions that dominate hazardousness in specific cases. For example, we may read that commercial aviation is high in the factor Catastrophic and nondistinctive in the other four; or that power mower accidents

are extreme in none of the five factors, while nuclear war–radiation effects are extreme in four.

A Seven-Class Taxonomy of Extremes

Table 4 leads naturally to a seven-class taxonomy with three major groups, as shown in Table 5. The groups are "multiple extreme hazards," "extreme hazards," and "hazards." The first includes cases with extreme scores in two or more factors, the second contains cases with extreme scores on one factor, and the third collects all other hazards.

The emphasis on extremes in Table 5 leaves the bulk of hazards unstructured. If the intent is to focus on society's most important worries, this is appropriate. Further structuring of nonextreme hazards may, however, be achieved in several ways. One approach is to utilize the distinction between energy and materials hazards already described in Figure 4. Another approach, suggested in an earlier paper (Hohenemser, Kasperson, and Kates 1982) is to divide nonextreme hazards into macro- and microhazards. In the first case, threatening releases occur on a macroscopic scale, do gross damage to the human body (as in broken bones), and have largely acute consequences; in the second case, releases are microscopic, do damage on a molecular scale without detectable macroscopic change, and have largely delayed consequences.

Alternative Factor Analyses

As defined here, the taxonomy depends crucially on the structure uncovered in the factor analysis. How valid is our factor analysis? Although the factor analysis of the 93 hazards in our sample is robust in the manner we have described, the factor solutions depend significantly on the hazard set analyzed. For example, if only energy hazards are chosen, a different factor structure emerges than when all 93 hazards are analyzed. To illustrate, we present three alternative factor analyses in Tables 6–8, with results as follows: (1) For the 36 energy hazards alone, a four-factor solution is obtained which explains 74% of the variance of the sample and scrambles all of the original factors save Biocidal; (2) for the 60 materials hazards alone, a five-factor solution is found which explains 80% of the variance of the sample, and again scrambles all but the original factor Biocidal; and (3) for the 93 energy and material hazards with 17 added natural hazards (see Table 9), a five-factor solution is

Table 5. A Seven-Class Taxonomy

1. Multiple extreme hazards (extreme in more than one factor)	Nuclear war—radiation, recombinant DNA, pesticides, nerve gas—war use, dam failure
2. Extreme hazards (extreme in one factor)	Chain saws, antibiotics, vaccines
a. Intentional biocides	
b. Persistent teratogens	Uranium mining, rubber manufacture
c. Rare catastrophes	LNG explosions, commercial aviation crashes
d. Common killers	Auto crashes, coal mining—black lung
e. Diffuse global threats	Fossil fuel—CO_2, SST—ozone depletion
3. Hazards (extreme in no factor)	Saccharin, appliances, aspirin, skateboards, power mowers, bicycles

Table 6. Thirty-Six Energy Hazards: Factor Structure

Factor			Hazard descriptors	
No.	Name	Variance explained (%)	Name	Factor loading[a]
1.	Catastrophic	34	Spatial extent	0.83
	Global		Human mortality (maximum)	0.79
	Delay		Persistence	0.75
			Recurrence	0.68
2.	Biocidal	17	Nonhuman mortality (experienced)	0.90
			Nonhuman mortality (potential)	0.89
			Intentionality	0.81
3.	Delay	13	Delay	0.82
	Global		Transgenerational effects	0.72
			Concentration	−0.70
4.	Mortality,	10	Human mortality (annual)	0.89
	Global		Population at risk	0.65

[a] Factor loadings are the result of varimax rotations.

obtained which retains the original factors Delay and Catastrophic but scrambles Biocidal, Global, and Mortality.

Descriptor scores for natural hazards are given in Table 9. Details of the factor analyses are given in the extended version of this paper (Hohenemser et al. 1983).

A necessary conclusion is that energy, materials, and natural hazards are structurally distinct groups. For energy and materials hazards this was already apparent in Figure 4. One specific expression of this structural difference is that some descriptors are incapable of distinguishing among hazards of a given subset: for example, the descriptors "delay" and "persistence" have very little variability for energy hazards and cannot be important factor components; they serve a useful function only in distinguishing materials hazards.

Do the different factor structures of Tables 6–8 suggest that the factor analysis of the original set of 93 is too arbitrary to be useful? We have already shown that energy/materials

Table 7. Sixty Materials Hazards: Factor Structure

Factor			Hazard descriptors	
No.	Name	Variance explained (%)	Name	Factor loading[a]
1.	Biocidal	32	Nonhuman mortality (experienced)	0.86
			Nonhuman mortality (potential)	0.83
			Intentionality	0.77
2.	Catastrophic	16	Nonhuman mortality (maximum)	0.90
	Delay		Transgenerational effects	0.80
			Recurrence	0.77
3.	Delay	13	Delay	0.91
			Persistence	0.61
4.	Global	11	Concentration	0.84
			Spatial extent	−0.55
5.	Mortality	8	Population at risk	0.71
	Global		Human mortality (annual)	0.70

[a] Factor loadings are the result of varimax rotation.

Table 8. Ninety-Three Technological and Seventeen Natural Hazards: Factor Structure

Factor			Hazard descriptors	
No.	Name	Variance explained (%)	Name	Factor loading[a]
1.	Biocidal	30	Nonhuman mortality (potential)	0.89
	Global		Nonhuman mortality (experienced)	0.86
			Spatial extent	0.64
2.	Delay	20	Transgenerational effects	0.87
			Delay	0.85
			Persistence	0.77
3.	Catastrophic	11	Human mortality (maximum)	0.89
			Recurrence	0.87
4.	Global	10	Concentration	0.82
	Biocidal		Intentionality	0.64
5.	Mortality	9	Population at risk	0.82
	Global		Human mortality (annual)	0.64

[a] Factor loadings are the result of varimax rotation.

distinction is a powerful cut that creates distinctive subsets in our description. If we were only interested in one subset or the other, a more restricted set of descriptors and factors might be appropriate. Since, however, we are interested in describing the whole domain of technological hazards, the descriptors and factor analysis obtained for the combined set of 93 should be our choice.

This leaves the question why the addition of 17 natural hazards significantly perturbs the factor analysis of the 93. Like energy and materials hazards, the natural hazards chosen

Table 9. Descriptor Codes for Seventeen Natural Hazards[a]

Natural hazard	Descriptor code
1. Avalanche—surge	663-213-53-1-76-4
2. Coastal erosion—mass movement	693-913-11-1-64-6
3. Drought—moisture deficit	993-863-61-1-92-7
4. Earthquake—shaking	663-213-65-2-86-6
5. Flood—surge	663-413-54-3-65-5
6. Flood—inundation	993-623-53-2-73-6
7. Frost—freeze	663-543-51-1-82-6
8. Hail—falls	663-313-41-1-82-5
9. Hurricane—wind	663-513-74-3-85-7
10. Hurricane—surge	693-413-74-3-75-5
11. Landslide—mass movement	663-513-43-1-86-4
12. Lightning—strike	663-113-44-3-98-2
13. Tornado—wind	663-313-54-3-86-5
14. Tsunami—surge	693-313-84-2-65-5
15. Urban snow accumulation	663-533-54-3-93-6
16. Volcano—blast	693-313-93-1-57-6
17. Windstorm—wind	663-413-43-2-94-6

[a] The descriptor code for each hazard consists of a digit for each descriptor, and represents scores on the scales defined in Table 1. To help visualize the factor structure, descriptors have been grouped by factor in the order defined in Table 2.

constitute a distinct group. Because factor analysis of just the 17 natural hazards over the 12 descriptors is statistically invalid, we do not report on that analysis. Further work on natural hazards and their relation to technological hazards is under way.

How useful is our approach to hazard classification? To succeed, it must approximate the essential elements that make specific hazards threatening to humans and the things they value, reflect the concerns of society, and offer new tools for hazard management. On the first point we invite the review and evaluation of specialists; on the second and third we have additional evidence which we discuss next.

COMPARING PERCEPTIONS

The scores for 93 hazards are products of judgments relying on explicit methods, a scientific framework, and deliberate efforts to control bias. None of these are necessarily attributes of lay perception. Indeed, many scientists believe that lay judgments of hazards vary widely from scientifically derived judgments (Kasper 1980). Given that hazard policy in our society is determined to a large extent by people inside and outside government who are not scientists or hazard assessment experts, it is important to know whether lay people are able to understand and judge our hazard descriptors and whether these descriptors capture their concerns. Although we cannot offer a definitive answer to these questions, we can report on the results of a pilot study of a group of 34 college-educated people (24 men, 10 women, mean age 24) living in Eugene, Oregon.

To test perception, we created nontechnical definitions and scoring instructions for the causal descriptors of hazard and asked our subjects to score our hazard sample. (See Hohenemser et al. 1983.) After an initial trial, "concentration" was judged too difficult for our respondents to score. For similar reasons, 12 of the less familiar hazards were omitted. The subjects then scored 81 hazards on 11 measures, using only our instructions and their knowledge, reasoning, and intuition.

The results indicated reasonably high correlations between the scores derived from the scientific literature and the mean judgments of our lay sample. As shown in Table 10, correlation coefficients ranged from a low of 0.65 to a high of 0.96 for the 11 descriptors that were scored. As illustrated in three sample scatter plots (Figure 6), despite high correlation coefficients, deviations of a factor of 100 between scientific and lay estimates were encountered. This suggests that there are significant biases in lay perceptions for some descriptors and some hazards. There is also a tendency by the subjects to compress the scale of their judgments; in effect, lay judgments exhibit systematic overevaluation of low scoring hazards and systematic underscoring of high scoring hazards. This effect is not an artifact of regression toward the mean but appears in the scores of individual subjects as well. Similar effects have been found by Lichtenstein et al. (1978) in previous comparisons of "perceived risk" and annual mortality.

To test whether our causal structure descriptors capture our subjects' overall concern with risk, we collected judgments of "perceived risk," a global risk measure whose determinants have been explored in previous psychometric studies (Fischhoff et al. 1978; Slovic, Fischhoff, and Lichtenstein 1980). Subjects were asked to consider "the risk of dying across all of U.S. society," as a consequence of the hazard in question and to express their judgement on a relative scale of 1–100. The correlation between perceived risk defined in this way and our descriptor scores across all 81 hazards is illustrated in Table 11 (top). Modest positive correlation coefficients, between 0.30 and 0.57, were obtained in 9 or 12 cases. This implies

Table 10. Correlation of Lay and Scientific Judgments of Hazard Descriptors

Hazard descriptor	Correlation coefficients		
	Energy hazards	Materials hazards	All hazards
Technology descriptor			
1. Intentionality	0.95	0.84	0.89
Release descriptors			
2. Spatial extent	0.83	0.89	0.87
3. Concentration	N/A	N/A	N/A
4. Persistence	0.33	0.62	0.79
5. Recurrence	0.85	0.73	0.80
Exposure descriptors			
6. Population at risk	0.77	0.73	0.74
7. Delay	0.88	0.92	0.96
Consequence descriptors			
8. Human mortality (annual)	0.79	0.77	0.76
9. Human mortality (maximum)	0.89	0.75	0.79
10. Transgenerational	0.34	0.56	0.65
11. Nonhuman mortality (potential)	0.82	0.75	0.78
12. Nonhuman mortality (experienced)	0.63	0.73	0.71

that each individual hazard descriptor can explain only a small portion of the variance in perceived risk.

In Table 11 (bottom), we show the correlation of the five factors with perceived risk.* Modest positive correlations were obtained in four of five cases. Because the factors are linearly independent, the summed variance of the factors may be used to determine the total variance "explained" by our hazard descriptors. Based on the sample of 34 young Oregonians, we conclude that our hazard descriptors account for about 50% of the variance in perceived risk. As might be expected from the earlier work on risk perception, perceived risk shows no significant correlation with the factor mortality.

When the analysis is carried out using not our descriptor scores but average ratings obtained from our 34 subjects, correlations with perceived risk increase substantially and factor scores derived from the subjects' descriptor ratings explain 85% (not 50%) of the variance in perceived risk (see Table 12). We conclude, therefore, that our hazard descriptors are well understood by our pilot sample of nonexperts and that they capture most of the global concern with risk that is expressed in the variable "perceived risk." Nonetheless, before these conclusions can be cast in a more general form, much additional work is needed with larger, more representative samples.

APPLICATIONS TO HAZARD MANAGEMENT

In addition to improving our understanding of hazards, our conceptualization of hazardousness can assist in the social and technological controls that society employs to ease the burden of hazards. Though detailed discussion of hazard management is beyond the scope of this paper, we can envision three ways of improving this process.

* In this case, since we are interested only in statistical correlation, we used standardized factor scores derived from factor analysis.

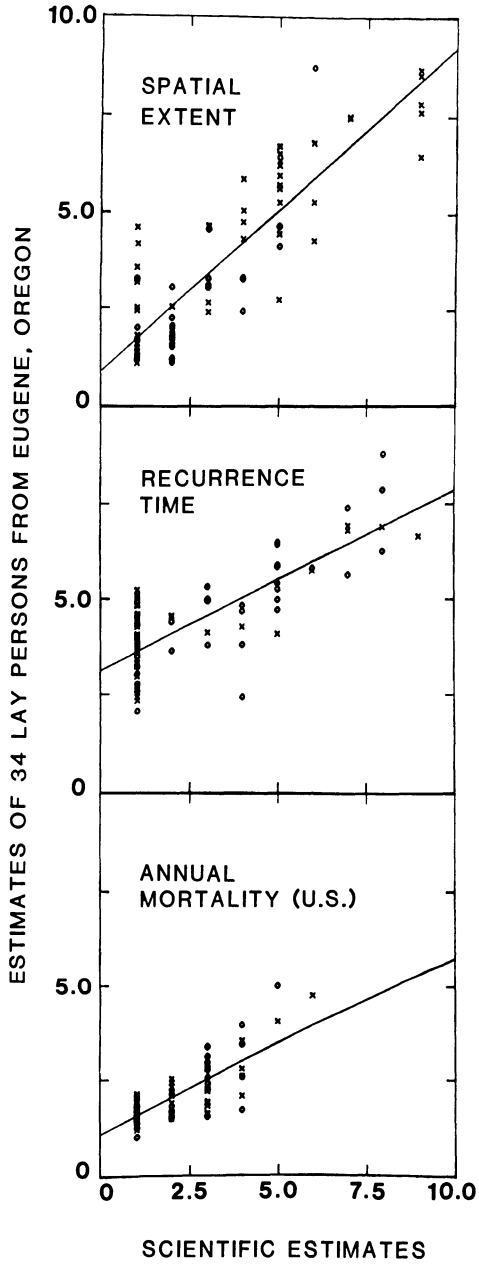

Figure 6. Scatter plots with linear regression lines indicating correlation between mean lay judgments and our estimates of hazard descriptors. The three cases illustrate the principal features of these correlations: (1) a generally high degree of correspondence between the two types of judgment; (2) some deviations corresponding to a factor of as high as 1000 (3 scale points) on quantitatively defined logarithmic scales; (3) except for the case of spatial extent (top graph), a significant compression of scale for lay judgments, indicated by a slope less than unity.

Comparing Technologies

Basic to hazard management are comparisons and choices between competing technologies. In debates on electricity generation, for example, comparisons between coal and nuclear power are common. Insofar as such comparisons involve hazards, they are invariably couched in terms of mortality estimates. A controversial recent example is the estimate by Inhaber (1979) that coal has a 50-fold larger mortality rate than nuclear power, as illustrated in Figure 7 (top). Quite aside from the validity of Inhaber's methods, which have been questioned (Holdren et al. 1979; Herbert, Swanson, and Reddy 1979), such one-dimensional comparisons create considerable controversy and dissatisfaction because they ignore other

Table 11. Correlation of Causal Structure Descriptors with Psychometrically Determined Values of "Perceived Risk" across Eight-One Hazards

Hazard descriptor	Correlation coefficient (only r values at greater than 0.95 confidence level are given)
Technology descriptor	
1. Intentionality	0.28
Release descriptors	
2. Spatial extent	0.57
3. Concentration	—
4. Persistence	0.42
5. Recurrence	—
Exposure descriptors	
6. Population at risk	0.42
7. Delay	0.30
Consequence descriptors	
8. Human mortality (annual)	—
9. Human mortality (maximum)	0.53
10. Transgenerational	0.43
11. Nonhuman mortality (potential)	0.53
12. Nonhuman mortality (experienced)	0.30
Factors	
1. Biocidal	0.32
2. Delay	0.41
3. Catastrophic	0.32
4. Mortality	—
5. Global	0.30
Variance explained = Σr^2	0.50

Table 12. Correlation of Decision Research Causal Structure Descriptors with Psychometrically Determined Values of "Perceived Risk" across Eighty-One Hazards

Hazard descriptor	Correlation coefficient (only r values greater than 0.95 confidence level are given)
Technology descriptor	
1. Intentionality	0.46
Release descriptors	
2. Spatial extent	0.72
3. Concentration	[a]
4. Persistence	0.56
5. Recurrence	—
Exposure descriptors	
6. Population at risk	0.67
7. Delay	0.34
Consequence descriptors	
8. Human mortality (annual)	0.32
9. Human mortality (maximum)	0.71
10. Transgenerational	0.72
11. Nonhuman mortality (potential)	0.71
12. Nonhuman mortality (experienced)	0.48

[a] No data for this descriptor.

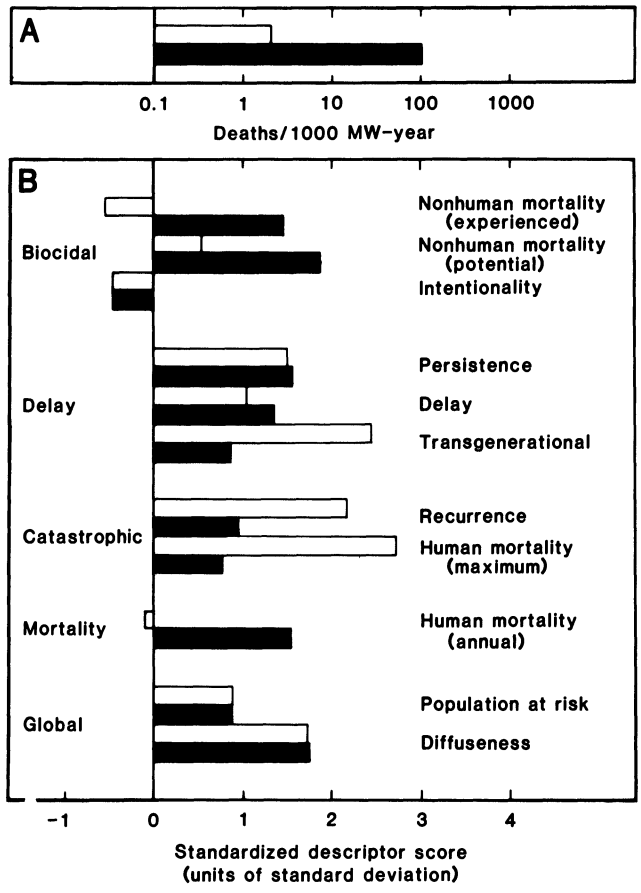

Figure 7. Comparison of nuclear and coal-fired electric power, shown by light and dark shading, respectively, using Inhaber's analysis (top) and our hazardousness concept (bottom). Labels on the left are factor names, labels on the right are names of descriptors belonging to each factor. For the method used in computing the "combined" descriptor scores plotted here, see footnote * on p. 271.

important differences, including other aspects of hazardousness between the two technologies.

Our broader conceptualization of hazardousness offers a partial solution. To illustrate, we show in Figure 7 (bottom) our multidimensional hazard profile for coal and nuclear power. This profile was obtained by combining descriptor scores for each of several hazard

Table 13. Factor Score Coefficient Matrix

Variable			Factor score coefficients for factors				
No.	Mean	S.D.	1	2	3	4	5
12	3.9	1.5	0.42	−0.07	−0.15	−0.03	−0.08
11	4.6	2.4	0.31	−0.05	−0.00	−0.14	0.15
1	3.7	1.6	0.41	−1.2	−0.04	0.18	0.09
4	4.4	3.0	0.01	0.32	−0.02	−0.10	−0.08
7	4.8	3.1	−0.03	0.38	−0.18	0.01	−0.07
10	4.4	1.9	−0.21	0.47	0.15	0.25	−0.10
5	2.7	2.4	−0.09	−0.08	0.47	−0.10	−0.08
9	1.8	1.6	−0.06	0.09	0.44	0.10	0.03
8	2.1	1.2	0.02	0.08	−0.00	0.67	0.03
6	7.6	1.7	0.11	−0.06	0.02	0.30	0.57
3	5.1	1.8	0.14	0.07	0.05	0.17	−0.59
2	3.5	2.5	0.02	0.06	0.19	−0.29	0.27

chains making up the multihazards of coal and nuclear power.* As can be seen, coal exceeds nuclear power in human mortality, as would be expected from Inhaber's analysis. Coal also exceeds nuclear in nonhuman mortality (that is, environmental effects). Nuclear power, on the other hand, dominates in transgenerational effects and in the catastrophic factor. The two technologies show little difference in persistence, delay, population at risk, and diffuseness.

We believe that our 12-descriptor profile better captures the complexity of choice in energy risk assessment and management than the common mortality index. At the same time, it in no way settles the problem of choice but raises an interesting, new, and largely normative question: How should society weight the different dimensions of hazardousness?

Dealing with the Hazard of the Week

Analysis of national news media shows that 40–50 hazards receive widespread attention each year (Kates et al. 1977). In theory, each new hazard goes through a sequence of problem recognition, hazard assessment, and managerial action. Often there is need for early managerial response of some kind. To this end, our descriptors of hazardousness provide a quick profile allowing new hazards to be grouped with other hazards having similar profiles.

To illustrate this possibility we scored the new hazard "tampons—toxic shock syndrome" using available information. From profile comparisons we were able to determine that this hazard was most similar in structure to the previously scored hazards "contraceptive IUDs side effects," "aspirin overdose," "Valium misuse," and "Darvon overdose." Such comparisons will provide industrial or governmental hazard managers immediate access to relevant, albeit incomplete precedents, and can provide warning of unexpected problems, a range of suggested managerial options, and, at the very least, a measure of consistency in public policy. Indeed, subsequent societal response on tampons has paralleled that of IUDs, the hazard in our inventory closest in structure to tampons.†

A Case for Triage?

As a society we cannot make extraordinary efforts on each of the 100,000 chemicals or 20,000 consumer products in commerce. If our causal structure and its descriptors reflect key aspects of hazards—threats to humans and the things they value—then our taxonomy provides a way of identifying those hazards worthy of special attention. Cases with extreme scores in each of the five composite dimensions of hazard have already been identified in Table 3, and these lead naturally to a proposal for "triage": extraordinary attention for

* To obtain "combined" hazard profiles, the hazards of coal-fired electric power were taken to be numbers 11, 47, 48, 49, and 58 in Table 3, and those of nuclear electric power numbers 69, 72, and 88. Consistent with the logarithmic character of most of the descriptor scales, corresponding descriptor scores from different hazard chains were combined through the addition algorithm: score $(a + b + c \ldots)$ = maximum $(a,b,c \ldots)$. In effect, combined hazardousness on a given descriptor is determined by the highest scoring component hazard. Because of the negative loading of "concentration" on the Global factor, "minimum" was substituted for "maximum" in applying the above algorithm to the descriptor "concentration."

† Management for IUDs and tampons included three responses: (1) removal of the specific product(s) most associated with health effects, (2) stricter classification and scrutiny by the regulatory agency, and (3) warnings and recommendations for use packaged with all other products in generic class. Details of managerial activity on IUDs are discussed by M.P. Lavine, *Contraceptives: hazard by choice*, in: *Perilous Progress: Managing the Hazards of Technology*, R.W. Kates, C. Hohenemser, and J.X. Kasperson, eds., Westview, Boulder, CO, 1985; data on tampons are from L. Kobren, Bureau of Medical Devices, Food and Drug Administration, personal communication on 23 June, 1981.

multiple extreme hazards, distinctive effort for each of the groups of extreme hazards, and an ordered, routine response for the remainder.

While we regard the suggestion of triage as a potentially useful application of our taxonomy, it is well to remember that many of the extreme hazards (e.g., nuclear weapons) are among a group that has defied solution for a long time and that special effort expended on them may produce few concrete results. This leads some to argue that society should focus its effort on cases of proven cost-effectiveness—cases with the maximum reduction in hazardousness per unit expenditure.

We regard neither triage nor adherence to cost-effectiveness criteria as adequate foundations of hazard management; rather, we see them as two horns of a familiar dilemma: whether to work on the "big questions" where success is limited, or to work on the normal, where success is expected. In this context, our taxonomy at the very least provides a means for identifying the "big hazards" in a consistent manner.

SUMMARY AND CONCLUSIONS

All taxonomies are based on explicit or implicit assumptions, and ours is no different. We assume that technological hazards form a single domain, that they are defined by causal sequences, and that these are usefully measured by a few carefully chosen physical, biological, and social descriptors. Our approach leads us to distinguish between energy and materials releases and provides a method for constructing profiles of hazardousness that considerably extend the conventional concept of "risk" as annual human mortality.

Based on a pilot study, we have shown that our profiles of hazardousness appear comprehensible to lay people and that they capture a significant fraction of our subjects' concern with hazardousness. This suggests that some conflict between experts and lay people may be resolved by clarifying the way by which hazardousness is defined.

Based on preliminary investigations, we expect that our approach can improve the quality and effectiveness of hazard management. In particular, it may help in comparing hazards of competing technologies, provide for a quicker, more orderly response to new hazards, and offer society a rational approach to "triage."

We recognize that our work is still largely conceptual and illustrative. As such, it requires critical evaluation by others, as well as further elaboration by ourselves. For example, there are obviously other descriptors that might be used in measuring hazards, as well as other ways of analyzing and displaying their correlational structure. These may lead to alternative and perhaps better ways of representing the essential features of hazards and the relation between them. Beyond that, it is clear that ways must be found for assigning weights to different descriptors of hazardousness. We have not addressed the weighting question here because in the present stage of the work this is premature.

Whatever the outcome of future elaboration, we are confident that our basic assumptions will hold: that hazards as causal sequences form a coherent domain which can be ordered through a number of independent physical, biological, and social descriptors.

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REFERENCES

Bick, T. and R.E. Kasperson 1978. Pitfalls of hazard management; the CPSC experiment. *Environment* 20(8):30–42.

Burton, I., R.W. Kates, and G.F. White 1978. *The environment as hazard.* Oxford University Press: New York.

Cohen, B.L. and I. Lee 1979. A catalog of risks. *Health Physics* 36:707–722.

Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, and B. Coombs 1978. How safe is safe enough?—a psychometric study of attitudes towards technological risks and benefits. *Policy Sciences* 8:127–152.

Greenwood, D.R., G.L. Kingsbury, and J.G. Cleland 1979. *A handbook of key federal regulations and criteria for multimedia environmental control,* Report Number EPA-600/7-79-175. Environmental Protection Agency: Washington.

Haddon, W. 1975. Reducing the damage of motor-vehicle use. *Technology Review* 77 (July/Aug):52–59.

Harriss, R.C., C. Hohenemser, and R.W. Kates 1978. Our hazardous environment. *Environment* 20(7):6–13.

Herbert, J.H., C. Swanson, and P. Reddy 1979. A risky business: energy production and the Inhaber report. *Environment* 21(6):28–33.

Hohenemser, C., R.E. Kasperson, and R.W. Kates 1982. Causal structure: a framework for policy formulation. In *Risk in the technological society,* ed. C. Hohenemser and J.X. Kasperson. Westview Press: Boulder.

Hohenemser, C., R.W. Kates, and P. Slovic 1983. The nature of technological hazard. *Science* 230:378–384.

Hohenemser, C., et al. 1983. Methods for analyzing and comparing technological hazards: definitions and factor structures. CENTED Research Report No. 3. Center for Technology, Environment, and Development: Clark University, Worcester, Mass. 01610.

Holdren, J.R., K. Anderson, P.H. Gleick, I. Minter, G. Morris, and K.R. Smith 1979. *Risk of renewable energy resources: A critique of the Inhaber report.* Berkeley Energy and Resources Group: University of California: Berkeley.

Inhaber, H. 1979. *Risk of energy production.* Report number AECB 1119/rev.3, 4th edition. Atomic Energy Control Board: Ottawa, Canada.

Kasper, R. 1980. Perceptions of risk and their effects on decision making. In *Societal risk assessment: How safe is safe enough?* ed. R.C. Schwing and W.A. Albers, Jr. Plenum: New York.

Kates, R.W., W.C. Clark, B. Fischhoff, R.E. Kasperson, S. Lichtenstein, and P. Slovic 1977. *Managing technological hazard: Research needs and opportunities.* Institute for Behavioral Science, University of Colorado: Boulder.

Lawless, E.T. 1977. *Technology and social shock.* Rutgers: New Brunswick, N.J.

Lawless, E.T., M.V. Jones, and R.N. Jones 1984. *Comparative risk assessment: Toward an analytical framework.* Midwest Research Institute: St. Louis.

Lichtenstein, S., P. Slovic, B. Fischhoff, M. Layman, and B. Coombs 1978. Judged frequency of lethal events. *Journal of Experimental Psychology: Human Learning and Memory* 4:551–578.

Litai, D., D.D. Lanning, and N.C. Rasmussen 1981. *The public perception of risk.* Department of Nuclear Engineering, Massachusetts Institute of Technology: Cambridge.

Lowrance, W.W. 1976. *Of acceptable risk: Science and the determination of safety.* William Kaufmann: Los Altos, Calif.

National Safety Council 1982. *Accident Facts.* National Safety Council: Chicago.

Nuclear Regulatory Commission 1975. *Reactor safety study,* WASH-1400, NUREG 75/014. Nuclear Regulatory Commission: Washington.

Otway, H.J. and J.J. Cohen 1975. *Revealed preferences: Comments on the Starr risk–benefit relationship;* Report number IIASA-RM-75-5. International Institute for Applied Systems Analysis: Laxenburg, Austria.

Rowe, W.D. 1977. *The anatomy of risk.* Wiley: New York.

Slovic, P., B. Fischhoff, and S. Lichtenstein 1979. Rating the risks. *Environment* 21(3):14–20, 36–39.

Slovic, P., B. Fischhoff, and S. Lichtenstein 1980. Facts and fears: understanding perceived risk. In *Societal risk assessment: How safe is safe enough?,* ed. R. Schwing and W.A. Albers, Jr. Plenum: New York.

Starr, C. 1969. Social benefit versus technological risk. *Science* 166:1232–1238.

Tuller, J. 1985. Economic costs and losses. In *Perilous progress; Managing the hazards of technology,* ed. R.W. Kates, C. Hohenemser, and J.X. Kasperson. Westview: Boulder, Colo.

Vlek, C. and P.J. Stallen 1981. Judging risks and benefits in the small and large. *Organizational Behavior and Human Performance* 28:235–271.

Wilson, R. 1979. The risks of daily life. *Technology Review* 81(Feb.):40–46.

World Health Organization 1976. *World Health Statistics Annual.* World Health Organization: Geneva.

11

Risk–Cost–Benefit Methodology and Equal Protection

Kristin Shrader-Frechette

INTRODUCTION: A LESSON IN METHODOLOGY

Ten years ago, it was commonplace for economists to calculate the value of human life as the lost economic productivity associated with a shortened life-span.[1] As is well known, such a view has been shown to be grossly inadequate. Most obviously, it leads to counter-intuitive results, such as that the value of the life of a 65-year-old laborer is equal to the sum of his remaining earnings until retirement or that the value of the life of a small child is near zero, since her future earnings are discounted at a market rate of interest.

From a methodological point of view, the great tragedy of using this formula to estimate health risks and benefits, is not merely that it misrepresents the worth of human life. A significant problem is also that uncritical use of such simplistic assumptions has probably helped to produce a reactionary rejection of all attempts, even sensitive and sophisticated ones, to analyze rationally certain risks and benefits and to quantify many parameters of various safety programs, two necessary components of reasoned policy making. My purpose here, however, is not to outline a defense of analytic assessment techniques, even though I strongly support them.[2] My concern, instead, is to argue that these analytic methods ought to be improved. In particular, I argue that assessors ought to reject uncritical use of one highly doubtful methodological tenet which I call the "commensurability presupposition." This is the assumption that the marginal cost of saving lives, across opportunities, ought to be the same. If this presupposition is not used more cautiously, then its employment may jeopardize both the success and the acceptance of analytical risk–cost–benefit assessment, much as incautious use of the earlier presupposition (that human lives ought to be valued solely in terms of remaining discounted economic productivity) has jeopardized both the success and the acceptance of cost–benefit analysis.[3]

In this essay, I examine some of the doubtful epistemological and ethical premises upon which the commensurability presupposition rests. In general, I ask whether subscribing to

Kristin Shrader-Frechette • Department of Philosophy, University of Florida, Gainesville, Florida 32611.

this presupposition commits one to begging the question of whether a given level of risk is acceptable. In particular, I analyze three claims often made to support the presupposition: the equity claim, the rationality claim, and the responsibility claim. Next, I evaluate several criteria in terms of which the use of the commensurability presupposition may be judged acceptable or unacceptable in certain situations. I maintain that, while use of this presupposition is acceptable in specific types of "easy cases", it is unacceptable in so-called "hard cases." I argue that, although the commensurability presupposition ought not to be accepted in all instances, two principles help to determine the cases in which its use is acceptable. These are the principle of *prima facie* egalitarianism and the principle of everyone's advantage.

THE COMMENSURABILITY PRESUPPOSITION AND CURRENT RISK ANALYSIS

Faced with the task of evaluating the acceptability of various risks, analytic assessors usually address at least two questions: (1) How has society valued certain risks? and (2) Given these evaluations, how ought public monies be spent to reduce various societal risks? Assessors often employ the commensurability presupposition because it provides them with a clear criterion for answering question (2). Provided that use of this criterion is consistent with acceptable societal evaluations, it defines an expenditure for risk reduction as desirable, so long as the same funds could not be used more cost-effectively to reduce a greater risk.

In attempting to answer question (1), assessors generally follow one of two methodologies "for inferring social values": "revealed preferences" or "observed preferences,"[4] and "expressed preferences" or "psychometric survey."[5] Apart from which of these two methodologies they follow in answering question (1), risk assessors generally adhere to the commensurability presupposition when they address question (2). Theorists such as Starr, Whipple, Hushon, Okrent, Maxey, Cohen, and Lee, for example, agree that the effort required to control societal risk, as measured by the cost per life saved, ought not to vary from one risk to another. Moreover, they claim, preferred safety policies ought to be those which save the greatest number of lives for the least amount of money.[6]

In defending the commensurability presupposition, its proponents typically rely on three different arguments, each of which deserves careful analysis. I call these the equity claim, the rationality claim, and the responsibility claim.

The "Equity Argument" for the Presupposition

The equity claim is that policy makers ought to follow the commensurability presupposition because doing so will provide all people with equal treatment and equal protection from societal hazards. Advocates of politically "left" policy, as well as risk assessors, often champion this claim. They maintain that, unless the commensurability presupposition is followed, more funds will be spent to safeguard the health and safety of politically powerful groups, while fewer monies will be spent to protect the well-being of politically powerless people.

In defending the equity claim, one critic of risk assessment asks, for example, why government regulations on coke oven emissions have been designed "to protect the lives of steelworkers at $5 million each," while a national Pap smear screening program, "that would save women's lives at less than $100 thousand each," has gone unfunded.[7] Similar equity-related questions have been raised regarding other societal risks, particularly in cases where

government appears to be reducing the risks faced by the rich and powerful more than those borne by ordinary people. Airplane risks, for example, are faced primarily by those who have above-average wealth and political power, while automobile risks cut across a wider and more diverse group of affected persons. According to some theorists, society spends more to save people from airplane accidents than from automobile accidents precisely because airline safety is championed by the powerful people most likely to be affected by it. On this view, the common man has no comparable champion. In the absence of a societal mandate to follow the commensurability presupposition, say proponents of the equity claim, the net result is that societal expenditures implicitly value the lives of air travelers more than those of automobile travelers.

After noting that in France $30,000 is spent annually per life saved through automobile accident prevention, while $1 million is spent annually per life saved through airplane accident prevention, Okrent criticizes the fact that the same "value of life" was not used.[8] Likewise, Starr and Whipple maintain that, in an optimum safety policy, "the comparative marginal cost-effectiveness of each opportunity for saving lives would become the guiding principle in the allocation of resources, and the value of life would be implicit in the total national allocation of funds."[9] According to participants in a recent panel on risk assessment, use of the commensurability presupposition is one way to treat people equitably; "in terms of establishment of uniform rates of the value of life, a basic unit for health insult is needed. Different agencies must reach a common basis for making decisions."[10] If they do not, claim assessors, our cherished traditions of equal protection will be eroded.

The "Rationality Argument" for the Presupposition

Proponents of the rationality claim make a somewhat different case for the commensurability presupposition. In appealing for consistency in the marginal cost of risk reduction across opportunities, they assert that their goal is "to make people approach risks more rationally."[11] Supporters of this argument appear to believe that there is a univocal concept of rationality. Rational choices, for them, are economically efficient choices. For proponents of the rationality argument, like Hafele and Okrent, subscribing to this univocal concept of rationality is merely a matter of being consistent. "Consistent," rational people, they claim, would spend the same amount of money for the same level of risk abatement, regardless of the risks involved. People do not deal with all hazards in a consistent and rational manner, says Hafele, because they have unreasonable fears stemming largely from their ignorance of technology, especially new technology. He maintains that they have irrational perceptions of how to deal with risks such as those from liquefied natural gas (LNG) and nuclear facilities. Following this same line of argument, Okrent asks why we spend great sums of money to save persons from accidents at LNG facilities, but virtually nothing to save them from natural disasters such as flooding.[12]

Fischhoff, Slovic, and Lichtenstein ask why our legal statutes are "inconsistent"; why are they less tolerant of carcinogens in the food we eat than of those in the water we drink or the air we breathe? Why, they ponder, should we spend more to protect people from carcinogens in food than from carcinogens in air or water? In the United Kingdom, they maintain that this same inconsistency is apparent; 2500 times as much money is spent there, to save one life through safety measures in the pharmaceutical industry, as is spent to save one life through safety measures in the agricultural industry.[13]

Proponents of the rationality argument claim that failure to subscribe to the commensurability presupposition is to be guilty of inconsistency. They believe that it is not consistent to expend funds to achieve a particular level of health and safety in one area, if spending

the same or fewer monies would provide a greater level of health and safety in another area. In other words, the key assumption behind the rationality claim is that reasonable, consistent people save the "cheapest" lives first, or spend funds so as to maximize health and safety for the greatest number of people.

The "Responsibility Argument" for the Presupposition

Another defense of the commensurability presupposition is made on the grounds of the responsibility claim. Proponents of this view argue that, if one does not follow the commensurability presupposition, then he is responsible for the lives or health lost by pursuing schemes which do not save the "cheapest" lives first. They maintain, for example, that if one opts to spend $1 million to save one life through airplane accident prevention, when the same expenditure for automobile prevention could have saved 33 lives, then one is responsible for the 32 excess deaths.[14]

Proponents of the responsibility claim place great weight on the fact that resources for the reduction of risk to the public are not infinite. They maintain that if we tolerate different marginal costs for saving lives, "if we are spending the available resources in a way that is not cost-effective, we are, in effect, killing people" and are "responsible for unnecessary deaths."[15]

By virtue of their emphasis on spending finite funds so as to save the greatest number of lives, proponents of the responsibility claim implicitly appeal to a triage way of thinking. Borrowed from French military medicine, the term *triage* refers to doctors' practice of separating battlefield wounded into three groups: (1) those for whom immediate medical care will make a difference between life and death; (2) those who will likely die, even if they receive immediate medical attention; and (3) those who will likely live, whether or not they receive immediate medical attention. Since the doctors have limited resources (time and medical supplies), they are often said to have a duty to attend first to the wounded in category (1). If they do not follow this strategy, they might be said to be responsible for excess battlefield deaths. For the proponents of the responsibility claim, limited medical resources on the battlefield are analogous to the limited societal resources for risk abatement. They believe that, just as the battlefield doctors ought to maximize the numbers of lives saved with their finite resources, so also policy makers ought to follow the commensurability presupposition and maximize the number of deaths averted through risk abatement. Otherwise, they are "responsible" for excess deaths.

REASSESSING THE COMMENSURABILITY PRESUPPOSITION

Problems with the Presupposition

Plausible as are these three appeals for equity, rationality, and social responsibility, there are a number of reasons why none of them provides convincing grounds for adherence to the commensurability presupposition in all, or even most, instances. Let us examine each of the claims more closely.

Five Faulty Assumptions Underlying the Equity Claim. The equity claim rests on the fundamental assumption that, to guarantee persons equal protection, the marginal costs of saving lives ought to be the same for all risks. In other words, proponents of this view maintain that sameness of expenditures (that is, spending the same amount per life

saved), across risk-reduction schemes, is necessary for providing persons with equality (sameness) of protection.

This is a powerful claim and a compelling assumption, especially because many people chafe at the thought of different amounts of money being spent to save persons' lives, depending on whether they are rich or powerful or male, precisely because they are rich or powerful or male. Our populist sympathies probably lie almost totally with sameness of expenditures. Discrimination in protection is profoundly disturbing. Yet, the emotive power of the equity claim camouflages a number of reasons why it fails to provide convincing ethical grounds for following the commensurability presupposition. In the following paragraphs, I will uncover the precise nature of the errors inherent in the equity claim. These errors include the assumption that sameness of risk expenditures provides either necessary or sufficient conditions for sameness of protection against risk, that sameness of protection is not significantly different from equality of protection, that sameness of concern or respect is not significantly different from sameness of treatment, and that rights to equality or sameness of protection are rights in the strong sense. Let us examine each of these assumptions in detail.

In arguing that the marginal cost of saving lives across public safety programs ought to be the same, proponents of the equity claim appear to be assuming that persons subject to diverse risks all need the same level of protection from the government. It is not clear, however, that everyone needs the same level of expenditures to protect him from given societal risks. Some proponents of the equity claim maintain, for example, that policy makers who pursue risk reduction ought to cost the lives of automobile travelers the same as those who travel by plane (see note 8). However, the safety of automobile travelers is far more dependent on individual choices, e.g., whether to ride with a drunken driver or whether to use a seat belt, than is the safety of airplane passengers. In this sense, it is not clear that automobile travelers need the same level of government-guaranteed risk reduction as airplane passengers do. If the airplane and auto cases are fundamentally disanalogous in that the individual has more control over risk reduction in automobiles, then it is less plausible to argue that the government ought to guarantee the same levels of expenditures for both, thereby ignoring the effects of an individual's behavior on his level of protection.[16] At least in the case where the same expenditures are not needed to provide the same protection, sameness of expenditures is not a necessary condition for the same protection.

Second, not only is sameness of expenditures not a necessary condition for the same protection against various risks, but it also is not a sufficient condition. Simply costing people's lives the same, across different risk-reduction programs, does not guarantee them the same protection. If one costed lives the same, for example, in reducing auto risk and radiation risk, this would not provide the same protection for all potential victims of automobile accidents and radiation exposures. In part this is because medical differences among persons place some of them at a higher risk from radiation. Children, those with allergies, and those with previous X-ray exposures, bear a higher risk than do others when all lives are costed the same. Providing the same level of protection is impossible, given persons' different levels of susceptibility but the same expenditures for risk reduction.[17]

Third, even if the same expenditures (across safety programs) did guarantee the same level of protection from risk, it is not clear that there are always morally relevant reasons why persons ought to receive the same protection. Genuinely equal protection might require protection which is not the same for all individuals. Without going into lengthy consideration of why all individuals might not deserve the same protection in all situations, I can suggest a few cases in which, given appropriate conditions, one ought to allow exposure to different levels of risk. Although these are not universalizable, the cases might include circumstances

in which the different protection is given/allowed: (1) as a reward for merit or virtue, (2) as a recompense for past deeds or actions, (3) as an incentive for future actions held to be highly socially desirable, or (4) as a provision for special needs. Obviously, for example, if one wishes society to have the benefit of the services of those persons who perform much needed functions, e.g., acting as president of the United States, then one must somehow give those persons better than equal protection in certain respects. Following circumstances (3) and (4), this "better" protection might be justified on grounds of incentives necessary to attract candidates to the office of president or necessary to provide stability to the country.

As legal philosopher Ronald Dworkin observes, there don't appear to be ethical grounds for claiming that everyone ought to receive the same treatment. There appear to be ethical grounds for claiming only that everyone ought to have the same concern or respect in the political decision about how goods, protection, and opportunities are to be distributed.[18] His point, and my observation about circumstances (1)–(4) above, is not that anyone's rights may be ignored in the safety calculations, but that one's interests may be outweighed by another's interests. For example, in certain circumstances, protecting the president of the United States may outweigh protecting a particular citizen. If this is so, then one ought to choose the risk-abatement policy which gives everyone the same concern or respect, but which provides an equitable basis for deciding when one person's interests outweigh another's. This means that use of different marginal costs, per life saved across opportunities, cannot be shown to be unethical merely because its effects do not give persons the same protection. To show this, one must argue either that there were no morally relevant reasons for different protection, or that persons were not given the same concern or respect, or that some persons' interests were erroneously judged to outweigh those of others. In other words, proponents of the equity claim make too simplistic an appeal to equal protection. At best, they are able to show only that, in a given case, good reasons support spending the same funds per life saved. Later in the essay, I will discuss what some of these good reasons might be.

Two Faulty Assumptions Underlying the Rationality Claim. Equity, however, is not the only basis alleged to support the commensurability presupposition. Numerous assessors have argued for it on the grounds of the rationality claim. This is the assertion that reasonable, consistent people would agree to spend funds in such a way as to maximize health and safety for the greatest number of people. In other words, they assume that rational people would choose to spend monies on risk reduction so as to save the greatest number of lives, or buy the greatest amount of health for the available dollars. However, there are a number of problems with this line of argumentation. What Okrent and other assessors forget, when they appeal to the rationality of setting risk-reduction priorities on the basis of economic efficiency, is that economic efficiency is neither the sole, nor necessarily the best, criterion for rational policy making. There are no common denominators among the costs, risks, and benefits of various health and safety programs. As a consequence, numerous evaluative assumptions are required to define some parameter as a basis for comparison among alternative programs. In this case, many assessors assume that "cost per life saved" provides an adequate basis in terms of which safety options may be ranked, even though this parameter alone is clearly not sufficient grounds for preferring one program over another. That it is not sufficient grounds is shown by numerous examples of rational decision making not based on "cost per life saved."

Consider four cases, in each of which safety options are ranked by a criterion other than economic efficiency. In the first, the so-called "rights case," the goal of guaranteeing rights trumps the goal of economic efficiency. Suppose, for example, the government funds

two safety programs, one to protect seasonal campers from volcanic activity in a given region, and one to protect civilians from radioactive emissions at a government weapons-testing facility. Obviously, government has a greater responsibility to protect citizens from risks which it involuntarily imposes than to protect them from those which are solely natural, or which they impose on themselves by their decision to camp in a particular area. This is in part because radioactive emissions can be controlled or mitigated, while many natural disasters cannot. Government, therefore, has more responsibility for that which is under its control. Second, the Fifth and Fourteenth Amendments to the U.S. Constitution provide guarantees against state action which limits equal protection, not against all natural events threatening well-being. This means that, although one has a legal right to equal protection from state-induced hazards, one has no clear legal right to equal protection from natural hazards. This being so, risk-reduction priorities in the volcanic safety/weapons safety case need not be set according to economic efficiency. Even though it might cost more to save lives/health in the weapons safety case, this might be the more rational policy choice. The reason is that victims in the weapons situation might have a stronger legal claim for rights violations than would victims in the volcano case.

In a second, or so-called civil liberties case, the goal of maximizing civil liberties might trump the goal of economic efficiency. Numerous examples of this situation come to mind. Suppose, for instance, that the government is funding two safety programs, one to provide centers for voluntary, no-cost checking of blood pressure, and the other to monitor drunken driving by administering mandatory breath tests between 10 p.m. and 6 a.m., to all drivers at selected checkpoints. Even if it could be shown that more lives per dollar would be saved by checking late-hour drivers, rather than by providing free blood-pressure monitoring, this would not mean that additional expenditures for administering breath tests were more desirable. A rational person or government, admittedly opposed to drunk driving, could well decide to maximize civil liberties and to avoid coercive controls on such driving. His decision to let civil liberties "trump" economic efficiency might be justified in part on the grounds that citizen participation in blood-pressure checks would be voluntary, while monitoring late-hour drivers would be involuntarily imposed.

Third, people or government could well make a rational decision to let pleasure trump economic efficiency. For example, suppose government were trying to decide whether to spend funds to prohibit the addition of sugar to selected cereals, breads, and juices, or to use the same monies for mass screenings for TB. Even if it could be shown that more lives per dollar could be saved by regulating sugar, it is not clear that government ought to accord this a higher priority than TB screenings. This is because a rational policy might allow people to maximize their pleasure from eating certain foods, rather than simply to save the greatest number of lives. Obviously many people choose, on given occasions, to maximize their pleasure rather than their health or safety. To claim that such valuations are irrational is to assume, erroneously, that the only rational, human goal is to protect health and safety. However, without some pleasure, perhaps health or safety is of little concern. As Bergstrom put it, "I know of no one who acts as if he subordinates all desire for other pleasures to maximizing his probability of survival."[19] After all, those who engage in hang gliding, skydiving, motorcycle riding, or even in eating rich desserts or drinking saccharin-spiked soda, can hardly be said to be making irrational choices.

Fourth, rational policy making could well be based on maximizing temporal, rather than economic, efficiency. For example, each time a person decides to take a trip on a small, private plane rather than on a commercial carrier, because the former mode of travel is quicker, he is maximizing temporal, rather than economic, efficiency. Analogously, the government could well decide rationally to spend funds in such a way that would enable

people to save time, rather than to maximize health/safety, especially if the risks to health and safety were very small and the time gains were very great. For example, the government might decide to spend safety funds to regulate automatic doors on subways rather than to spend the same monies to mandate speed reductions on the same trains. Even if the speed-regulation programs saved more lives per dollar than did the door safety programs, it could still be argued that efficiencies in time are sometimes more important than economic efficiencies and that the monies ought to be spent to regulate the doors.

What these four cases illustrate is that "cost per life saved" is often not a sufficient criterion for ranking public policy options. Because it is not, proponents of the rationality claim err in valuing health and safety above all else. Every time that a society affirms that it is willing to go to war, for example, it assents to the thesis that it values things other than health and safety. On a much more mundane level, people daily make trade-offs in favor of other kinds of values over safety: excitement, comfort, freedom, for instance. Many people also choose to live in a city, even though it is by now evident that doing so threatens their health and safety more than would rural life. In other words, safety or security in itself is not always something of value. Whether it is or not depends on what it and the threat to it are, and on what ends it is meant to serve. Security is merely the assurance that given interests will not be adversely affected. Since most policies decrease the ability to meet one set of interests, but increase the ability to fulfill others, no policy can be viewed as desirable purely on the grounds of meeting the interests of security.[20]

The insufficiency of the cost-per-life-saved criterion illustrates very well what Shackle calls "the problem of the single maximand."[21] There is no single parameter according to which two different safety programs may be ranked. This is because problems of resource allocation require multivariate solutions, taking many variables into account, rather than maximizing only the health or safety factor. As he puts it, society has no "weighing machine for the value of two actions."[22]

Besides the fact that there is no single maximand in deciding policy regarding health and safety, there is another problem with the rationality claim. This is that proponents of the claim are misguided in appealing to the consistency of the costs per life saved across opportunities. The appeal is misguided because allocative decisions in no way place a "value" on human life. If government spends x dollars to save y lives in one case, but w dollars to save z lives in another case, no inference about the relative value of life, in the two cases, can be drawn, purely on the basis of the relative expenditures. It is not true that the value of life in the first case is $\$x/y$, but that it is $\$w/z$ in the second case. Rather, the expenditures merely reveal a particular decision about how policy makers believe government ought to spend a given sum of money. More funds (per life saved) may be spent to aid victims in one situation, rather than another, because some victims are less able to control their own health/safety, or because certain classes of victims have a greater right to protection, or for some other reasons. Because such expenditures may be justified by appeal to many different value judgments, they do not necessarily contain any implicit statements about the relative value of life in various cases.[23] Hence, it makes no sense to appeal to the consistency of "valuations of life" across opportunities. Moreover, appeals for consistency of expenditures per life saved ignore the fact that many cases are quite disanalogous. One case might concern an involuntarily imposed, catastrophic risk to health and safety, for example, while another might concern a voluntarily chosen, individual risk. If the risks are dissimilar in these and/or other relevant respects, it is not clear why they should be treated consistently with respect to expenditures per life saved. Hence, it is not clear that one ought to support the rationality claim by a simple appeal to consistency across cases. Moreover, as the problem of the single maximand and my four counterexamples show, rational policy making cannot be identified

simply with maximizing economic efficiency. But if it cannot, then the rationality claim does not provide unequivocal support for the commensurability presupposition. At best, proponents of this claim are able to show only that, in a given case, good reasons support spending equal funds per life saved. Later in the essay, I will discuss what some of these good reasons might be.

Two Faulty Assumptions Underlying the Responsibility Claim. Just as there are problems with using the rationality claim and the equity claim to support the commensurability presupposition, so also there are difficulties with the responsibility claim. Formulated by Okrent and others, this claim is that whoever tolerates different marginal costs for saving lives is "responsible for unnecessary deaths."[24] In other words, if societal monies are not spent so as to save the greatest number of lives per dollar, then those who made this fiscal decision are responsible for the excess deaths, just as a battlefield doctor who does not follow triage is responsible for excess casualties. To avoid responsibility for having "killed people," goes the argument, one ought to support the commensurability presupposition.

The plausibility of the responsibility claim is a function of both its intuitive appeal and its implicit use of the economists' notion of opportunity costs. On the intuitive level, numerous people would probably want to say that policy makers who use tax monies to build bombs, rather than to feed impoverished people, are responsible for the malnourishment of many persons. They would probably want to claim that the bomb builders are responsible for exacerbating poverty, much as Okrent wants to claim that those who reject the commensurability presupposition are responsible for "killing people."

Such claims of responsibility are also plausible in light of the fact that persons are routinely held responsible for the opportunity costs of their actions and that excess deaths may be considered to be one type of such a cost. Every expenditure for a given program has (what an economist would call) an "opportunity cost." This is defined as the cost of foregoing other options for investment or for spending the funds. The opportunity costs of funds used in the production of good *A* consist of foregone opportunities of producing good *B*. For example, using water as a receptive medium for pollutants has, as an opportunity cost, precluded use of the water for drinking.[25]

Just as an industry is responsible for the opportunity costs of its decision to use water as a receptacle for pollutants, perhaps also the policy maker could be said to be responsible for the opportunity costs of his decision to fund one risk-abatement program rather than another. And if funding this program causes fewer lives per dollar to be saved, then the policy maker might be said to be responsible also for the excess deaths, since these are part of the opportunity costs of his decision.

Proponents of the responsibility claim—who maintain that policy makers are responsible for the "excess deaths" caused by pursuing one safety program over another—err, in general, by failing to limit the scope of their concept of responsibility. In subscribing to a notion of responsibility which is virtually unbounded, they make two main assumptions, both of which deserve further discussion. The first assumption is that one's responsibility for the opportunity costs of his actions always requires him to avoid the opportunity costs of excess deaths. The second assumption is that because excess deaths are allegedly an opportunity cost of one's actions, one is clearly responsible for them. Several considerations reveal that both assumptions are doubtful.

Consider first the assumption that one always ought to avoid the contingent opportunity cost of excess deaths. In making this assumption, proponents of the responsibility claim appear to believe that the opportunity costs of various safety investment programs are

analogous and ultimately reducible to issues of health and survival. On the contrary, they do not seem to me to be reducible in so simple a fashion.

The opportunity costs of two investments often differ because their purposes differ. The two programs mentioned by Okrent, for example, prevention of deaths from canyon flooding, and prevention of fatalities from LNG accidents,[26] are not reducible merely to the purpose of saving the most lives for the least money. Officials implementing safety programs in a given canyon, for example, cannot merely pursue risk reduction by prohibiting all building in the flood plain. Values such as the freedom of persons to buy their land and build on it, as well as rights to privacy and to property, have to be addressed alongside of, and perhaps instead of, the value of risk reduction.

Moreover, it seems clear that there is less justification for the government's telling a potential flood victim to what extent he can endanger himself on his land ("user" risk) than there is for the government's telling the LNG industry to what extent it can endanger the lives of other people ("third-party" risk). As it is, however, Okrent and other proponents of the responsibility claim have masked the impact of their value judgments about matters such as freedom, property, and privacy. This making has occurred, in large part, because of improper data comparisons (e.g., LNG vs. flooded-canyon hazards) stemming from an oversimplification of the problem of safety allocation.

But if the purposes, values, and goals of the two programs cannot be reduced simply to issues of health or survival, then the opportunity costs of these programs are not reducible simply to excess deaths or ill health. Investing in risk reduction at liquefied natural gas (LNG) facilities, for example, may include one type of opportunity cost (e.g., the excess deaths caused by not spending the LNG monies, instead, to prevent canyon flooding), while investing in risk reduction to protect potential victims of canyon flooding may include another type of opportunity cost (e.g., loss of certain property rights dealing with one's ability to use his land as he wishes). Because the opportunity costs in the two programs are not the same (i.e., loss of life vs. loss of rights), it is misleading to charge merely that investors who do not follow the commensurability presupposition are "responsible" for the excess deaths that could have been prevented through another investment. The charge is misleadingly accusative of the investor, both because not following the commensurability presupposition also would make one "responsible" for other undesirable opportunity costs, e.g., loss of certain property rights, and because, if one grants that persons are always responsible for the opportunity costs of their actions, then there is never a way for any investor to avoid responsibility for some type of negative opportunity costs.

Thus, while an investor may be "responsible" somehow for excess deaths, as Okrent claims, it is not obvious that he ought always to accept certain opportunity costs (e.g., violations of property rights) but always to avoid other opportunity costs (e.g., excess deaths caused by not maximizing the lives saved per dollar). This is because, as was explained in criticism of the rationality argument, one is not bound always to maximize the lives saved per dollar. But if this is so, then one's alleged responsibility for excess deaths is not necessarily grounds for subscribing to the commensurability presupposition. Hence, even if one is somehow "responsible" for excess deaths, this fact alone does not prove that one ought not to have taken the policy action allegedly resulting in these excess deaths. In other words, there is no clear connection between accepting the responsibility claim and therefore accepting the commensurability presupposition.

More importantly, there may be little reason to accept the responsibility claim in the first place. This is because, in general, it is built on a concept of responsibility which is virtually unbounded. Its proponents assume that one is always responsible for all the opportunity costs (in this case, excess deaths) of his actions/investments/policy decisions. Their

assumption is doubtful, however, because the causal connection between a particular investment and the opportunity cost of excess deaths is sometimes very tenuous. Let's see intuitively why this is the case, and then examine some more complex philosophical bases for questioning the causal connection between a particular investment and excess deaths.

Consider the case of a public official who decided to spend government funds to provide summer recreation programs to help keep disadvantaged young people safe and off the streets, rather than to help save local children who were victims of leukemia. Suppose also that it could be shown that more lives per dollar could be saved through the leukemia program, rather than through the recreation program. Following the responsibility claim, ought one to argue that the official was somehow responsible for the deaths of the children who otherwise might have been saved? Would the person funding the recreation programs be "killing people whose premature deaths could be prevented," as Okrent put it? Are the youths who use the summer recreation program likewise "responsible" for killing leukemia victims? On all three counts, one might intuitively answer "no" or, at least, "not necessarily." This is likely because the causal connection between a particular funding decision and excess deaths is very tenuous.

In the case of Okrent's investor who pursues risk reduction for LNG facilities and thereby is "responsible" for canyon deaths caused by failure to fund a canyon flooding safety program, the causal connection between LNG investment and the "excess" canyon deaths is tenuous because implementing the LNG program, alone, is not sufficient to cause the canyon program not to be funded and, therefore, is not sufficient to cause the excess deaths. Other people and other factors also contribute to the deaths, e.g., perhaps the victims themselves, if they are careless. But if persons besides the investor or decision maker are also responsible, then it is inaccurate simply to say that he is as responsible for the canyon deaths as the polluter is for deleterious health effects which his emissions are alone sufficient to cause. Clearly, where responsibility is divided among many persons/groups, each person (e.g., the decision maker) bears less than total responsibility.

Bayles argues against similar grounds for holding decision makers in developed countries responsible for lives lost in underdeveloped countries, and his remarks appear applicable here. He maintains that it is wrong to claim that people in developed nations are solely responsible for deaths in third world countries, because such a thesis rests on "role responsibility, that of being ultimately in charge because of one's position." Although good reasons may exist for holding a person liable for another's death (e.g., holding the auto manufacturer liable in a car accident), says Bayles, the person alleged liable cannot be said to have caused the death. This is because "role responsibility" is not, of itself, sufficient to cause a thing to occur. Individual stockholders of corporations, and individual citizens of countries, affirms Bayles, cannot by themselves effect a change in the policy of their corporations or their countries.[27] Likewise, to the extent that an individual policy maker does not by himself cause excess deaths, to that degree is he less responsible for them. Hence, even if proponents of the responsibility claim are correct, policy makers may be responsible only in a limited sense.

Third, the fact that failure to fund a given safety program is an act of omission, rather than an act of commission, suggests that responsibility for excess deaths (somehow partially attributable to this failure) may be mitigated. There are several reasons why it appears that one is more responsible for acts of commission than for acts of omission. Acts of commission are usually accomplished by actively doing something, while acts of omission are often the product of no active doing, intention, or choice: they may result simply from passivity. Also, since acts of commission require one to do something, rather than merely to accept what has been done, they are generally accomplished with more deliberation and purpose.

Acts of omission often are characterized by little deliberation or purpose. Frequently, therefore, one is more responsible for acts of commission because they are more likely to be actively, deliberately, and purposively chosen.[28] But if one is often more responsible for acts of commission, and if failing to fund a particular safety program is an act of omission, not commission, then contrary to proponents of the responsibility claim, certain investors may not be fully responsible for "killing people."

Fourth, contrary to the responsibility claim, an investor may not be culpable for "killing people" if he has no obligation to help save the greatest number of lives per dollar. One of the reasons why responsibility for the alleged opportunity costs of an action often exists is that one has an obligation not to violate the rights of others. One's responsibility, for example, for the opportunity costs of using the air as a receptacle for dangerous pollutants exists in part because of an obligation not to violate other persons' rights to property and to equal protection. Were there no such rights, then it would be useless to blame someone for "killing others." In the case of one's alleged responsibility for excess lives lost, because of investing in a given safety program rather than in another, obligations appear to play little, if any, role. If such a responsibility exists, it is because of an ideal to enhance societal welfare, not because of an obligation to recognize rights.

Although it might be argued, following W. D. Ross, that one does have an obligation to benevolence, there are at least two reasons why there is no obligation to maximize the number of lives saved per dollar. First, such an obligation to maximization would be impossible to meet under all circumstances. Ought implies can. Second, one has no right to have society maximize his health and safety by means of the commensurability presupposition, but only a right not to be harmed unjustly by another.[29] This point is most obvious in cases where improvements in health and safety can be obtained most cost-effectively by preventing people from harming themselves. For example, if prohibition of alcohol were the most cost-effective way to save lives per dollar, it is not clear that citizens would have the right to prohibition programs. At best, if at all, one seems able to argue only that such programs are defensible on the grounds that they help one to pursue the ideal of enhancing societal health and safety. But if maximization of health and safety is something to which one need have no right, then it is not clear that an investor is culpably responsible for not maximizing health and safety.

A related point is that assertions of responsibility for doing or not doing something are dependent for their meaningfulness on there being an "ongoing rule regulated system of expectations" to which an action or inaction comes as an exception.[30] Applied to the responsibility claim, this means that one is culpable for not saving the greatest number of lives per dollar only if his failure to do so is an exception to a recognized "ongoing rule regulated system of expectations." Since there is no recognized rule to maximize only economic efficiency in saving lives, then there is no clear culpability for failure to do so.

Moreover, to say that one is responsible for lives lost because of funding a given safety program, just as one is responsible for the opportunity or social costs of his actions, is to presuppose a particular view of the state. Only if one believes that the state exists, not only to prevent harms, but also to increase/redistribute welfare, could one argue that decision makers are equally responsible both for recognizing rights to equal protection and for enhancing welfare. If one does not accept such an extensive role for the state, then it makes no sense to hold decision makers responsible for failures to increase welfare by saving the greatest number of lives per dollar. In either case, one cannot claim to have a right to have the state increase welfare by maximizing health and safety. And if not, then there are limited grounds for agreeing with the responsibility claim. This, in turn, means that appeal to the

responsibility claim to support the commensurability presupposition is successful only if supported by good reasons relevant to a particular case. Providing these good reasons would presuppose, for example, (1) that the situation were one in which health/safety per dollar ought to be maximized; (2) that there were a clear, defensible causal connection between a particular investment and "excess deaths"; (3) that the failure to fund a given program (in which excess deaths occurred) was not merely an indeliberate omission; and (4) that failure to prevent these excess deaths was somehow a violation of an obligation or of some right. This brings us to the question of how to judge whether the equity claim, the rationality claim, and the responsibility claim ought to apply to a given situation and what might constitute good reasons for appealing to these three claims. In other words, when might there be good reasons for appealing to one of these claims to support the commensurability presupposition?

Factual Criteria for Using the Commensurability Presupposition: Simple Cases and Difficult Cases

As Okrent's LNG/flooded canyon example suggests, when assessors naively make appeals for equity, rationality, and responsibility in evaluating the cost per life saved across opportunities, their arguments often fail. This is because they neglect to distinguish the simple cases, in which the appeals to consistency or equity work, from the difficult cases, in which they do not. As a consequence, they ignore the fact that even in choosing safety programs, society must promote many values in addition to safety.

Let us look at an example in which the appeals to equity and rationality are successful, and thereby discover why similar appeals are frequently not successful. Consider the case of auto safety. On the basis of cost per traffic fatality forestalled, one could easily argue that it probably makes more sense to increase monies for building medians on all major highways than to step up funding for driver education programs.[31] In this example, there appear to be at least three good, factual reasons why the appeals to equity and rationality, across opportunities, are sensible, and why they have been used quite successfully in auto assessments by the U.S. Office of Technology Assessment.

First, there is a single constituency, the taxpayers, who bear the cost of the two alternative programs, and a single constituency, automobile drivers and pedestrians, who receive the benefits of both programs. Moreover, in developed countries, the class of all automobile drivers and pedestrians very nearly approximates the class of all taxpayers. This means that the class of those receiving the benefits of both safety programs is almost the same as the class of those bearing the costs of both programs. As a consequence, it is much less likely that troubling questions of distributive equity will arise in this example, as compared to cases whose constituencies are vastly different.

Second, both programs (driver education and road construction) share a quite narrow purpose and value: improving the health, safety, and efficiency of automobile travel. On the contrary, consider what might happen if one were to compare two safety programs with quite different purposes and values. Suppose one were directed at the private sector, e.g., reducing fatalities from fires at private residences, while the others were directed at the public sector, e.g., reducing fatalities from fires in rental units or hotels. If these two cases were compared, then one would have to take different values into consideration. These might include the rights to private property and the responsibility to protect the common good. But, as a consequence of having to consider somewhat diverse goals and values for

each safety program, it would be far less plausible merely to compare the two programs solely on the basis of their marginal cost per life saved.

Third, another reason for the success of the appeals to equity and rationality in the two auto safety cases is that the two programs address the same sorts of hazards having the same types of effects; that is, the risks and benefits are in the same class. Obviously it is less question begging to assume that two programs ought to be consistent, with respect to the value they place on saving life, if the effects of the two cases are similar. For example, it appears somewhat reasonable to compare two broad-spectrum chemical pesticides, each with similar effects, solely on the grounds of the commensurability presupposition, in order to determine how one might save the most lives for the least money. The comparison would be less reasonable, however, if the policy alternatives included both biological and chemical forms of pest control. This is because the options obviously have quite different costs, benefits, and effects, that is, quite diverse ecological, agricultural, economic, medical, and political effects. In this latter case, the goals, values, and constituencies, as well as the effects, of the various pest-reduction programs, are much more diverse than in the first pesticide case. For this reason the latter situation is much less amenable to formulations considering only economic efficiency in saving lives.

All this suggests that the "hard cases," the safety program comparisons in which a simple appeal to consistency (in marginal cost per life saved across opportunities) is unlikely to work, are those having (1) diverse constituencies, (2) different purposes and goals, and (3) risks, benefits, and effects of many different types. Likewise, use of the commensurability presupposition appears most likely to be reasonable in situations in which the constituencies, goals, risks, benefits, and consequences of the safety program are similar.

If Margaret Mead is right, then the difficult cases (in which use of the presupposition is not reasonable) very likely outnumber the simple ones in risk assessment. As a consequence, we may well wish to draw some problematic distinctions about how best to allocate funds. We may wish, for example, to spend more to save persons from slow, painful deaths than to save them from relatively quick, painless ones.[32] Or, we might wish to go to extraordinary lengths to save people who are suffering in extraordinary circumstances.[33] Moreover, as several authors have pointed out,[34] we may wish to spend more to save persons from uncompensated risks than from compensated ones. If so, then we may wish to spend more money in programs to avoid slow and painful deaths, or uncompensated risks, than in programs to avoid relatively quick and painless deaths, or compensated risks. Presumably, one might justify such marginal-cost differences in saving lives by arguing that the risks addressed by the two safety programs are quite different, and that greater monies could well be spent to avoid the more horrible sorts of deaths. In general, then, evaluating the similarity among the constituencies, goals, risks, benefits, and consequences of alternative safety programs provides some preliminary factual grounds for deciding how to spend funds for risk abatement.

In general, this preliminary observation is analogous to another observation which appears to be quite obvious. Just as unequal treatment tends to be less justifiable, in a given situation, to the degree that all persons are equal in all relevant respects, so also unequal treatment of potential victims, across risks, appears to be less justifiable to the degree that the constituencies, goals, risks, benefits, and consequences of the safety programs are similar. Consistent with the principle that equal beings in similar situations ought to be treated equally, this observation (about constituencies, etc.) specifies relevant respects in which safety situations might be similar or dissimilar. As such, this observation reveals the factual conditions under which discrimination is likely to be justified or not. What might be some ethical conditions under which discrimination is likely to be justified among safety programs?

Ethical Criteria for Using the Commensurability Presupposition

Inasmuch as decisions about using the commensurability presupposition can be addressed by ethical criteria, these tend to focus on the issue of equal protection. If, following the earlier discussion, use of this presupposition cannot be justified by a simple, general appeal to equal protection, then it becomes important to know what constitutes good reasons, in a particular case, for following the commensurability presupposition. The argument of the forthcoming pages is that two principles furnish some useful guidelines regarding this presupposition. I call them, respectively, (1) the principle of *prima facie* egalitarianism and (2) the principle of everyone's advantage.

The Principle of Prima Facie Egalitarianism. According to the principle of *prima facie* egalitarianism, although equality (sameness) of protection is not desirable in all situations (for some of the reasons spelled out earlier) it ought to be adopted as a "*prima facie* principle." This means that it is presumed applicable in a particular case unless it is shown to be inapplicable. According to the principle of *prima facie* egalitarianism, only unequal protection (spending unequal amounts, per life saved, to reduce risk) requires justification.[35]

With the proponents of the equity claim, advocates of this principle believe that equal protection is desirable. Unlike them, however, they believe that good reasons can sometimes be shown to argue against spending the same amounts per life saved, in all risk situations. This means that, while the principle of *prima facie* egalitarianism is not absolute and does not hold for all cases, it is *prima facie* desirable. Therefore, the burden of proof ought to be placed on the person who wants to "discriminate" through unequal protection. Not to do so would be to encourage expenditures for risk reduction to become the political footballs for various interest groups. For example, it would be to encourage the United States to continue to spend millions of dollars to save the lives of middle-aged, overweight heart-attack victims, but virtually nothing to save the lives of 4-month-old victims of sudden infant death syndrome. Whether such expenditures are justifiable or not, the proponents of the principle of *prima facie* egalitarianism believe that the presupposition ought to be in favor of equal protection, and for at least four reasons: (1) the comparison class is all humans, and all humans have the same capacity for a happy life[36]; (2) free, informed, rational people would agree to the principle[37]; (3) it provides the basic justification for other important concepts of ethics; it is a presupposition of all schemes involving justice, fairness, rights, and autonomy[38]; and (4) equality of treatment is presupposed by the idea of law; "law itself embodies an ideal of equal treatment for persons similarly situated."[39]

As was already pointed out, one might have good reasons for spending unequal amounts to save lives in alternative safety programs if those programs have different constituencies, goals, risks, benefits, and consequences. Hence, according to the principle of *prima facie* egalitarianism, the fact that a law, action, or policy discriminates among persons does not necessarily make it wrong, contrary to what proponents of the commensurability presupposition believe. Discrimination among safety programs is wrong only if it is done arbitrarily or for irrelevant reasons.[40]

The Principle of Everyone's Advantage. Although a clear and precise line between relevant and irrelevant reasons for discrimination (with respect to equal protection) is not evident in every case, at least one ethical criterion for drawing such a line comes to mind. This is what I call the "principle of everyone's advantage," the thesis that unequal protection (spending different amounts, per life saved, across risk opportunities) among persons is justified if the "discrimination" works to the advantage of everyone.[41] (The principle is not

equivalent to the Pareto criterion, since "advantage" is not employed in it in a purely economic sense.)[42]

For example, suppose government regulations require lives to be saved at a cost of $\$x$ each in most safety programs. But suppose also that if lives were saved at a cost of $\$2x$ in a particular LNG program, then as a consequence everyone would be better off, in economic as well as noneconomic terms, because of the increased safety of the facility. But if everyone would be better off, then the discrimination would be justifiable. Of course, the problematic aspects of this example are judging whether everyone indeed would be better off as a consequence, and defining what it is to be "better off." In this case, the judgment that the discrimination in fact will work for the advantage of everyone might be a function of several claims. These include, for example, the "fact" that a $\$2x$ cost per life saved might decrease opposition of local residents to the LNG facility. Or, it might cause more equity in the distribution of goods and resources than otherwise would have occurred without the initial discrimination in favor of persons put at risk by the LNG facility.

Admittedly, drawing the conclusion that it would be to everyone's advantage to discriminate in this manner rests on a chain of tenuous causal inferences and assumptions, some of which arise out of ethical theory. In spite of the obvious practical difficulties in judging whether a discrimination in fact will contribute to everyone's advantage, this principle appears to be the most promising theoretical candidate for an ethical criterion to determine acceptable discrimination. This is because almost any other principle would be open to the charge that it sanctioned using some persons as means to the ends of others.[43]

Because humans may not be used as means to some end (a principle which we take to be self-evident), fulfilling the principle of everyone's advantage is a necessary condition for justifying discrimination among potential victims protected by alternative safety programs.[44] It is also a sufficient condition, since presumably any legitimate grounds for opposing discrimination (e.g., the existence of certain rights) would be equivalent to the claim that the discrimination did not serve the authentic advantage of everyone.

One major objection to this principle is that, as Dr. Douglas MacLean of the University of Maryland puts it, no technology-related "discrimination" against equal (the same level of) protection will ever, or has ever, worked to the advantage of everyone. On the contrary, it is not evident to me that no such discrimination has met, or will ever meet, this criterion. To determine whether a given discrimination might work to everyone's advantage, it seems that one would need to employ some fairly sophisticated economic and ethical analyses. Moreover, even if MacLean is correct, his point appears not to be a damning one against use of the principle. This is because, in at least some cases, all victims could likely be adequately compensated, if a given discrimination were not to their advantage.[45]

FUTURE DIRECTIONS AND THE COMMENSURABILITY PRESUPPOSITION

The principle of everyone's advantage provides both a necessary and a sufficient condition for justifying discrimination. This realization outlines the theoretical constraints governing use of the commensurability presupposition. That is, the commensurability presupposition (which requires sameness of marginal costs across opportunities) ought not to be held, and discrimination among potential victims in alternative safety programs is justifiable, provided that the discrimination works to everyone's advantage. Given this insight, the task facing risk assessors is threefold, if they wish to apply these results to actual decisions about allotments of funds and to avoid uncritical acceptance of analytic risk methodology. Each

of these tasks requires substantial ethical analysis to determine whether, in a particular situation, withholding use of the commensurability presupposition will indeed work to everyone's advantage.

What are the three tasks facing future researchers? First, assessors must ascertain, in a given safety expenditure decision, whether everyone's interests can be accorded the same concern and respect, even if the commensurability presupposition is not held. In other words, one necessary condition for a given discrimination's serving everyone's advantage is that, as Dworkin says, it does not violate anyone's right to equal concern or respect. Second, considering the morally relevant reasons justifying unequal treatment (as a reward for merit, etc.), assessors must determine, in a particular safety–expenditure decision, whether recognition of any of these (or other) morally relevant reasons, in this specific case, works to everyone's advantage. If decision makers do not follow the commensurability presupposition, it is necessary that this be shown. Third, assessors must ascertain, in a given safety–expenditure decision, whether there are morally relevant factual dissimilarities among the constituencies, goals, and consequences of alternative safety programs, such that these dissimilarities justify failure to subscribe to the commensurability presupposition. Although determining these facts is not necessary for justifying discrimination, the absence of factual dissimilarities could constitute a strong argument for using the commensurability presupposition in a given case.

In addition to specific research consisting of ethical analysis of each of these three issues, risk assessors are also faced with some complex economic and social–scientific work, if they are to discover the limits of the use of the commensurability presupposition. As I pointed out previously, one of the main tasks in this regard is establishing a network of plausible causal inferences enabling one to determine, given safety expenditures not consistent with the commensurability presupposition, whether these expenditures indeed are likely to work to everyone's advantage.

As is already clear from this overview of the tasks still to be accomplished, this essay met several theoretical aims. It has exposed the limitations of wholesale use of the commensurability presupposition, suggested factual and ethical conditions under which the presupposition ought and ought not to be used, and provided a necessary and sufficient ethical condition for discriminating among potential victims in safety programs. What remains is to apply these ethical and methodological conclusions to specific risk-analysis cases. This application will require both philosophical (ethical and methodological) and scientific (especially economic) expertise.

SUMMARY AND CONCLUSIONS

If the preceding discussion is correct, then there are strong grounds for rejecting absolute acceptance of the commensurability presupposition and the reasons typically used to support it (the equity claim, the rationality claim, and the responsibility claim). Rather, situations of costing lives, across opportunities, appear to fall into two classes, one of which is more amenable to use of this presupposition, and one of which is less so. One set of risk-abatement situations is generally more amenable to use of this presupposition because the safety programs at issue have similar constituencies, goals, risks, benefits, and consequences. The other set is less amenable to it because the programs being compared have dissimilar constituencies, goals, risks, benefits, and consequences.

In terms of ethical criteria for using the commensurability presupposition in given safety situations, I argued that two principles are useful. The principle of *prima facie* egalitarianism

establishes the *prima facie* desirability of giving the same protection to prospective victims whose needs are addressed by various safety programs; further, it places the burden of proof on the person wishing not to give equal (the same level of) protection. The principle of everyone's advantage provides a necessary and sufficient condition for justifying unequal protection in a given situation.

All these arguments suggest that there are strong reasons for believing that the marginal costs of saving lives need not always be the same, across opportunities, and that there is at least one ethical principle according to which people may receive unequal "protection" with respect to this marginal cost. Employment of this principle requires, however, extensive ethical analysis and evaluation of numerous causal inferences, in order to determine what courses of action, in fact, will contribute to the goodness of people's lives or to their advantage. This means that the whole issue of the marginal cost of saving lives, across opportunities, is not so much a matter of economic consistency as of ethical analysis.

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NOTES

1. See, for example, L. Lave and E. Seskin, "Air Pollution and Human Health," *Science* 169, No. 3947 (1970): 723–733; hereafter cited as: APHH. See also D. Rice, *Estimating the Cost of Illness*. PHS Publication No. 947-6. (Washington, D.C.: U.S. Government Printing Office, 1966.)
2. In two essays, I argue in favor of analytic assessment techniques. See "Technology Assessment and the Problem of Quantification," in R. Cohen and P. Durbin (eds.), *Philosophy and Technology,* Boston Studies in the Philosophy of Science (Boston: D. Reidel, 1983), forthcoming, and "Die Technikbewertung und das Problem ihrer genauen Berechnung," in F. Rapp (ed.), *Technikphilosophie in der Diskussion,* (Weisbaden: Vieweg Verlag, 1982), pp. 123–138.
3. See A. Kneese, S. Ben-David, and W. Schulze, "A Study of the Ethical Foundation of Benefit–Cost Analysis Techniques." Working paper, 1979, pp. 23 ff.; hereafter cited as: *Foundations*.
4. This method consists of experts' formalizations of past societal policy regarding various risks. Followed by assessors such as Starr and Whipple, the technique rests upon the assumption that past behavior regarding risks, benefits, and their costs is a valid indicator of present preferences. In other words, the "best" risk–benefit trade-offs are defined in terms of what has been "traditionally acceptable," not in terms of some other (e.g., more recent) ethical or logical justification. This, of course, involves the assumption that past behavior is normative, whether it was good or bad, or right or wrong. For this reason, some theorists have argued that the method of "revealed preferences" is too conservative in making consistency with past behavior a sufficient condition for the correctness of current risk policy (see B. Fischhoff et al., "How Safe is Safe Enough?" *Policy Sciences* 9, No. 2 (1978): 149: hereafter cited as: *Safe*.) See also note 5.
5. Unlike the method of "revealed preferences," that of "expressed preferences" does not rely on past policy. Developed by assessors such as Fischhoff and Slovic, this approach consists of using questionnaires to measure the public's attitudes toward risks and benefits from various activities. The weakness of this method, of course, is that often what people say about their attitudes toward various risks appears inconsistent with how they behave toward them. Some theorists also view the method as too variable since it takes no account of past societal behavior but only relies on selected responses as to what people say they believe about risks (see Fischhoff et al., *Safe,* p. 149.) See also C. Starr, *Current Issues in Energy* (New York: Pergamon, 1979), p. 7; hereafter cited as *Energy*.
6. See C. Starr and C. Whipple, "Risks of Risk Decisions," *Science* 208, No. 4448 (1980): 1118; hereafter cited as: *Risks,* and J. Hushon, "Plenary Session Report," in the Mitre Corporation, Symposium/Workshop on

Nuclear and Nonnuclear Energy Systems: *Risk Assessment and Governmental Decisionmaking* (McLean, Virginia: The Mitre Corporation, 1979), p. 748; hereafter cited as: Hushon, Report, and Mitre, *Risk*. See also D. Okrent, "Comment on Societal Risk," *Science* 208, No. 4442 (1980): 374; hereafter cited as: *Risk*, and M. Maxey, "Managing Low-Level Radioactive Waste," in J. Watson (ed.), *Low-Level Radioactive Waste Management* (Williamsburg, Virginia: Health Physics Society, 1979), p. 401; hereafter cited as: Maxey, *Wastes*, and Watson, *Waste*. Finally, see C. Comar, "Risk: A Pragmatic De Minimus Approach," *Science* 203, No. 4378 (1979): 319; hereafter cited as: *Pragmatic*, and B. Cohen and I. Lee, "A Catalog of Risks," *Health Physics* 36, No. 6 (1979): 707; hereafter cited as: *Risks*.

7. F. Hapgood, "Risk–Benefit Analysis," *The Atlantic* 243, No. 1 (January 1979): 28; hereafter cited as: *RBA*. See also J. Norsigian, in Congress of the U.S., *Fertility and Contraception in America*. Hearings before the Select Committee on Population, 95th Congress, Second Session, III, No. 4 (Washington, D.C.: U.S. Government Printing Office, 1978), p. 375. Norsigian points out that investments in contraceptive research and development are inequitable because the cost per male life saved is much greater than the cost per female life saved.
8. See note 6.
9. Starr and Whipple, *Risks*, p. 1118 (note 6).
10. Hushon, *Report*, p. 748 (note 6).
11. W. Hafele, "Energy," in C. Starr and P. Ritterbush (eds.), *Science, Technology, and the Human Prospect* (New York: Pergamon, 1979), p. 139; hereafter cited as: Hafele, *Energy*, and Starr and Ritterbush, *ST*. See also A. Lovins, "Cost–Risk–Benefit Assessment in Energy Policy," *George Washington Law Review* 45, No. 5 (1977): 941; hereafter cited as: *CRBA*.
12. Okrent, *Risk*, p. 373 (note 6).
13. B. Fischhoff et al., "Which Risks are Acceptable?" *Environment* 21, No. 4 (May 1979): 17; hereafter cited as: *Risks*.
14. Okrent, *Risk*, p. 374 (note 6). See also Starr, *Energy*, pp. 22–23, and D. Okrent and C. Whipple, *Approach to Societal Risk Acceptance Criteria and Risk Management*. PB-271 264 (Washington, D.C.: U.S. Department of Commerce, 1977), pp. 3–11; hereafter cited as: *Approach*. Others who share this point of view include: C. Sinclair et al., *Innovation and Human Risk* (London: Centre for the Study of Industrial Innovation, 1972), pp. 11–13, and Committee on Public Engineering Policy, *Perspectives on Benefit–Risk Decisionmaking* (Washington, D.C.: National Academy of Engineering, 1972), p. 12. These latter two works are hereafter cited (respectively) as: Sinclair, *Risk*, and Committee, *Perspectives*.
15. Okrent, *Risk*, p. 375 (note 6). See Starr, *Energy*, p. 10 (note 5), and L. Sagan, "Public Health Aspects of Energy Systems," in H. Ashley et al. (eds.), *Energy and the Environment* (New York: Pergamon, 1976), p. 89; hereafter cited as Sagan, *Public*, and Ashley, *Energy*.
16. In an insightful query in a private conversation, Stuart Spicker has asked how individuals' needs are relevant to moral obligations to them. He fears that there might be a confusion between "ought talk" and "need talk" here. However, I am asserting no general claim to the effect that moral obligations to do "x" are proportional to someone's need for "x." Rather, the claim is that, all things being equal, government has more obligation to reduce risks to citizens when citizens have little control over their own safety, and less obligation to reduce risks to citizens when they have more control. The point is a relative one; given two risk situations—alike in all respects save that, in one, the individual has more control over his safety, while in the other, he has less—government has more obligation to help those who cannot help themselves.
17. See K.S. Shrader-Frechette, *Nuclear Power and Public Policy* (Boston: D. Reidel, 1983), second edition, pp. 34–35.
18. R. Dworkin, *Taking Rights Seriously* (Cambridge: Harvard University, 1977), p. 273; hereafter cited as: *Rights*.
19. T.C. Bergstrom, "Living Dangerously," in D. Okrent (ed.), *Risk–Benefit Methodology and Application* (Los Angeles: UCLA School of Engineering and Applied Science, 1975), p. 233.
20. For a similar argument, see M. Bayles, *Morality and Population Policy* (University, Alabama: University of Alabama Press, 1980), pp. 28–31; hereafter cited as: *Morality*.
21. G.L.S. Shackle, *Epistemics and Economics: A Critique of Economic Doctrines* (Cambridge: Cambridge University Press, 1972), p. 82; hereafter cited as *EE*.
22. Shackle, *EE*, p. 82.
23. E. Mishan, *Cost–Benefit Analysis* (New York: Praeger, 1976), pp. 153–174; hereafter cited as: *CBA*. See also Peter Self, *Econocrats and the Policy Process* (London: Macmillan, 1975), p. 68.
24. Okrent, *Risk* (note 6), p. 375.
25. H. Siebert, *Economics of the Environment* (Lexington, Massachusetts: Lexington Books, 1981), pp. 16–17; hereafter cited as: Siebert, *EE*.
26. Okrent, *Risk* (note 6), pp. 372–375.
27. M. Bayles, *Morality* (note 20), p. 121.

28. Alan Gewirth, *Reason and Morality* (Chicago: University of Chicago Press, 1978), pp. 222–240, argues that many omissions are morally reprehensible, and I do not wish to take issue with (what I believe is) an essentially correct point. My thesis is that one is likely more responsible for acts of commission than for acts of omission. Gewirth's book is hereafter cited as: *Reason*.
29. Gewirth, *Reason*, p. 226.
30. This point is also made by Gewirth, *Reason*, p. 223.
31. Congress of the U.S., Office of Technology Assessment, *Technology Assessment of Changes in the Future Use and Characteristics of the Automobile Transportation System: Summary and Findings*, 2 vols. (Washington, D.C.: U.S. Government Printing Office, 1979) II, pp. 207–208, 219.
32. Cited by Maxey, *Wastes* (note 6), p. 401.
33. E. Lawless, *Technology and Social Shock* (New Brunswick, N.J.: Rutgers University, 1977), pp. 509–512.
34. Kneese et al., Foundations (note 3), p. 26. K. Shrader-Frechette, *Nuclear Power and Public Policy* (Boston: D. Reidel, 1983), pp. 108ff.
35. For an excellent defense of this position, see W.K. Frankena, "Some Beliefs about Justice," in J. Feinberg and H. Gross, *Philosophy of Law* (Encino, California: Dickenson, 1975), pp. 252–257; hereafter cited as: Frankena, Beliefs, in Feinberg and Gross, *POL*. See also W.K. Frankena, *Ethics* (Englewood Cliffs, N.J.: Prentice-Hall, 1963), p. 41. "*Prima facie* egalitarians" (Frankena calls them "procedural egalitarians") are to be distinguished from substantive egalitarians, who believe that there is some factual respect in which all human beings are equal. *Prima facie* egalitarians deny that there is some such factual respect. I am grateful to Dr. Douglas MacLean of the University of Maryland for suggesting that I use the term *prima facie egalitarian*.
36. W.T. Blackstone, "On Meaning and Justification of the Equality Principle," in Blackstone, *Equality*.
37. See note 36. John Rawls, "Justice as Fairness," in Feinberg and Gross, *POL* (note 35), p. 284, also makes this point; hereafter cited as Rawls, *Fairness*.
38. For arguments to this effect, see M.C. Beardsley, "Equality and Obedience to Law," in Sidney Hook (ed.), *Law and Philosophy* (New York: New York University Press, 1964), pp. 35–36; hereafter cited as: *Equality*. See also Isaiah Berlin, "Equality," in Blackstone, *Equality* (note 36), p. 33; Frankena, Beliefs (note 35), pp. 250–251; M. Markovic, "The Relationship Between Equality and Local Autonomy," in W. Feinberg (ed.), *Equality and Social Policy* (Urbana: University of Illinois Press, 1978), p. 93; hereafter cited as Markovic, *Relationship*, and Feinberg, *Equality*. See also Rawls, *Fairness* (note 35), pp. 277, 280, 282, and G. Vlastos, "Justice and Equality," in R.B. Brandt (ed.), *Social Justice* (Englewood Cliffs, N.J.: Prentice–Hall, 1962), pp. 50, 56; hereafter cited as Brandt, *Justice*.
39. J.R. Pennock, "Introduction," in J.R. Pennock and J.W. Chapman (eds.), *The Limits of Law*, Nomos XV, the Yearbook of the American Society for Political and Legal Philosophy (New York: Lieber–Atherton, 1974), pp. 2, 6; hereafter cited as: Pennock and Chapman, *LL*.
40. R.A. Wasserstrom, "Equity" in Feinberg and Gross, *POL* (note 37), p. 246, also makes this point. Even the Fourteenth Amendment, under the equal-protection clause, does not prohibit all discrimination, but merely whatever is "arbitrary." In this regard, see N. Dorsen, "A Lawyer's Look at Egalitarianism and Equality," in J.R. Pennock and J.W. Chapman (eds.), *Equality*, Nomos IX, Yearbook of the American Society for Political and Legal Philosophy (New York: Atherton Press, 1967), p. 33; hereafter cited as: Look in *Equality*.
41. See John Rawls, *A Theory of Justice* (Cambridge: Harvard University Press, 1971); hereafter cited as: Rawls, *Justice*. See also Charles Fried, *Right and Wrong* (Cambridge: Harvard University Press, 1978); and Alan Donagan, *The Theory of Morality* (Chicago: University of Chicage Press, 1977). See also S.I. Benn, "Egalitarianism and the Equal Consideration of Interests," in Pennock and Chapman, *Equality* (note 50), pp. 75–76. See also Frankena, *Ethics* (note 37), pp. 41–42.
42. I am grateful to Dr. Toby Page of California Institute of Technology, for pointing out the question of whether the Principle of Everyone's Advantage is identical to the Potential Pareto criterion. There appear to be two reasons why they are not the same. First, the principle requires that everyone's advantage be served in fact, and that compensations be carried out, if everyone's advantage requires it. The Pareto criterion, however, does not require that the compensations actually be carried out. Second, the principle defines "advantage" as overall welfare (including noneconomic well-being), whereas the Pareto criterion defines "advantage" in a purely economic sense. As was pointed out earlier in this paper, serving everyone's advantage might include according them their rights to equal concern and respect. Such rights, however, do not fall within the scope of the Pareto definition of "advantage."
43. W.K. Frankena, "The Concept of Social Justice," in Brandt, *Justice*, pp. 10, 14.
44. In the second to last section of this paper, we observed that discrimination in safety programs might be less justifiable to the degree that the programs shared similar constituencies, goals, risks, benefits, and consequences. Interpreting this preliminary observation in the light of the principle of everyone's advantage, we can now

affirm that discrimination (among potential victims affected by alternative safety programs) is likely to be justifiable to the degree that the programs have dissimilar constituencies, goals, risks, benefits, and consequences—provided that the discrimination works to the advantage of everyone.

45. Continuing our private conversation on the issue of whether any discrimination might work to everyone's advantage, Dr. MacLean's response to my rejoinder about compensation is that it would be "practically impossible" to accomplish such compensation. To this response, at least two points can be made. First, unless compensation is attempted in the cases in which it appears reasonable and equitable to try it, one will never know if it might be successful. Hence, the only way not to beg the question of whether compensation might work is to try it. Second, the move toward compensation is at least plausible since welfare economists such as Mishan have discussed recognition of amenity rights, which would likely involve at least some cases of compensation. Recognition of amenity rights might require governments to examine the whole set of social costs (including imposed risks and various discriminations) in our society. Compensating the victims of such costs need not be more complex, in principle, than providing for the many current types of income tax deductions and government subsidies prevalent today.

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Improving Risk Analysis

R. Talbot Page and John A. Ferejohn

INTRODUCTION

Incorporating Feedback in Risk Assessment

In the past few years, a number of federal regulatory programs have come to make use of quantitative risk assessments to provide information for policy decisions. But, current methods of risk assessment are flawed in a number of respects. Risk assessments are costly in time and effort; they often result in vague and unusable estimates; and it is difficult to separate the good ones from the bad ones because the probabilistic predictions are not observed for many years. Because of these facts, it is difficult for the assessors themselves to identify and learn from their mistakes.

In part, these problems stem from the fact that risk assessment methodology is relatively new and that the needed professional expertise has yet to mature. But some of the deficiencies are due to the nature of the risk assessment task posed by decision makers or from the fact that risk analysis activities take place in an administrative and political setting. We believe that the application of some of the newly developing methodologies in the area of institutional design can help to clarify some of the problems in the application of risk analysis and, in some cases, even aid in finding useful revisions in established approaches.

Many of the problems of risk assessments come from the fact that the decision makers need to guess the likelihood of rare and difficult-to-observe events. The unlikelihood of the events means that little data will exist that will allow an analyst to estimate probabilities and that he must instead rely heavily on theory to construct his assessment. In some areas theories are well enough developed to enable professionals to make strong predictions about consequences; but, in many of the areas of current governmental activity, not enough is known about the physical and biological world to make estimates of rare or unique events in which one would have a great deal of confidence.

R. Talbot Page • Environmental Quality Laboratory, California Institute of Technology, Pasadena, California 91125. *John A. Ferejohn* • Department of Political Science, Stanford University, Palo Alto, California 94305.

As a general principle, the estimation of probabilities is improved by incorporating feedback mechanisms in the estimation process. If risk assessors are able to tell how close their probabilistic predictions are to actual outcomes they will have an opportunity to "calibrate" their estimation techniques over time. Numerical probabilistic predictions provide a means for this. In our language, assessors should be asked to provide "bottom line" numerical estimates of "indicator events" rather than vague, qualitative estimates of difficult to observe occurrences.

Decision makers are interested in whether or not a particular chemical is carcinogenic or whether or not a certain industrial practice will produce catastrophic consequences for society. How, then, can we hope to gain information about these events by requiring analysts to provide predictions of "indicator events"? The short answer is that we must choose indicator events that carry some information about the event of interest. Thus, for the Ames test to be useful as an indicator event, the probability that a chemical is carcinogenic given a positive result on an Ames test must be higher than the probability of carcinogenicity given a negative Ames test. If information is so structured, we can hope to make use of predictions about more and more informative test results to help us get closer and closer to a good estimate of the event of interest to policy makers.

Even if we have a set of indicator events that can be used to evaluate estimation, we will not be able to make efficient use of them unless the analysts are required to keep track of how their estimations compare with test results. Without keeping track of the accuracy of predictions, the information from the indicators will not be efficiently used, if it is used at all.

This chapter is largely concerned with developing methods for incorporating feedback into the risk assessment process. The possibilities of doing this depend largely on the ability of decision makers to induce assessors to make clear quantitative predictions of indicator events. We argue that in many circumstances this is a feasible requirement for assessors and that it could produce substantial improvements in the analysis of risky decisions.

If there is agreement that risk assessments could be improved by incorporating techniques which allow the use of feedback, it remains to be shown how the institutions and practices of risk analysis should be changed to achieve these effects. In order to address this issue, we find it useful to embed the risk assessment problem in the general institutional design framework so that we can systematically examine the motivations of assessors to do research and to report faithfully information they acquire. This framework also allows us to examine a variety of institutional issues having to do with the role of industry, the courts, Congress, and the agencies in decision making regarding societal risk.

The Weak Evidence Principle

Even if we are able to develop a system of risk analysis in which assessors are able to develop better and better information about indicator events and to learn from their experiences during the analysis process, we must still develop an appropriate way to link decisions with the outcomes of the assessment process. In general, given a set of indicator events, it would seem prudent to base policy decisions on the occurrence or nonoccurrence of such events. We can state this idea in the form of a principle: *Weak evidence of a hazard should lead to weak precautionary action and strong evidence should lead to strong precautionary action*. If, for example, a chemical is known to be mutagenic, an agency might very well wish to require further testing as a condition for marketing, or it might consider banning the product in certain uses if such testing is sufficiently expensive. In fact, this council of prudence can be seen to be an application of the principle of welfare maximizaton. We may

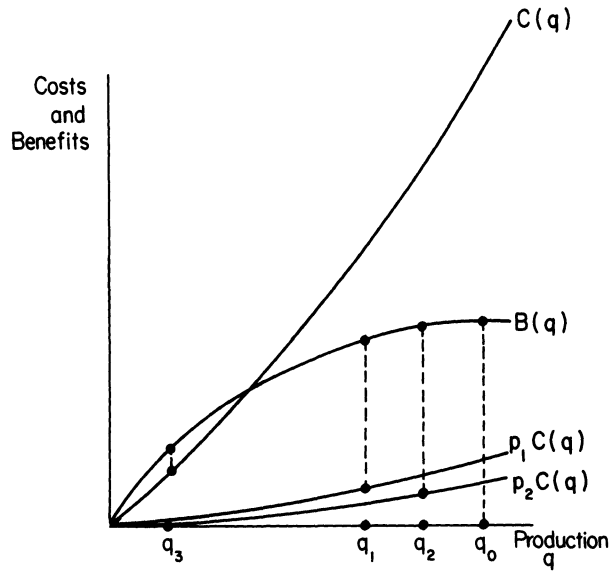

Figure 1. Geometry of the weak evidence principle.

illustrate the principle with the example in Figure 1. Suppose the net benefits of a chemical $B(q)$ depend upon its production q. These are benefits net of the cost of production. If the chemical is a carcinogen, it has health costs $C(q)$ which are a function of exposure (for simplicity we assume exposure is proportionate to production). If the chemical is not a carcinogen, there are no health costs. A risk analysis is done and the judgmental probability that the chemical is a carcinogen is p. The expected health costs $pC(q)$ are shown as proportionately less than $C(q)$. To be concrete, suppose p is 15% or p_1 in the figure. Then the curve $p_1C(q)$ is 85% less than $C(q)$.

The net expected benefits of the chemical are $B(q) - p_1C(q)$, which are maximized at the production level q_1 for which $B'(q_1) = p_1C'(q_1)$. This is the q with the greatest gap between the two curves $B(q)$ and $p_1C(q)$ in Figure 1.

Now suppose the risk analysis had come out a little differently. Suppose that the judgmental probability was assessed as 10% ($p = p_2 = 10\%$) in Figure 1. In this case the curve of expected costs, $p_2C(q)$ is a little flatter and the q maximizing net expected benefits is $q_2 > q_1$. If it were known for sure that the chemical is not a carcinogen ($p = 0$) then the best q is where $B(q)$ is maximized, at q_0. As long as the probability is greater than zero, some precautionary control is required to achieve mazimum net expected benefits. By the geometry of Figure 1, the larger the probability of carcinogenity, the greater the precautionary control.*

The regulation of chlorofluorocarbons under Section 6 of TSCA is an application of the weak evidence principle. The evidence for the hypothesis of ozone depletion was considered strong enough to justify a mild precautionary action, banning CFCs as aerosol propellants. But the probability of the hypothesis was considered too low to justify stronger actions such as banning CFCs in refrigerants, or banning CFCs entirely.

* For expositional simplicity, the principle has been stated without qualification. More rigorously, the principle applies when the decision function $d(p)$, shortly to be defined, is continuous and monotone decreasing. This condition obtains when $B(q)$ and $C(q)$ are smooth, $B(q)$ is concave and $C(q)$ is convex, and at least one of them is strictly so.

The rest of this paper is concerned with working out some of the implications of these basic ideas. We make use of the results in the theory of institutional design to suggest ways of building feedback mechanisms into risk analysis techniques. We show just how these suggestions make use of the structure of indicator events and how they depend on ensuring that assessors are given incentives to provide appropriate information to policy makers. In addition we show that, under the appropriate conditions, the weak evidence principle will in fact be followed by decision makers in the appropriate institutional setting. Thus, if the appropriate institutional structures are developed, there are good reasons to believe that social institutions will make use of information about risks in appropriate ways.

PREVIOUS WORK

Because risk analysis is a multidisciplinary area, it draws upon many strands. For us, a principal strand is the literature on decision making under uncertainty. Although the field is relatively recent, there are by now standard or classic works on the subject. As a basic primer on the subject we have found no improvement on Raiffa's *Decision Analysis: Introductory Lectures on Choices under Uncertainty* (1970), which is not to be disparaged for being both elementary and lucid. DeGroot's *Optimal Statistical Decisions* (1970) is particularly helpful because it focuses on the problem of developing judgmental probabilities, based on Bayesian statistical inference. Savage's *The Foundations of Statistics* (1972) is, of course, the original classic on the subject. However, in many ways DeGroot's book supercedes Savage's.

Because we are dealing with judgmental probabilities and these judgments are themselves uncertain, the literature on second order probability is also relevant. Ellsberg's "Risk, Ambiguity, and the Savage Axioms" (1961) raised fundamental issues about second order probabilities. Marschak's symposium (1975) on the issue of second order probabilities is a useful source. Second order probabilities are used in our current work (see Page, 1986 on the analysis of feedback or transfer mechanisms).

The seminal work on proper scoring rules can be traced back to Brier (1950). De Finetti (1962) contributed an insightful paper which argued that many decisions are basically equivalent to judgments about probabilities. Following De Finetti, we shall attempt to show that proper scoring rules play a foundational role, not only in risk analysis, but also in all decision making under uncertainty. A great deal of work of Winkler, Murphy, Brown, and Stael von Holstein should be mentioned. Again, the classic paper on the foundations of proper scoring rules was written by Savage (1971)—in fact, this was the last paper that Savage wrote.

The literature on applied research in risk analysis is also enormous, and only a few papers will be mentioned for elucidative purposes. Howard, Matheson, and North (1972) analyzed the risks involved in the decision of whether or not to seed hurricanes. Their analysis was a Bayesian one in which several risk analysts' judgments were aggregated according to credibility weights and the use of Bayes' theorem. It was only a short step from this to using posterior probabilities, based on later knowledge as feedback to evaluate the analysts' performance. This extension was done by Page (1979) for a setting in which risk analysts compete against each other in trying to establish and raise their own credibility. In a competitive but nonstrategic context, Roberts (1965) applied Bayes's theorem to evaluate the performance of risk analysts. And in a recent report the National Academy of Sciences (1984) based its approach to setting priorities for testing chemicals on the decision theoretic concept, value of information.

Concern with incentive problems in risk analysis goes back at least to 1950 when Brier (1950) developed his scoring rule not only to verify the performance of weather forecasters but also to prevent them from taking advantage of his verification system by "playing the system," as he put it. Becker, DeGroot, and Marschak (1964) developed an elicitation mechanism with incentives for a risk analyst to reveal his best, unbiased guess of the probability of some event. This mechanism was based on a seller's price auction. Later Savage (1971) also based his characterization of proper scoring rules on the seller's price auction and credits this idea to Marschak. Grether developed the seller's price auction further and used it in an experimental study of probabilistic assessment and decision making. The seller's price auction was used in another context, in developing a theory of the problem of revealing willingness to pay for a public good. Green and Laffont (1979) describe a mechanism for revealing willingness to pay for a public good, the Groves mechanism, and they trace the seminal idea to Marschak's second price auction (the "essence" of the Groves mechanism); however, they cite different papers from those cited by Savage. Moreover, Savage makes no mention of the public goods problem and Green and Laffont make no mention of the scoring rules problem. (One of our results is to show the close link between these areas.)

It might appear on first glance that the vast literature on tort law is far removed from the subject of feedback mechanisms in risk analysis. Nonetheless, much of liability law can be viewed in terms of probabilistic feedback mechanisms. Learned Hand's (1947) famous decision on Carroll Towing recast negligence law in terms of judgmental probabilities and expected value balancing. This idea has been developed and expanded in Posner's (1977) *Economic Analysis of the Law*. The Supreme Court decision (1980) on benzene states: "The burden was on OSHA to show, on the basis of substantial evidence, that it is at least more likely than not that long term exposure to 10 ppm of benzene presents a significant risk of material health impairment." The most straightforward interpretation of this criterion is one of probabilities of probabilities (second order probabilities). The decision also required that "economic benefits of (OSHA's) standard bear a reasonable relationship to the expected costs." The decision did not call for explicit quantitative expected value balancing, but it did suggest the use of judgmental probabilities and a qualitative balancing of costs and benefits. As we shall see, this legal balancing, especially in terms of liability rules, is closely related to proper scoring rules. This connection is developed in Page (1978, 1981).

The seminal work on the problem of cognitive bias in the elicitation of judgmental probabilities is Tversky and Kahneman (1974). A great deal of useful work by cognitive psychologists and others is contained in the volume *Judgment under Uncertainty: Heuristics and biases* (1982), which bears the same title as the original paper by Tversky and Kahneman. In the book the chapters of particular usefulness for us are "Debiasing" by Fischhoff, and "Calibration of Probabilities: The State of the Art to 1980" by Lichtenstein, Fischhoff, and Phillips. Murphy (1972) has shown the close connection between calibration and the Brier proper scoring rule by his partitioning of the latter rule. Morgan et al. (1978) elicited judgmental probabilities in assessing the risks associated with sulfur oxides in the air.

Risk analysis and risk management take place in the context of particular institutions. These institutions shape the way in which risk analysis and risk management are done. An example of the growing interest in designing institutions to improve the performance of risk analysis and management is Calkins et al. (1980). This study suggests a two-step process, the first step focusing on issues of science and the second on issues of policy. As already noted, the literature on incentive compatibility is concerned with the design of institutions, more generally.

CURRENT RESEARCH

Our research on feedback mechanisms in risk analysis and management defines an approach which we illustrate by examples in the first part of this section. In the second part we discuss some of the conceptual results of this research. In the third part we consider some applications.

The Approach

Risk Analysis with a Bottom Line. Under the Toxic Substances Control Act (TSCA) up to 50 chemicals are placed on a priority list. Once a chemical is placed on a priority list, the administrator must decide within a year whether or not to require testing under section 4. To decide whether a chemical "may present an unreasonable risk" (part of the legal finding needed to require testing), the Office of Pesticides and Toxic Substances (OPTS) undertakes risk analyses of the chemicals placed on the list.

As an illustration of our approach, we suppose that the administrator does the following. He provides a budget of $5000 per chemical to the Office of Hazard Review and instructs its director that in one month the analysis is to be completed. The analysis is to have a bottom line. At the bottom line the director is to write his, or his division's, best judgment of the probability that if the chemical were tested in the NCI bioassay, it would test positive. In other words, the bottom line is a number (or several numbers if the analysis considers risks of several types of effects). Within a limited time and budget, the director is to produce his best judgment of this bottom line. The rest of the package, the risk analysis sent back to the administrator, consists of the reasons why the judgment came out the way it did.

In contrast, risk analysis is currently defined as a process rather than as a product with a bottom line. The case of chloromethane provides an extreme example of this alternative approach. Chloromethane was one of the first chemicals placed on the priority list after TSCA became effective in 1977. The division director was instructed to undertake a risk analysis of the chemical, but there was no clearly defined product for the analysis, no bottom line. Nonetheless, the existing evidence on the toxicity of chloromethane was reviewed and a risk assessment package produced. This package was then sent to outside reviewers, who wrote comments on it. The original analysts were asked to respond to these comments. A revised package was sent to outside reviewers and more comments were elicited. The original analysts were asked to respond to these comments, and so on; the process continued for more than three years. (Some of those involved in the process said there were 20 to 30 iterations; the cost to EPA of analysis was estimated to be considerably in excess of the costs of the tests which might have been required as a consequence of the analysis.)

As another example of an assessment without a bottom line, consider the following summary of a risk analysis undertaken by OPTS:

> The weight of scientific evidence produced by six long term rat and mouse studies . . . plus the use of three oncogenicity ranking and classification schemes lead the Toxicology Branch to conclude that [the pesticide's] potential for induction of oncogenicity in experimental animals is low and that the likelihood of oncogenic effects in humans is non-existent or extremely low. (Subcommittee on Department Operations, Research, and Foreign Agriculture, 1983, pp. 248–249.)

Terms such as *low* and *extremely low* are known as "weasel words" inside the agency. Because they are vague it is difficult to look back later to validate the analysis in light of new information. The vague terms make communication between the analyst and the decision maker more difficult. Is the administrator to conclude that "low" means a 30% likelihood of oncogenic effects or a 1% likelihood?

The incentives for using weasel words are not hard to find. We asked an OPTS division director responsible for risk analyses why he did not use quantitative probability judgments as his bottom line. His reply was that judgmental probabilities would just become another "target" and opposing lawyers would demand why the number was 15% rather than 10%. According to him it would be difficult to explain such a difference in judgment and EPA would be pressed to defend itself on yet another matter.

To facilitate future scoring and feedback, the probabilistic prediction at the bottom line should be for some indicator event which may be observed in the not-too-distant future, for example, the outcome of an NCI bioassay. The Cancer Assessment Group produces probabilistic risk assessments (e.g., a 10^{-5} lifetime risk for some chemical). Similarly, the Nuclear Regulatory Commission produces probabilistic risk assessments. But often, in both cases, the events predicted are hard to observe and score.*

Indicator Liability. We now consider how a feedback mechanism can be based on an observable indicator event. For an illustrative example, consider the Pre-Manufacturing Notification Program under the Toxic Substances Control Act. Each year there are about a thousand new chemicals which the industry wishes to introduce into the marketplace. EPA has the responsibility of looking at each new chemical and requiring further information or testing if the chemical "may present an unreasonable risk." With so many chemicals to look at, the Office of Pesticides and Toxic Substances has very limited time and resources to undertake risk analysis for each chemical. In fact, since the Toxic Substances Control Act was enacted in 1976 there have been only about three actions under Section 5e requiring further information and data. Interviews with agency personnel suggest that most chemicals receive cursory attention.

Given EPA's sharply limited resources to undertake risk analysis for each new chemical, it is sensible to step back and look at the problem from a more general point of view. Is it possible to delegate the process of risk analysis back to the firms which are developing the chemicals? Is it possible to establish a feedback mechanism so that each firm would find it in its own best interest to provide an unbiased risk analysis?

For example, let us suppose that this balancing of values has led to a policy decision which says that when the probability of carcinogenicity is above 10%, the chemical should be tested in a reference battery of tests costing $60,000; and when the probability is less than 10%, the chemical can be marketed without further testing.

In the example, EPA decides to decentralize the process of risk analysis and to let each firm do its own judgmental assessment of the probability of carcinogenicity. As a part of the premanufacturing notice for a new chemical, EPA asks that the firm introducing the chemical write down on the notification form its judgmental probability that the chemical would score positive in the reference set of tests if these tests were undertaken. EPA also

* The clearest example of a bottom line with a probabilistic prediction for an observable indicator event is probabilistic weather forecasting. We may ask how risk analysis with a bottom line (probabilistic prediction for an *observable* event) came into practice in weather forecasting. For a decade after the original conceptual work was done by Brier and others, forecasters resisted probabilistic prediction. According to Allan Murphy, probabilistic forecasting was adopted in 1965, largely in response to the advocacy of Charles Roberts, who was at the middle level of the agency. Similarly, we might expect risk assessment with a bottom line in other agencies only if an administrator found it in his interest to do so—if, for example, an administrator decided that the bottom line improved communication between his office and the scientists undertaking the risk analysis, that it increased his control and their accountability, and that the courts would accept the agency's probabilistic predictions on the basis of the supporting arguments much as they now accept judgmental estimates of quantitative costs, benefits, and numerical p-values in statistical tests.

Table 1. Expected Cost to Chemical Firm

	$p < 0.10$	$p > 0.10$
Reports $r < 0.10$	<60,000	>60,000
Reports $r > 0.10$	60,000	60,000

agrees to take these risks analyses at face value in the sense that when the judgmental probability is less than 10%, no further testing will be required (in the ordinary case) and when the judgmental probability is greater than 10%, the firm will be required to undertake the reference battery of $60,000 worth of testing.

It should be clear that there is a problem of incentive compatibility. What is to prevent a firm from understating its own best judgment of the probability of a test positive to avoid undertaking the expensive testing? As Steven Jellinek, former assistant administrator for toxic substances, puts it, "Industry almost always comes in with low assessments of risk, compared with EPA's assessment, and these in turn are both lower than those assessments made by environmental organizations."

The problem is one of establishing a feedback mechanism which makes the incentive structure facing the industrial firm compatible with the costs and benefits falling upon society at large. A possible solution is for EPA to ask the firm to agree to pay $600,000 under the following conditions: (1) it reports a judgmental probability of less than 10%; (2) it does not perform the tests itself; (3) some other accredited organization tests the chemical; and (4) the chemical tests positive. The $600,000 is to be paid to the organization which tested the chemical and found the (validated) positive result. If the firm truly believes that the probability of a test positive is extremely low, then there is little risk to the firm in agreeing to this set of contingencies. However, if the firm truly believes that the probability of carcinogenicity is high, then this agreement would be very risky for the firm.*

With the contingency agreement as a feedback mechanism, we can consider the compatibility of incentives as shown in Table 1. In Table 1, p is the firm's best judgment of the probability that the chemical would test positive if indeed it were tested; r is the probability of a test positive which the firm actually reports to EPA. If the firm truly believes that the probability is less than 10% and if the firm reports that the probability is less than 10%, it saves the cost of testing but bears the risk of having to pay $600,000 with probability less than 10%. The expected value of this prospect is less than $60,000, as shown in the upper left cell of the matrix. If the firm truly believes that the probability is greater than 10% but still reports "less than 10%," the firm avoids the cost of testing but faces the risk of having to pay $600,000 with probability greater than 10%. The expected value of this prospect is greater than $60,000, as long as the firm believes that at least one entrepreneur also agrees with the firm's private assessment of a probability greater than 10% and undertakes the testing. In the bottom row, if the firm reports a probability greater than 10%, it tests with costs of $60,000 regardless of whether p is less or greater than 10%.

With these contingencies, we can easily describe the incentive structure facing the firm.

* To provide a motivation for the firm to sign such an agreement EPA could require each chemical without such an agreement to be tested. The grounds for this requirement are that the firm's refusal to sign the agreement is *prima facie* evidence that the firm does not regard the probability of a test positive as negligibly small. Thus, the firm's refusal is evidence that the chemical "may present an unreasonable risk," the legal grounds upon which EPA can require further testing.

Table 2. Expected Return to Entrepreneurial Organization

	Best judgment	
	$p < 0.10$	$p > 0.10$
No test	0	0
Test	<0	>0

If the firm believes that the probability of carcinogenicity is less than 10% ($p < 0.1$), the firm does better by reporting an $r < 0.1$ than it does by reporting an $r > 0.1$. If the firm believes that the probability of carcinogenicity is $p > 0.1$, it does better by reporting a probability $r > 0.1$ than it does by reporting a probability $r < 0.1$. In each case, the firm does best by reporting its own best judgment of the probability of carcinogenicity.

We can also consider incentives facing the entrepreneurial organizations that might be motivated to test in order to gain the $600,000 bounty. Such an organization might be an accredited university laboratory or an accredited privated firm or a federal organization such as National Toxicology Program. These organizations would have to follow the code of good laboratory practices (EPA guidelines for GLP) in order to validate their test results. Table 2 shows the expected profit to such an entrepreneur. If the entrepreneur believed that the probability of carcinogenicity was less than 10% and it nonetheless tested the chemical, its expected profit would be less than 0 (this is because the cost of the test is $60,000, whereas the expected return is some amount less than 0.1 × $600,000). Alternatively, if the entrepreneur believed that the probability of carcinogenicity was greater than 10% and it tested, its expected profit would be greater than 0 (something greater than 0.1 × $600,000 less the cost of the test, 60,000, is greater than $0). For the top row of Table 2, if the entrepreneur did not test, it would earn a zero profit whether or not it believed the probability of carcinogenicity was greater or less than 10%. It can be easily seen that this feedback mechanism is incentive-compatible with the entrepreneur as well. Tests are undertaken when the entrepreneur believes that the probability is greater than 10% and not undertaken when the entrepreneur believes that the probability is less than 10%.* The basic structure of the above example is as follows. A probabilistic prediction (p) is made concerning some indicator event (whether or not the chemical would test positive in the $60,000 reference tests, if the chemical were tested). Once this analysis is done, choices are made on the basis of it. This is an instance of what De Finetti (1962) calls the "well known conclusion of decision theory that the choice of a particular action among a sufficiently wide set of permitted possibilities is equivalent to an evaluation of the probabilities concerned" (p. 359).

There are two principal objections to the example just described. First, it is clear that an entrepreunerial firm has an incentive to find a test positive, to claim its bounty. This is a serious objection but it is important to note that it applies equally to the present system. Under the present system, a firm required to test a chemical it produces either tests the chemical itself or contracts to have it tested. If the firm tests the chemical itself, the firm

* In about one-third of the premanufacturing notifications, the firm requests confidentiality for the identification of the chemical being submitted. Thus, presumably many firms might object to this feedback mechanism on the grounds that it would reveal to rival firms information as to its marketing strategy for new chemicals. If the National Toxicology Program were to play the role of the entrepreneur, it could maintain this confidentiality in the same way that EPA does now.

has an incentive to find a test negative. It also has an incentive to contract with a testing firm with a history of finding test negatives.*

Thus, the first objection is not an objection to the idea of the feedback mechanism compared with the present system. Rather, it is a concern with the possibility of malfeasance in testing. To some extent this problem is addressed by the code of good laboratory practices and by audit procedures. To the extent that these safeguards are insufficient, reforms and further safeguards are needed for the present system, as well as for the alternative in the example.

The second objection relates more directly to the example. Firms are likely to object to the burden of the financial risk of $600,000 for each new chemical that they choose not to test. The burden is real, from the point of view of the firm. However, under the present system, the costs from the risk of insufficient testing are also real (insufficient precautionary control, with unnecessary extra health effects). The purpose of a liability system is to shift the risk burden back from those who ultimately bear the costs to those who generate the risks. In doing so, the idea is to create incentives to undertake appropriate precautionary actions at the time of the initial decision. Here the action concerns the decision of whether or not to test. The novel feature of the example is that liability is geared to a test result rather than to the final result (e.g., excess cancers).† The reason for tying liability to a short-term indicator is to sharpen the incentive structure and lower the stakes at risk. The final result is both severe and long delayed. Imagine a coal mine owner who wants to control the risk of deaths from methane. He tells his foreman, "I don't want any of my men to die," as he hands the foreman a canary in a cage. "And if this canary dies, you're fired." The foreman is made liable for the outcome of a short-term indicator.

Strict Liability and Proper Scoring Rules. Indicator liability for test results is at present a hypothetical example (at least we have not found agencies implementing this feedback mechanism). In contrast, strict liability is an example of a feedback mechanism in widespread application. In this section we discuss the connections between the weak evidence principle, strict liability, and proper scoring rules.

To continue the previous example, suppose that the chemical company is made strictly liable for the toxic effects its chemical produces. For simplicity, suppose that $B(q)$ are private market benefits and there is no issue as to causation.‡ Then under strict liability the chemical company faces the same structure of costs and benefits as does society. If the liability system is working correctly, the company's maximization of its own net expected benefits is the

* There has been recent concern with Industrial Bio-Test (IBT), which was once the world's largest contract laboratory for toxicity testing. This firm furnished hundreds of studies funded by industry and used in regulatory proceedings. Several of its officers have now been convicted on fraud charges and many of the test results have been declared invalid. (For background, see Marshall, 1983.)

† Liability systems are, of course, widely used (e.g., performance bonds in construction contracts, product liability, medical malpractice). In these other instances of liability, risks of large adverse financial judgments are often made easier to bear, from the point of view of the risk generator, by risk spreading through insurance. Insurance companies, as a condition of issuing insurance, may require certain management practices and may raise their rates for "bad risks"—insured parties with poor performance. The Resource Conservation and Recovery Act provides for requiring toxic waste disposal sites to be insured, thus establishing a market for risk estimation and control. Similarly in the example of test liability, small firms could buy insurance and expect their rates to go up if they underestimate the risk of a test positive too often.

‡ Often there are issues of causality. A firm might be held strictly liable for the toxic effects of its product, but in a particular case the firm could argue if that was some other firm's product that caused the damage. Then the preponderance test would be applied with the same problems as discussed in Page (1983).

same as the maximazation of the social net expected benefits. This is because under strict liability the firm bears the full costs of social hazard of the potential toxicity.*

From the second example it is but a short step to follow De Finetti's insight, translating the action on q into an evaluation about probabilities and scoring rules. Recall the net expected benefits are $B(q) - pC(q)$. Next we define a decision function $d(p)$, as follows. For each p find the q which maximizes $B(q) - pC(q)$; set that q equal to $d(p)$. And finally we can define the following scoring rule (or reward rule). If the chemical is not toxic, the reward is $\alpha B(d(r)) + k_1$; if the chemical is toxic the reward is $\alpha(B(d(r)) - C(d(r))) + k_2$ where α is the positive constant and k_1 and k_2 are constants. It is a straightforward exercise to show that the expected reward is maximized at $r = p$ (where p is the judgmental probability of toxicity and r is the reported or acted-upon probability of toxicity). This means that the reward rule is a proper scoring rule.† It is also possible to show that all proper scoring rules can be generated in this way, by an underlying structure of costs and and benefits. Facing a company with strict liability is the same as facing it with the proper scoring rule derived from the total social costs and benefits associated with the company's actions.

Note that when a proper scoring rule is based on net social costs and benefits, the stakes can be large, in the millions of dollars—sometimes, as in the case of asbestos, in the billions. Thus, the scale is enormously different from that of scoring rules used in experimental psychology and economics, where the rewards are often very small.

Note also that a firm which maximizes net expected profits and which is under a strict liability rule follows the weak evidence principle.‡ Its best level of prediction q is a decreasing function of its judgmental probability of toxicity and successful suit, the function given by $q = d(p)$. From the geometry of Figure 1, weak evidence of toxicity (and a later successful suit) leads to a small precautionary action (its best q is close to q_0). Strong evidence of toxicity leads to a strong precautionary action (its best q is close to q_3).

Conceptual Results

In this section we briefly mention some of the more technical results so far obtained in our study of feedback mechanisms in risk analysis and risk management.

Formal Analogy between Two Models. It is useful, when developing a model in one problem area, to discover it has a similar mathematical structure to another model

* Note that this compatibility of private incentives with social net benefit maximization would not work if the firm were allowed to protect itself from liability by arguing that it had undertaken "due care" in its risk analysis in assessing the probability of harm. This difference between the concept of strict liability and due care is illustrated in a story told by a naval officer about Admiral Burke, who was chief of naval operations in the latter 1950s. The story is about a serious accident with an elevator on a aircraft carrier: When Burke was told about the accident [the Naval Officer said], the admiral immediately declared; "I want that captain fired." But, the admiral was told, it was just bad luck, the captain was not really responsible. "I don't care," Burke was said to have answered. "I don't want any unlucky captains." After word of the incident got around, the officer said, captains on all of the Navy's carriers rushed to make careful inspections of their elevators [*The Los Angeles Times*, part 1, page 18, June 6, 1981]. Thus, the application of strict liability led to more careful risk analysis (inspections of the elevators) and presumably more careful management practices. An obvious question, which we address as current research, is when the incentives are for too much research and precautionary behavior.

† By definition, a proper scoring rule is a reward rule, taken as a function of a reported r, where the expected reward is maximized at $r = p$ and where p is the judgmental probability of the event to be probabilistically assessed.

‡ Unless, of course, the regularity conditions previously footnoted do not apply.

in another problem area. In our case we were developing a model for several expert analysts offering probabilistic predictions. The experts may differ and even compete with each other strategically. It turns out that the problem of eliciting judgmental probabilities from several analysts is similar in structure to the problem of eliciting willingness to pay for a public good. Discovering the analogy has led to the discovery of a new mechanism for eliciting judgmental probabilities. We call this mechanism the Groves-like mechanism, after the analogous to the Groves mechanism used in the public goods model (Page, 1986).

Characterization Theorem for Proper Scoring Rules. As we have seen, liability rules can be interpreted as proper scoring rules. Further, we have discovered a connection between proper scoring rules and the new mechanism, the Groves-like mechanism. We have shown that the new mechanism can be viewed as a generalization of proper scoring rules, and proper scoring rules can be characterized as special cases of the new mechanism (Page, 1986).

Optimal Research Incentives. A problem which has not been fully resolved is to define how much research in a risk analysis is "enough." If the consequences of a risk management decision involve millions of dollars, but the analyst is rewarded by a proper scoring rule scaled by α in the thousands of dollars, the incentive for research may be too weak. Foreman (ms) has proposed the possible solution of offsetting this weakness by subsidizing the research effort.* (This result depends upon monitoring the research cost accurately.) We have also investigated another part of the problem by characterizing the proper scoring rule which maximized incentives for research over a given set of standardized proper scoring rules (Page, 1986).

The Consensus Estimate and Feedback Mechanisms. When there are several analysts, it is common practice to define a consensus of judgmental probabilities by taking an average of the individual judgments. This is done in the Delphi process and has been recommended by Savage (1971) and DeGroot (1974). However, we have found examples of information structures for which the average of individual "best estimates" of a probability are bad aggregations of the available data (Page, ms). We have also investigated the conditions under which the average is a good estimator.

Feedback from Private to Public Information. In one version of a Delphi process, individuals begin with their own private information and develop a judgmental probability estimate on the basis of that. The average of the individual estimates is made publicly available. Individuals revise their estimates on the basis of both their private and the public information, and report new probability estimates. These are averaged and the average made publicly available, and the process further iterated.

In investigating this process we have found that when individuals start with common prior probabilities, but different private information, the process eventually converges. When the process does converge, the individual private information has become incorporated into the publicly available average, and all the analysts agree on their judgmental probabilities (their current posterior probabilities). This result implies that each individual's own private

* Dissertation research, California Institute of Technology; this research is partially supported by the Technology Assessment and Risk Analysis program, National Science Foundation, under Grant No. PRA 81-14463.

information becomes valueless, although it was valuable during the process (McKelvey and Page, 1986).

The conditions for this result are idealized and one would not expect to apply this result directly—for example, in developing policy conclusions on who must test chemicals and who must pay for the testing. Nonetheless, the analysis can be applied indirectly. For example, when we do not expect individuals to start with common priors, it would probably become necessary for test results to be published publicly, for we would not expect the information to be spread adequately through aggregate market signals such as prices. (At present, TSCA requires test results to be reported to EPA, but not necessarily made public.) Under the ideal conditions for the theorem, the study provides a foundational analysis of the Delphi process and other related processes.

Applied Work

Priority Setting and Tier Testing. A major problem in risk analysis and risk management is posed by the large number of potentially toxic chemicals in the environment. It is now estimated that there are about 66,000 chemicals of commercial use (National Academy of Sciences, 1984), augmented by about a thousand new chemicals each year. The problem of toxic chemicals spreads over into all three environmental media: as air pollution, water pollution, and hazardous wastes. Of the 66,000 chemicals in commercial use, only a small fraction have been tested adequately for toxicity. For example, only about 600 chemicals have been tested adequately for carcinogenicity. Of these, about 300 have been classified as carcinogens. This does not mean that half of the chemical universe is carcinogenic; because of the enormous selection bias, the most suspicious chemicals have been tested first. Taking the selection bias into account, experts guess that about 3–5% of the chemical universe is carcinogenic. This 3–5% baseline figure is a soft number in the sense that additional information is likely to modify it. But information as to other forms of toxicity (e.g., teratogenicity, pulmonary disease) is even more fragmentary. For most chemicals, there is no toxicity information at all.

The federal government is currently allocating yearly resources sufficient to test about 20 chemicals in long-term bioassay, each assay costing about $700,000, and about 2000 short- and medium-term tests, costing between $10,000 and $60,000 each. The priority problem is to decide which chemicals to test each year.

The problem is like that of a nearsighted person who has misplaced his glasses. These glasses are weak, cracked, and scratched, but he needs them to drive down to the store to pick up his new and stronger pair. He must use his weak and poor quality information to acquire somewhat better information and to use that information to guide his decisions in acquiring still better information. We have approached this problem as one of decision making under uncertainty, and we have used the criterion of maximizing the expected value of information, where weak information is used to guide decisions to gather stronger information.

Although that is a straightforward application of the theory of decision making under uncertainty, it appears that this approach has not been applied before. Previous systems for setting priorities for testing chemicals have indeed focused on the two factors of critical importance for the value-of-information approach (for a review see National Academy of Sciences, 1984). For the first factor, increasing suspicion of toxicity increases the priority for testing. For the second factor, greater uncertainty about the suspicion also increases the

priority for testing. But the existing systems for setting priorities have encountered difficulties in combining these two factors—positive evidence of suspicion and uncertainty or lack of evidence. The value-of-information approach provides a natural solution to this problem of aggregating of the two factors.

The primary result of this work is the development of an optimization model which selects the best priority setting process from an enormous universe of possible priority setting processes (Bogle and Page, 1983). The model was used in the National Academy of Sciences report *Toxicity Testing* (1984).

The development of this model and the assessment of the input parameters have highlighted major differences between the approach of decision making under uncertainty and traditional risk analyses for potentially toxic chemicals. The model requires the input of judgmental probability, both for the prevalence rate (the probability that a chemical drawn randomly from the universe is carcinogenic—this has the role of a Bayesian prior) and also for the false positive and false negative probabilities of each of the information-gathering and interpreting activities. These latter assessments include judgments of the false positive and negative probabilities of the short- and long-term tests for which priorities are being set. The toxicologists and other experts who were asked to provide these judgments found the experience novel and uncomfortable, in much the same way that weather forecasters did when first asked to provide probabilistic predictions. The model also required, as input, judgments of the relative costs of different forms of misclassification.

Science is separated from policy in the sense that scientists are asked to make judgments of false positive and false negative probabilities and of the underlying prevalences, while policy makers are asked to contribute judgments of the relative costs of this classification. However, once these judgments are made they are entered as inputs in the model simultaneously and in some places these two types of inputs play symmetric roles in the optimization. Thus, the role of scientific judgment and the role of policy judgment are not completely separated and the risk analysis is not done as a two-step process when one step is completed before the second step is undertaken. Because each of the probabilistic judgments is made numerically or quantitatively, it can be calibrated against later frequency information as chemicals pass through the priority process and some are tested. The quantitative form of the model provides the opportunity for later feedback and validation of the judgmental probabilities used to initialize the model.

The problem of tier testing is to design a sequence of tests where the results from a lower tier guide decisions as to which tests to require in a subsequent tier. In its mathematical structure, this problem is identical to setting priorities for testing. Thus, we have the integration of two problem areas, and a single approach applicable to both.

In this application, our attention has shifted from looking at chemicals on a one-by-one basis to designing a process which deals with the chemical universe as a whole. In the next application of our approach, we consider a more narrowly focused risk analysis problem.

Analyzing the Risk of Carcinogens in Drinking Water. Since 1971 when the safe drinking water act was first debated in Congress, there has been a considerable and increasing interest in the risks posed by toxic chemicals in drinking water. There are by now about 20 empirical studies which attempt to analyze these risks (see Crump and Guess, 1980, for a careful review). The approach of this chapter provides a perspective for analyzing the risks of cancer associated with drinking water.

Application of the weak evidence principle would refocus the way much of the current risk analysis on drinking water is done. Much of the discussion concerns whether or not

enough evidence of hazard exists to justify a conclusion of a causal relationship between toxic chemicals, drinking water, and excess cancers (for a discussion of the causality issues see Crump and Guess, 1980). But from the point of view of the weak evidence principle, the issue of causality is not central. Translated into the vocabulary of decisionmaking under uncertainty, "proving causality" means accumulating sufficient evidence so that a "reasonable person" would assign almost all his judgmental probability weight to a positive effect. In other words, a proof of causality is compatible with establishing a 99% probability that drinking water contaminated with synthetic organic chemicals raises the cancer rate by 0.1% over what it would be with uncontaminated drinking water.

However, for decision purposes it is more relevant to ask if the evidence is strong enough so that a reasonable person would put a 40% probability weight on there being a 5% or greater excess over background due to contaminated drinking water. This latter question is more relevant for two reasons. First, it appears from interviews with those who have undertaken the empirical studies that there is a general agreement that there is so much remaining uncertainty that most people's subjective probability distributions are too diffuse to allocate nearly all the probability weight to a greater-than-zero effect. Nonetheless, the suggestive evidence is sufficiently strong so that several of the researchers would allocate a substantial probability weight to there being a 5% or greater excess due to the drinking water effect. In the focus on causality, the evaluation of suspicious yet not definitively conclusive information is neglected. Second, as shown by analyses similar to that in Figure 1, when there are modest probabilities (probabilities in the range of 30–60%) of the existence of a moderate drinking water effect (a 5% or greater excess), some precautionary actions are justified in terms of a net expected benefit caluculation. With the weak evidence principle in mind, focus shifts to the elicitation of these modest levels of probability associated with moderate levels of effect.

To help evaluate the middle range of uncertainty, where the probabilities might be between 20 and 80%, we suggested (Page and Harris, 1983) looking at several clues. The most suggestive clue arises from the fact that independent estimates of the risk have been developed from two different methodologies using two independent data sets. One was based on human epidemiology and the other on extrapolations from animal experiments. Interestingly, these two risk estimates differ by about one or one-and-a-half order of magnitude. Taken separately, each is highly uncertain. Together they are strongly suggestive. As a second clue we can look at the early predictions and compare them with later results. One of the most important of these was the early identification of gastrointestinal and urinary tract cancers as the most important sites for the drinking water effect. At the time, the evidence appeared weak and there was some question whether or not these sites would be confirmed as the important sites by later studies (this has proved to be the case). A third clue is to look at the trend of the epidemiological evidence as it has accumulated over time (it appears this trend has been toward more positive rather than more negative results). A fourth clue can be obtained from analyses of statistical power. To forecast what patterns and apparent inconsistencies are likely to emerge as a function of different true levels of effect, a statistical power analysis is required. For such an analysis see Harris, Page, and Reiches, 1977, pp. 323–326.) Putting these clues together provides a basis for assessing the current evidence to make judgmental probability predictions of the drinking water effect.

Liability Law. As we have seen, legal rules of strict liability are closely related to proper scoring rules. Risk analysis is also related to the judicial process in tort law. For example, in cases of DES, thalidomide, and Bendectin, the probabilities of toxic harm are

weighed against the benefits of the chemical and the costs of the harm. In Page (1983), we argue that the current process of tort law is inconsistent with decision making under uncertainty in at least one important respect. In tort cases it is common for the judge to instruct the jury that it must find a preponderance of the evidence in favor of each "fact" alleged by the plaintiff in order for the plaintiff to win. Thus, in the Bendectin case, for the mother of the child born without arms to win, the jury must believe that there is a greater than 50% chance that bendictin is a teratogen. This standard of proof is applied without taking into account the relative costs of possible wrong decisions by the courts. For the approach of decision making under uncertainty, the relative costs are used to define the standard of proof.

The inconsistency is especially important when there are low probabilities of harms with large consequences. For example, the food dye "butter yellow" was used for several years to color margarine. The economic benefits of this food color were extremely small because there were close substitutes available (such as carotene, the natural color in carrots) which are cheap and have strong evidence of safety. On the other side of the ledger, butter yellow had a close chemical relationship to known potent carcinogens and, as the chief coloring agent for margarine, exposure was in the millions. Thus, if we compare the costs of a false negative (erroneously leaving butter yellow on the market if it is a carcinogen) with the cost of a false positive (erroneously substituting carotene for butter yellow if butter yellow is not a carcinogen) and if we take the exposure and the costs of cancer into account, we might easily calculate the cost of a false negative as a hundred times higher than the cost of a false positive. With this ratio, if we are to maximize expected benefits, then our standard of proof should be as follows: we should take the precautionary action of removing butter yellow from the market as long as its probability of carcinogenicity is greater than 1%. This, of course, is a far cry from the 50% standard of proof in the preponderance test.

In the long run, the manner in which courts interpret the standard of proof has an enormous impact on the way in which risk analysis is done in administrative agencies and private firms and, subsequently, upon the risks borne by society at large. A court's decision for or against liability in a particular case does not of course prevent a harm which has already occurred. However, the standards of proof and the consequent ease of difficulty of winning a liability suite provide incentives for research in risk analysis and precautionary actions for similar risks in the future. Thus, negligence law, along with strict liability, is a major example of a feedback mechanism for risk analysis and management.

Adjusting the standard of proof to maximize net expected benefits would lead to more precautionary actions than under the preponderance test, when the cost of a false negative is higher than the cost of a false positive, and to fewer precautionary actions, when the cost of a false negative is lower than the cost of a false positive.*

* Let 1 be the cost of false positive, x the cost of a false negative, and p the probability that the chemical in question is toxic (the weight of evidence). Under the preponderence test the plaintiff wins if he can convince the court that $p > 0.5$ (and loses otherwise). Under expected net benefit maximization, the plaintiff wins if he can convince the court that deciding in his favor has lower expected cost than deciding in favor of the defendant. The expected cost of deciding in favor of the plaintiff is the expected cost of a false positive $(1 - p)(1)$; the expected cost of deciding in favor of the defendant is px. To maximize net expected benefits, the plaintiff wins if he can convince the court that $1 - p < px$, or if he can convince the court that the probability of toxicity p is greater than $1/(1 + x)$. When $x = 1$, he must convince the court that $p > 0.5$, which is the preponderance test. When $x > 1$ (the cost of a false negative is greater than the cost of a false positive), the standard of proof $1/(1 + x)$ is less than 0.5 and judgments favoring the plaintiff and future precautionary actions are easier than under the preponderance test. When $x < 1$, the standard of proof is more stringent than under the preponderance test, with fewer judgments leading to precautionary actions.

FUTURE RESEARCH DIRECTIONS

The preceding research leads in several directions. We shall mention three of them.

Investigating the Process of Interpreting Information and Translating It into Numerical Judgmental Probabilities

There is a large literature investigating how numerical judgmental probabilities are developed, and this is by no means a neglected area. We have already mentioned the seminal work by Tversky and Kahneman on cognitive heuristics and biases, and the work by Fischhoff and others on calibration as a validating device. But our emphasis on feedback and reward mechanisms leads to a somewhat different perspective, which we will try to sketch here. First of all, in many psychological studies there is little feedback in the sense that we are talking about in this chapter. Often the experimental subjects are paid by the session or by the hour rather than by the consequences of their decisions. When payments are made on the basis of the subjects' actual decisions, these payments are often quite low. For example, in a study by Jensen and Peterson (1973) the subjects were paid on the basis of their decisions, but the earnings ranged from only \$0.94 to \$1.90 for a 1-hour session. Similarly, in an experiment by Coombs, Bezembinder, and Goode (1967) the subjects were paid on the average of about 60 cigarettes for five 2-hour sessions on the basis of their decisions, along with \$2.50 bonus for attendance in all 10 hours. Second, our approach emphasizes the study of interaction and competition among participants in the decision process.

It is interesting to note the two most prominent instances where assessors of judgmental probabilities are well calibrated: weather forecasters and parimutuel racetrack bettors (see Hoerl and Fallin, 1974, for evidence of accuracy in predictions from racetrack betting). For both instances the indicator events are well defined, the number of predictions is large, and the experience gained in making probabilistic predictions is consequently large, the feedback is prompt, and the feedback is tied directly to the probabilistic decisions made as we have discussed in this chapter. At least in the case of racetrack betting the rewards are potentially large, and they might be considered substantial as well for weather forecasters who find their work graded and evaluated in an explicit way inviting comparisons with other forecasters.

We are planning a series of experimental studies to investigate how information is translated into numerical judgmental probabilities. Although we will have to await the results of these studies, we do not expect that an increased emphasis on feedback mechanisms would lead to a disappearance of the kinds of cognitive problems described by Kahneman, Tversky, and others. However, we may find that an emphasis on feedback mechanisms does affect the process of risk analysis. For example, Grether and Plott (1979) studied the phenomenon of preference reversal, which had been previously identified by a number of psychologists. In their study, Grether and Plott emphasized the role of reward mechanisms and strengthened the evidence of preference reversal. Similarly, in an experimental setting which emphasized reward structures, Grether (1980) investigated the representativeness heuristic, somewhat confirming earlier results but also suggesting that financial incentives affect the process in a limited way.

Two pilot experiments have been conducted. These represent the first step of an empirical counterpart of the fundamental study of processes which combine private and public information, such as the Delphi process. Subjects were paid on the basis of their predictive performance, and the payments ranged from \$2 to \$17 for a single $1^1/_2$-hour session. As

predicted by the theoretical analysis, we found covergence to the consensus probability estimate. We found some convergence as well in the individual posterior probabilities, but this was not as pronounced. We would like to investigate this process more thoroughly on an experimental basis and conduct further experiments on the role of incentive systems in predictive performance.

Delegating Risk Analysis and Risk Management from Congress to the Administrative Agency

Aministrative agencies which undertake risk analysis and management are agents for Congress. In delegating responsibility to the agency, Congress establishes links of communication (oversight and hearings) and instruments of control (appropriations, legislative mandate, rights of judicial review, and access by third parties). Information from the administrative agency is fed back to Congress and the agency is rewarded or punished on the basis of it.

We are developing a model of this process (see McCubbins and Page, 1983). Briefly, the model suggests that when there is a low degree of uncertainty and conflict, the legislative mandate is likely to be specific in substantive terms but broad with wide discretions in its procedural requirements. Conversely, when there is much uncertainty and much conflict, there is likely to be a broader substantive mandate but more narrowly prescribed procedural requirements. How this process works itself out determines the context in which risk analysis is done by the administrative agency.

It is useful to increase our understanding of this process of delegation and control because if risk analysis is to be improved it must also accommodate itself to the structure it is embedded in. Otherwise even the best improvements will not be adopted.

Identifying the Best Assessor

De Finetti, Savage, Roberts, and others have all addressed the problem of identifying the best risk assessor. A principal might wish to identify the best assessment technique in order to rely upon it more or to invest in it. Or an agency might wish to identify the best risk analysts in order to hire them or promote them. It is important to know how well the risk analysts are doing in order to know how much to rely upon their predictions. For this identification some sort of scoring mechanism is necessary. We have looked at several and are planning to explore their properties by means of Monte Carlo simulation.

The simulation can be used to derive the probability that the risk analyst with the best information will have the highest total score after a given number of probabilistic assessments. Another way of putting the matter is that the simulation helps define how long it takes for verification scores such as those suggested by Brier (1950) to become good predictors of the best analysts.

CONCLUSION

Feedback mechanism in risk analysis and management are important for two reasons: to evaluate the performance of existing methods for estimating risks, in the sense of keeping score in a statistical sense and to provide scrutability and accountability of those engaged in the process of estimating risks and managing them. Risk analysis and management take

place in the context of institutions, where the term *institutions* is in the Constitutional sense of the rules of the game. The institutional context shapes the way in which risk analysis and management are done. The main institution existing for feedback is strict liability, where risk burdens are shifted back to those who generate them.

Surprisingly, rules of strict liability are found to be closely related to proper scoring rules. And perhaps even more surprisingly, proper scoring rules are found to be closely related to the Groves mechanism, which is a mechanism for the elicitation of willingness to pay for a public good. These connections give a broader perspective to the understanding of the role of feedback mechanisms in risk analysis and risk management. In this broader context, it is possible to study institutions, such as liability rules and scoring rules, which provide incentives for maximizing net expected benefits. The perspective of our approach can be described in terms of some of the main issues of risk analysis and management, as follows.

Acceptable Risk

Following the literature on decision making under uncertainty, we adopt in this chapter a criterion of expected value maximization. The objective being maximized may take into account social risk aversion and equity considerations. Nonetheless, our approach gives a definite perspective to the question of acceptable risk. Risks are controlled to the point of minimizing expected cost (adjusted for distributional considerations); the remaining risk is by definition "acceptable."

A consequence of expected net benefit maximization is the weak evidence principle, which says that weak evidence of a hazard should lead to weak precautionary action and strong evidence should lead to strong precautionary action. The response is continuous—as the weight of evidence becomes a little stronger, so too does the appropriate precautionary action.

Hypothesis Testing and Statistical Decision Theory

The weak evidence principle stands in contrast to the practical consequences of hypothesis testing. Risk analysis often depends upon the interpretation of statistical tests and experiments. In traditional hypothesis testing, the focus is on the significance level of the test, or p-values. These are probabilities of a false positive. To apply the weak evidence principle, it is necessary to derive a (judgmental) probability of the hazard on the basis of the test result and the prior information before the test. To do this, the full operating characteristics of the test are needed (false negative probabilities as well as false positive probabilities), as well as the prior probability. It is also necessary to take into account the costs of false positives and false negatives.

The practical consequence of relying on traditional hypothesis testing are threefold: the decision maker does not know how to interpret a negative result from a test, because the false negative probability has not been estimated; his decision making tends to be jumpy or discontinuous, depending on whether the test outcome is above or below some critical value; and he does not maximize net expected benefits.

If a decision maker wishes to maximize net expected benefits and to follow the weak evidence principle, he will need to move in the direction of statistical decision theory. As a first practical step, he can require statistical power analyses to be undertaken in the design and the interpretation of experimental tests.

Two-Step Risk Analysis

Calkins and others have recommended splitting risk analysis and management into two steps, the first stressing science and the second policy. Calkins et al. (1980) have noted that the process can be interactive with communication between those working on each of the steps. Our approach stresses the importance of the communication and suggests that the process might better be simultaneous rather than sequential. Our work on priority mechanisms and tier testing illustrates the simultaneous nature of the problem. All five inputs—underlying priors, probability of false positives and false negatives, and the costs of false positives and false negatives—are needed simultaneously for maximization of net expected benefits.

If risk analysis and management are set up as a feedback mechanism involving rewards (or liabilities), it will automatically become a simultaneous process, since the analyst will be faced with a structure of potential rewards (or liabilities) at the time he designs his research and interprets it. Common sense requires making the process at least somewhat simultaneous. Without some guidance of the relative importance of resolving various uncertainties, there is no way to decide how much research is enough and what direction of research to follow.

Separating Fact and Value

Part of the motivation for Calkins' proposal of a two-step process is to separate those who work on science (or factual) questions from those who work on policy (or value) questions. In our approach, the dichotomy between fact and value is refocused. Instead of the split being between objective and subjective, it is between two types of subjective judgments—judgments about probability or uncertainty and judgments about value (e.g., the cost of an excess cancer). It is still possible, and probably useful, to separate experts on the basis of their expertise, scientists working on science and policy makers on policy.*

Risk Analysis with a Bottom Line

One way of improving communication between scientists (or analysts) and the decision makers (or policy makers) is to define a risk analysis as a product with a bottom line. The bottom line is a (judgmental) predictive probability for some observable indicator event. Vague qualitative statements such as "low probability" are subject to gross misinterpretation. Structuring risk analysis with a bottom line allows predictive performance to be measured and validated. It also increases the accountability of the analysts.

Level of Analysis

We conclude by touching upon what we consider an issue too much neglected in the literature on risk analysis and management. Should a risk analysis focus on individual problems taken one at a time, or should it attempt to maximize net expected benefits taken over an entire decision process involving many problems? Should a risk analysis focus on single chemicals taken one at a time or should it focus on the universe of chemicals taken together?

In our review of risk analysis undertaken for government agencies, we have found the emphasis to be on single decisions taken one at a time. However, by considering the problem of designing institutions as feedback mechanisms, we direct attention to managing risks

* For a discussion of the difficulty in separating fact from value, see Whittemore (1983).

generically rather than on a one-by-one basis. Our work on the legal standard of proof for chemical hazards and on the problem of setting priorities are examples of the shift of analysis to the generic level. Both levels of analysis are needed, but we believe that the generic level deserves more attention.

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REFERENCES

Becker, G.M., M.H. DeGroot, and J. Marschak (1964). "Measuring Utility by a Single Response Sequential Method." *Behavioral Science,* Vol. 9, 226–232.

Becker, Gary and George Stigler (1974). "Law Enforcement, Malfeasance and Compensation of Enforcers." *Journal of Legal Studies* (Jan.).

Bogle, Gib and Talbot Page (1982). "Priority Setting for Testing Chemicals." in *Safety Evaluation and Regulation of Chemicals.* Homburger (ed). Boston: S. Karger.

Brier, Glenn (1950). "Verification of Forecasts Expressed in Terms of Probability." *Monthly Weather Review.*

Calkins, D.R., R.L. Dixon, C.R. Gerber, D. Zarin, and G.S. Omann (1980). "Identification, Characterization, and Control of Potential Human Carcinogens: A Framework for Federal Decisionmaking." *JNCI,* Vol. 64, No. 1: 172 (Jan.).

Coombs, C.H., T.G. Bezembinder, and F.M. Goode (1967). "Testing Expectation Theories of Decisionmaking without Measuring Utility or Subjective Probability." *Journal of Mathematical Psychology,* Vol. 4, 72–103.

Crump, K. and H. Guess (1980). "Drinking Water and Cancer: Review of Recent Findings and Assessment of Risks." Washington, D.C.: Council on Environmental Quality.

De Finetti, Bruno (1962). "Does It Make Sense to Speak of 'Good Probability Appraisers'?" in *The Scientist Speculates: An Anthology of Partly-Baked Ideas.* Toronto: Heinemann.

DeGroot, Morris (1970). *Optimal Statistical Decisions.* New York: McGraw-Hill.

DeGroot, Morris (1974). "Reaching a Consensus." *Journal of the American Statistical Association,* Vol. 69, No. 345 (March).

Ellsberg, Daniel (1961). "Risk, Ambiguity, and the Savage Axioms." *Quarterly Journal of Economics,* Vol. 75.

Fischhoff, Baruch (1982). "Debiasing" in *Judgment under uncertainty: Heuristics and biases.* Kahneman, Slovic and Tversky (eds). New York: Cambridge University Press.

Foreman, Joshua (ms). "Incentives in the Elicitation of Probability Estimates." Pasadena, Calif. California Institute of Technology.

Green, J. and J.J. Laffont (1979). *Incentives in Public Decisionmaking.* New York: North Holland.

Grether, David and Charles R. Plott (1979). "Economic Theory of Choice and the Preference Reversal Phenomenon." *American Economic Review,* Vol. 69, No. 4, 623–638 (Sept.).

Grether, David (1980). "Bayes Rule as a Descriptive Model: The Representativeness Heuristic." *Quarterly Journal of Economics* (Nov.).

Hand, Learned (1947). "United States vs. Carroll Towing." F. 2d 169 (2nd Cir 1947).

Harris, Robert, Talbot Page, and Nancy Reiches (1977). "Carcinogenic Hazards of Organic Chemicals in Drinking Water." *Origins of Human Cancer,* Cold Spring Harbor, New York: Cold Spring Harbor Laboratory.

Hoerl, Arthur E. and H.K. Fallin (1974). "Reliability of Subjective Evaluations in a High Incentive Situation." *Journal of the Royal Statistical Society,* Vol. 137, Part 2, p. 227.

Howard, R.A., J.E. Matheson, and D.W. North (1972). "The Decision to Seed Hurricanes." *Science* Vol. 176, 1191–1202.

Jensen, Floyd A. and C.R. Peterson (1973). "Psychological Effects of Proper Scoring Rules." *Organizational Behavior and Human Performance,* Vol. 9, 307–317.

Lichtenstein, S., B. Fischhoff and L.D. Phillips (1982). "Calibration of probabilities: The state of the art to 1980" in *Judgment under uncertainty: Heuristics and biases.* Kahneman, Slovic and Tversky (eds). New York: Cambridge University Press.

Marschak, Jacob, and others (1975). "Personal Probabilities of Probabilities." *Theory and Decision* (May).

Marshall, Eliot (1983). "The Murky World of Toxicity Testing," *Science,* Vol. 220, June 10, 1983.

McCubbins, Mathew and Talbot Page (1986). "A Theory of Congressional Delegation" in *Congress: Structure and Policy*. McCubbins and Sullivan (eds.). New York: Cambridge University Press (in press).

McKelvey, Richard and Talbot Page (1986). "Common Knowledge and Consensus with Aggregate Statistics." *Econometrica* (in press).

Morgan, M.G., S.C. Morris, A.K. Meier, and D.L. Shenk (1978). "A Probabilistic Methodology for Estimating Air Pollution Health Effects from Coal-Fired Power Plants." *Energy Systems and Policy,* Vol. 2, No. 3, 287–310.

Murphy, A.H. (1972). "Scalar and vector partitions of the probability score (Part I): Two-state situation." *Journal of Applied Meteorology,* Vol. 11, 273–282.

National Academy of Sciences (1984). *Toxicity Testing: Strategies to Determine Needs and Priorities*. Washington, D.C.: National Academy Press.

Page, Talbot (1978). "A Generic View of Toxic Chemicals and Similar Risks." *Ecology Law Quarterly,* Vol. 7, No. 2.

Page, Talbot (1979). "Keeping Score: An Actuarial Approach to Zero-Infinity Dilemmas" in *Energy Risk Management*. Goodman and Rowe (eds). New York: Academic Press.

Page, Talbot (1981). "A Framework for Unreasonable Risk in the Toxic Substances Control Act (TSCA)." *Annals of the New York Academy of Sciences,* Vol. 363, 145–166 (April 30).

Page, Talbot (1983). "On the Meaning of the Preponderance Test." *Law and Contemporary Problems,* Vol. 46, No. 3, 267–283 (Summer).

Page, Talbot (1986). "Pivot Mechanisms in Probability Revelation." Pasadena, Calif.: California Institute of Technology, Social Science Working Paper No. 596.

Page, Talbot and Robert Harris (1983). "A Cost–Benefit Approach to Drinking Water and Cancer" in *Water Chlorination: Environmental Impact and Health Effects*. (Vol. 4, Book 2). Jolley, Brungs, Cotruvo, Cumming, Mattice, and Jacobs (eds). Ann Arbor: Ann Arbor Science Publications.

Posner, Richard (1977). *Economic Analysis of the Law*. Boston: Little, Brown.

Raiffa, Howard (1970). *Decision Analysis: Introductory Lectures on Choices under Uncertainty*. Reading, Mass.: Addison-Wesley.

Roberts, Harry (1965). "Probabilistic Prediction." *Journal of the American Statistical Association,* (March).

Savage, Leonard J. (1971). "Elicitation of Personal Probabilities and Expectations." *Journal of the American Statistical Association,* Vol. 66, No. 336 (Dec.).

Savage, Leonard J. (1972). *The Foundations of Statistics*. New York: Dover.

Subcommittee on Department Operations, Research, and Foreign Agriculture (1983). "EPA Pesticide Regulatory Program Study." Washington, D.C.: Committee on Agriculture, House of Representatives Ninety-Seventh Congress, Second Session (Dec. 17).

Supreme Court of the United States. "Industrial Union Department, AFL-CIO v. American Petroleum Institute." Decided July 2, 1980.

Tversky, Amos and Daniel Kahneman (1974). "Judgment under uncertainty: Heuristics and biases." *Science,* Vol. 185 (Sept. 27).

Whittemore, Alice (1983). "Facts and Values in Risk Analysis for Environmental Toxicants." *Risk Analysis,* Vol. 3, No. 1 (March).

Winkler, R.L., A.H. Murphy, and R.W. Katz (1977). "The Consensus of Subjective Probability Forecasts: Are Two, Three . . . Heads Better than One?" Fifth Conference on Probability and Statistics in Las Vegas. Boston, Mass: American Meteorological Society.

13

Risk Evaluation
A Review of the Literature

Lloyd L. Philipson

INTRODUCTION

The risk evaluation phase of risk analysis is concerned with the appraisal of the sociopolitical significance of an estimated risk. This significance may reflect its acceptability (or, in some instances, "tolerability," when a risk exists that is not actually acceded to, but for whose mitigation no practicable approach is evident) or nonacceptability in relation to various possible criteria and/or as perceived by various groups. It may reflect the price paid in lost benefits if the risk is not accepted and the responsible hazardous activity is eliminated. Finally, it may reflect the costs required to mitigate the risk. This chapter reviews the literature on criteria or standards against which a hazardous activity's risk can be decided to be acceptable or to require mitigation, and/or against which the residual risk of the mitigated hazard can be compared for acceptability. It is recognized, however, that the establishment of such criteria or standards suffers from severe difficulties, and that these difficulties underlie, at present, many decisions on highly beneficial but also highly hazardous activities in our society. Nuclear power is the paramount example; many others that have exercised Congress, regulators, activist groups, and the general public could also be noted.*

It may be noted that there have been a few previous attempts at partial syntheses of the state of understanding of risk acceptance. Brookhaven National Laboratory surveys a part of the literature on acceptability criteria (Miller and Hall, 1981). A Rand Corporation report reviews many of the issues in risk acceptability and mitigations evaluation in the course of arguing for a simplified utility assessment approach (Salem, Solomon, and Yesley, 1980). Perhaps the most comprehensive review of risk acceptability concepts (but not available numerics) is part of a wider discussion of the theory of risk assessment by Sage and

* A large project for the National Science Foundation has illuminated many aspects of the risk estimation and acceptability evaluation problems. It is summarized in Okrent (1977). An introduction to the genesis of these problems from safety considerations is provided in Philipson (1977).

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White (1980). Finally, a recent article in *Science* by Starr and Whipple (1980) also reviews various aspects of the risk acceptance question, in the course of arguing for the development of quantitative risk criteria that can, at least, assist the public risk decision-making process.

The approaches to risk evaluation considered in the investigation and summarized here fall into the following categories: comparisons to ambient risks, comparisons to revealed preferences, and risk–cost–benefit evaluations. A fourth potential procedure, comparisons to risk perceptions (expressed preferences), will not be discussed, since this material is covered elsewhere in the volume (see, e.g., Chapter 1).

Some important past and present attempts to synthesize specific numerical acceptable risk levels on the basis of these approaches are then also noted. Finally, an analysis that was conducted of the responses of such attempts and other possible risk evaluation procedures to the previously identified uncertainties in the estimates of the risks (and, where appropriate, benefits, and costs) with which they are concerned is briefly summarized.

COMPARISONS TO AMBIENT RISKS

The simplest basis for arguing that some hazardous activity should be acceptable is a comparison of its predicted risk to that of other risks already present (and therefore already "accepted"); that is, to the" ambient" risks before the activity is introduced. This has been done considering generic ambient risks that result from averaging over an entire population, such as the total population of the United States or of all workers, or from site-specific data where this is possible for the immediate vicinity of the site of the proposed activity. The ambient risks considered may derive from natural or man-caused hazards. Their accepted levels may be explicit from historical data, or they may be implied from existing codes and practices.

Comparable Risks from Existing Natural and Technological Hazards

Figures 1 and 2, derived from the Nuclear Regulatory Commission's Reactor Safety Study (Rasmussen et al., 1975), illustrates the method considering ambient risks from natural and technological hazards, respectively. They show that, based on the study's estimates of nuclear power plant risks, 100 such plants have a chance per year of causing a large incident only about that of a meteorite striking the United States, and far less of a chance than that of any other natural or technological hazards. The main objective argument (questions of accuracy in the nuclear plant risk estimates aside) against the conclusion that, therefore, the 100 nuclear plants should be considered acceptably safe is that, unlike most natural and some technological hazards, the risks of the plants do not have to be accepted, no matter how low they may be; alternatives to nuclear power plants exist. Differences between who is benefited and who is involuntarily put at risk by the nuclear plants also lead to arguments against the concept.

Other historical data on ambient risks may be found, e.g., in Starr (1971a) and Cohen and Lee (1979). A most extensive compendium of ambient risk data is given in a recent Brookhaven National Laboratory report (Coppola and Hall, 1981). Harriss et al. (1978) consider health, as well as accident risks based on historical data, and, furthermore, treat risks to the ecology as well as to humans. Rothschild (1979) and Kletz (1977) in the United Kingdom exhibit historical public and occupational risks and argue that new risks should be put in the perspective of such "standards."

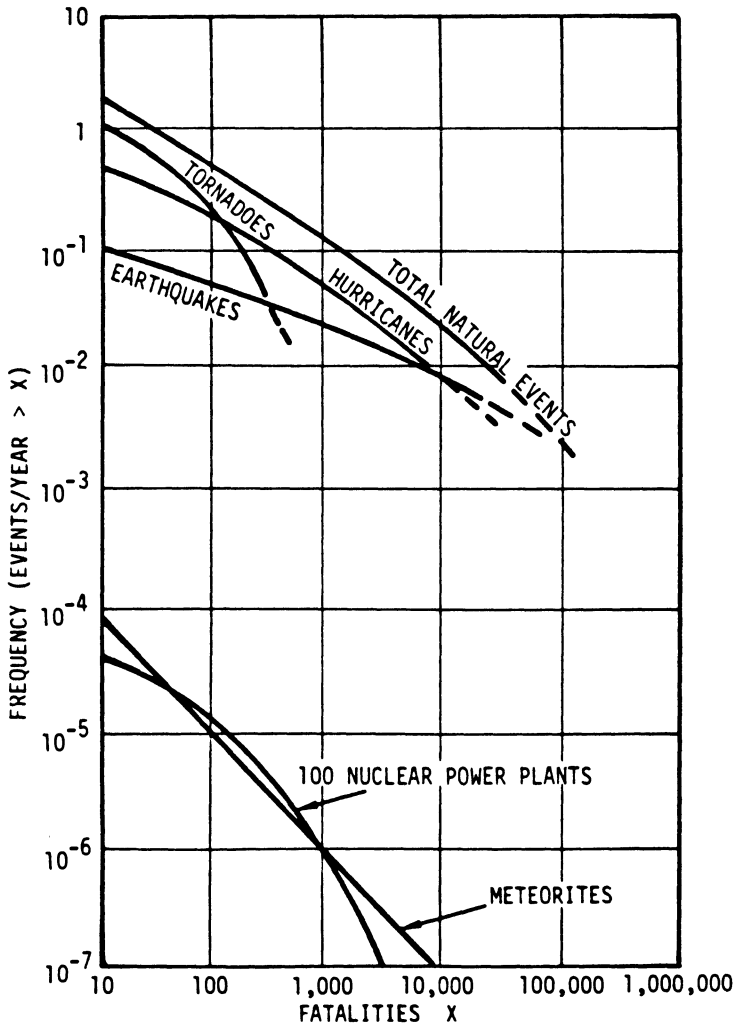

Figure 1. Frequency of natural events involving fatalities (Rasmussen, 1975).

Implied Acceptable Standards

It has also been suggested that government and industrial codes, engineering practices, sizes of investment for safety improvements, and other factors reflecting public and private decision makers' perceptions of the severity of various risks should provide a possible means for "backing out" imputed levels of accepted risk. Established seismic building codes, for example, ought to imply a level of risk that, after balancing the potential consequences of the hazard with the costs of mitigating it, has been presumably established as acceptable.

Unfortunately, the existence of great inconsistencies in public safety investment is well established. Table 1 of Cohen (1980) exhibits this clearly for a range of hazards and makes the point of the relatively excessive investment that prevails for radiation-related hazards. Evidently, the derivation of consistent risk acceptance criteria from the implications of existing safety standards is unlikely to be effective.

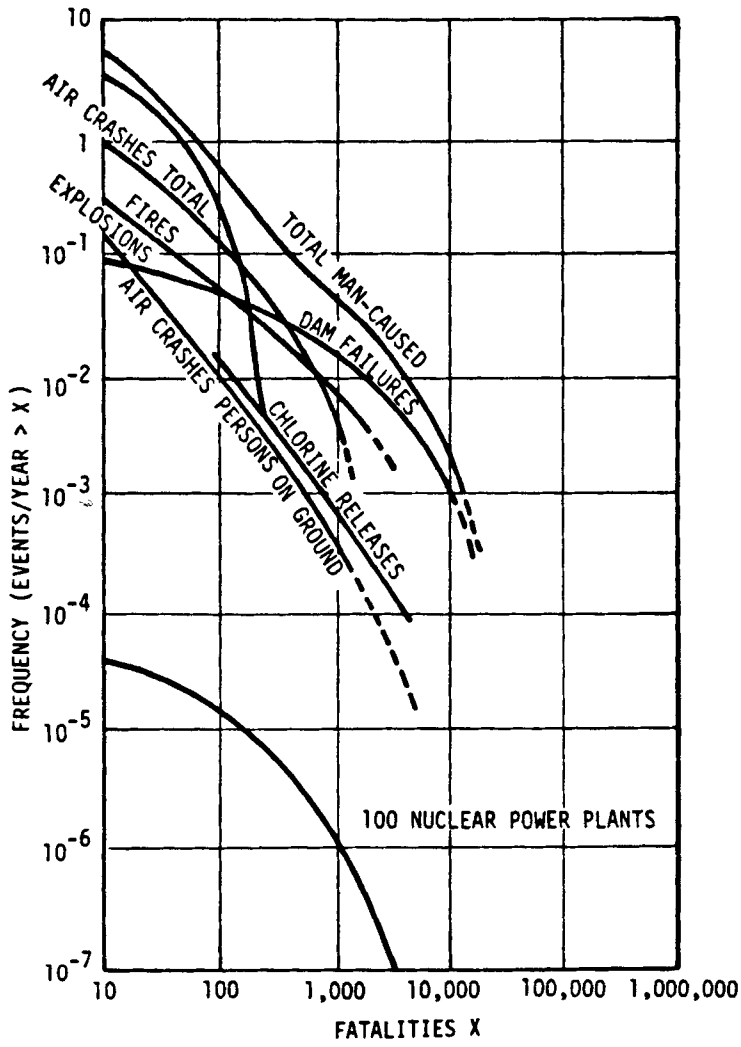

Figure 2. Frequency of man-caused events involving fatalities (Rasmussen, 1975).

Incremental Risks

One of the most popular means of exhibiting the presumed low significance of a new risk is to show that it subtracts no more from life expectancy than many existing risks which a given population is already exposed to. Accordingly, many tabulations of various ambient risks have been published and, in one form or another, the incremental contribution to premature death of the new risk is considered in relation to the ambient risks' contributions. Refinements on the procedure include considering, as much as possible, site-specific ambient risks, rather than wider averages, and the implications of competing risks that lower the significance of the new risks still further.

Thus, Wilson (1979) has published lists of rather ordinary incremental risks in which some new, high technology's risk contribution is also embedded. Table 2 is an example. Each hazard is defined so that it causes, over some sufficiently large population and some given period of time, an increase of 10^{-6} (one in a million) in the average chance of death per person exposed to the hazard.

Table 1. Cost per Fatality Averted (1975 Dollars) Implied by Various Societal Activities (Left Column) and Cost per 20 Years of Added Life Expectancy (Right Column)[a]

Item	$ per fatality averted	$ per 20-year life expectancy
Medical screening and care		
Cervical cancer	25,000	13,000
Breast cancer	80,000	60,000
Lung cancer	70,000	70,000
Colorectal cancer		
Fecal blood tests	10,000	10,000
Proctoscopy	30,000	30,000
Multiple screening	26,000	20,000
Hypertension control	75,000	75,000
Kidney dialysis	200,000	440,000
Mobile intensive care units	30,000	75,000
Traffic safety		
Auto safety equipment—1966–70	130,000	65,000
Steering column improvement	100,000	50,000
Air bags (driver only)	320,000	160,000
Tire inspection	400,000	200,000
Rescue helicopters	65,000	33,000
Passive three-point harness	250,000	125,000
Passive torso belt–knee bar	110,000	55,000
Driver education	90,000	45,000
Highway construction–maintenance practice	20,000	10,000
Regulatory and warning signs	34,000	17,000
Guardrail improvements	34,000	17,000
Skid resistance	42,000	21,000
Bridge rails and parapets	46,000	23,000
Wrong-way entry avoidance	50,000	25,000
Impact-absorbing roadside device	108,000	54,000
Breakaway sign lighting posts	116,000	58,000
Median barrier improvement	228,000	114,000
Clear roadside recovery area	284,000	142,000
Miscellaneous nonradiation		
Expanded immunization in Indonesia	100	50
Food for overseas relief	5,300	2,500
Sulfur scrubbers in power plants	500,000	1,000,000
Smoke alarms in homes	250,000	170,000
Higher pay for risky jobs	260,000	150,000
Coal mine safety	22,000,000	13,000,000
Other mine safety	34,000,000	20,000,000
Coke fume standards	4,500,000	2,500,000
Air Force pilot safety	2,000,000	1,000,000
Civilian aircraft (France)	1,200,000	600,000
Radiation-related activities		
Radium in drinking water	2,500,000	2,500,000
Medical X-ray equipment	3,600	3,600
ICRP recommendations	320,000	320,000
OMB guidelines	7,000,000	7,000,000
Radwaste practice—general	10,000,000	10,000,000
Radwaste practice (3)	100,000,000	100,000,000
Defense high-level waste	200,000,000	200,000,000
Civilian high-level waste		
No discounting	18,000,000	18,000,000
Discounting (1% year)	1,000,000,000	1,000,000,000

[a] Source: Cohen (1980).

Table 2. A Tabulation of Incremental Risks[a]

Risks that increase chance of death by 0.000001[b]	
Smoking 1.4 cigarettes	Cancer, heart disease
Smoking $\frac{1}{2}$ liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lung disease
Spending 3 hours in a coal mine	Accident
Living 2 days in New York or Boston	Air pollution
Traveling 6 minutes by canoe	Accident
Traveling 10 miles by bicycle	Accident
Traveling 300 miles by car	Accident
Flying 1000 miles by jet	Accident
Flying 6000 miles by jet	Cancer caused by cosmic radiation
Living 2 months in Denver on vacation from New York	Cancer caused by cosmic radiation
Living 2 months in average stone or brick building	Cancer caused by natural radioactivity
One chest X ray taken in a good hospital	Cancer caused by radiation
Living 2 months with a cigarette smoker	Cancer, heart disease
Eating 40 tablespoons of peanut butter	Liver cancer caused by aflatoxin B
Drinking Miami drinking water for 1 year	Cancer caused by chloroform
Drinking 30 12-oz. cans of diet soda	Cancer caused by saccharin
Living 5 years at site boundary of a typical nuclear power plant in the open	Cancer caused by radiation
Drinking 1000 24-oz. soft drinks from recently banned plastic bottles	Cancer from acrylonitrile monomer
Living 20 years near PVC plant	Cancer caused by vinyl chloride (1976 standard)
Living 150 years within 20 miles of a nuclear power plant	Cancer caused by radiation
Eating 100 charcoal-broiled steaks	Cancer from Banzopyrene
Risk of accident by living within 5 miles of a nuclear reactor for 50 years	Cancer caused by radiation

[a] Source: Wilson (1979).
[b] 1 part in 1 million.

COMPARISONS TO REVEALED PREFERENCES

The notion that acceptable risk levels can be revealed by data on the relationship of the losses from past hazardous activities with the benefits associated with them was first put forward by Starr (1969) in an article in *Science*. The debate on risk acceptance criteria may be said to have originated with this article, and has since expanded in many directions and with growing intensity. Starr attempted to show, more or less quantitatively, what apparent past risk acceptance behavior was in U.S. society, and, due to its consistency in certain ways, how it could provide a basis for judging what risks could be acceptable in the future. Otway and Cohen (1975), however, have critiqued Starr's findings and argued against the existence of the consistencies he claims. Baldewicz (1974) and many others have extended Starr's data developments into other types of activities, especially occupational ones, where "voluntary" risk acceptance is presumably obtained by the relatively clear job benefits that are associated with it. Wilson (1975a) and Ferreira and Slesin (1976), among others, have assessed special concerns with catastrophic group or societal risks, as distinct from average individual risks, and they have argued society's evaluations of such risks are "amplified" nonlinearly as a function of the potential catastrophic loss.

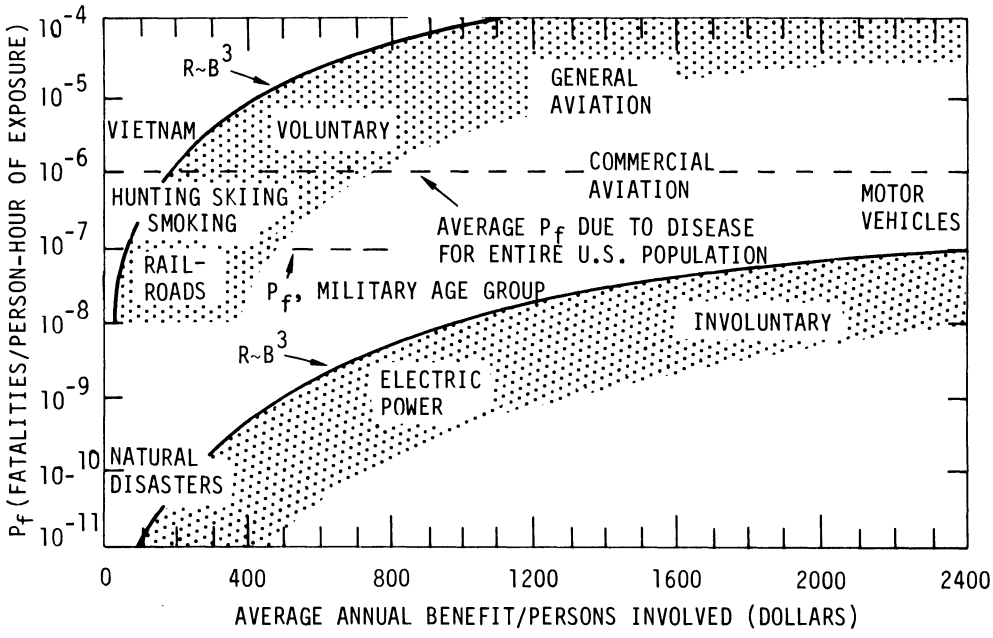

Figure 3. Starr's risk versus benefit curves (Starr, 1969).

Figure 3 presents Starr's original curves of historically accepted risks (that is, "revealed risk preferences") versus the actual or perceived benefits he estimates accrue from their acceptance in society, from various types of hazardous man-made activities and natural events. These curves derive from statistical data on the average numbers of fatalities that resulted from the hazards in these activities per hour of individuals' exposures to these hazards, versus dollar equivalents of the benefits (estimated in various direct and indirect ways) of such exposures. Starr's qualitative analysis of these curves leads him to the following fundamental conclusions: (1) voluntarily accepted risk levels are about 1000 times the levels of involuntarily accepted risks throughout the range of benefits; (2) the risk of death from disease is a rough upper limit on involuntarily accepted risks for any benefit, and apparently provides a psychological line of demarcation between boldness and foolhardiness in voluntary hazardous activities (e.g., sports); and (3) accepted risk levels are approximately proportional to the cube of the (real or imagined) benefits from the activities or events from which the risks derive.

Numerous arguments have been made against application of Starr's conclusions, however. First, it is argued that many past (and, for that matter, present) risk takers did not understand the risks they were accepting, so that the fact that they accepted them does not validate their or others' continuing to do so. Second," voluntary" risk takers may not actually have accepted risks "voluntarily," but because they had no viable alternative. As society and technology evolve, such alternatives may become more available, and, certainly, hazards may be reducible even for the same activity. Third, the use of average risks and benefits confounds the differences among specific risk takers and benefitters. Individuals accepting the highest risks may not be the same as those gaining the highest benefits. Finally, and perhaps most importantly, the use of averages also "washes out" the disproportionate impacts of catastrophic risks. Thus, the application of Starr's curves to justify the acceptance of nuclear power risks, for instance, is not considered proper by many.

To overcome this problem, complete risk profiles, such as are provided in the Reactor Safety study (recall Figures 1 and 2) could be generated, and a new hazard's profile could be compared to them. Simple weighting procedures have also been sought for reflecting the relatively greater impacts of a hazard's multiple fatality incidents. For example, Wilson (1975a) suggests that instead of just the number N of fatalities in a risk estimate for a potential incident, N^2 should be considered as a measure of effective loss to society. The hazards with greater potential for large-scale accidents would then have an increased expected effective loss.* This would better reflect society's apparently greater concern for the rarer but high-consequence incidents than the more common lower-consequence incidents, even though the latter may accumulate as many or more fatalities over time.

Wilson's arguments for N^2 are largely qualitative. Ferreira and Slesin (1976) have examined the issue more carefully. Figure 4 exhibits their basic data (derived from Metropolitan Life Insurance Company statistics). It is of considerable interest that the cumulative frequency versus severity curves for different types of hazards are not merely straight lines, but straight lines with similar slopes. A regression analysis establishes this fact rigorously, and also that the slope is such that the historically observed or "accepted" frequency of incidents due to all the types of hazards considered, is, in fact, approximately inversely proportional to N^3.

Ferreira and Slesin emphasize that since their data are very sparse for incidents with more than about 100 fatalities, the conclusion should not be drawn that N^3 is the properly weighted loss measure to consider for hazards with very large potential incidents. Nevertheless, it is clear that using any such measure would militate against hazards with potential for more than small accidents, and, as will become evident when risk–benefit evaluations are discussed below, would justify much larger investments of resources for mitigating low-probability but high-consequence risks.

RISK–COST–BENEFIT EVALUATIONS

Another basic approach to evaluation of the significance of the risks of a hazardous activity is to assess these risks in relation to the benefits the activity provides (Wilson, 1975b). (This assessment is a direct one for the particular activity, not a comparison with historical risk–benefit balances for a range of activities and events as in the revealed preferences evaluation procedure discussed in the previous section.) Three variations in this approach are considered.

First, and quite simply in principle, if alternative means are, or can be made, available to provide the desired benefits, the alternative that does this at the lowest risk is to be preferred. It is assumed that costs of the alternatives are all considered acceptable and that they are about the same, or, if not, that their differences can either be ignored or negatively subsumed in the net benefits equated across the alternatives. This procedure is referred to as equibenefit risk comparison. The risk of the lowest risk alternative defines the putative level of acceptable risk (provided it is agreed that one of the alternatives must be selected). On this basis, Inhaber (1979), for instance, evaluates the risks (expected immediate and delayed fatalities) of a wide range of energy production alternatives, as exemplified in Figure 5.

* Roughly, the average or expected loss would then not be proportional to $P_n n$ but $P_n n^2$ where p_N is the probability of occurence of an incident with N fatalities. Large N incidents could then contribute significantly to the size of the summation even if their p_N values are relatively small.

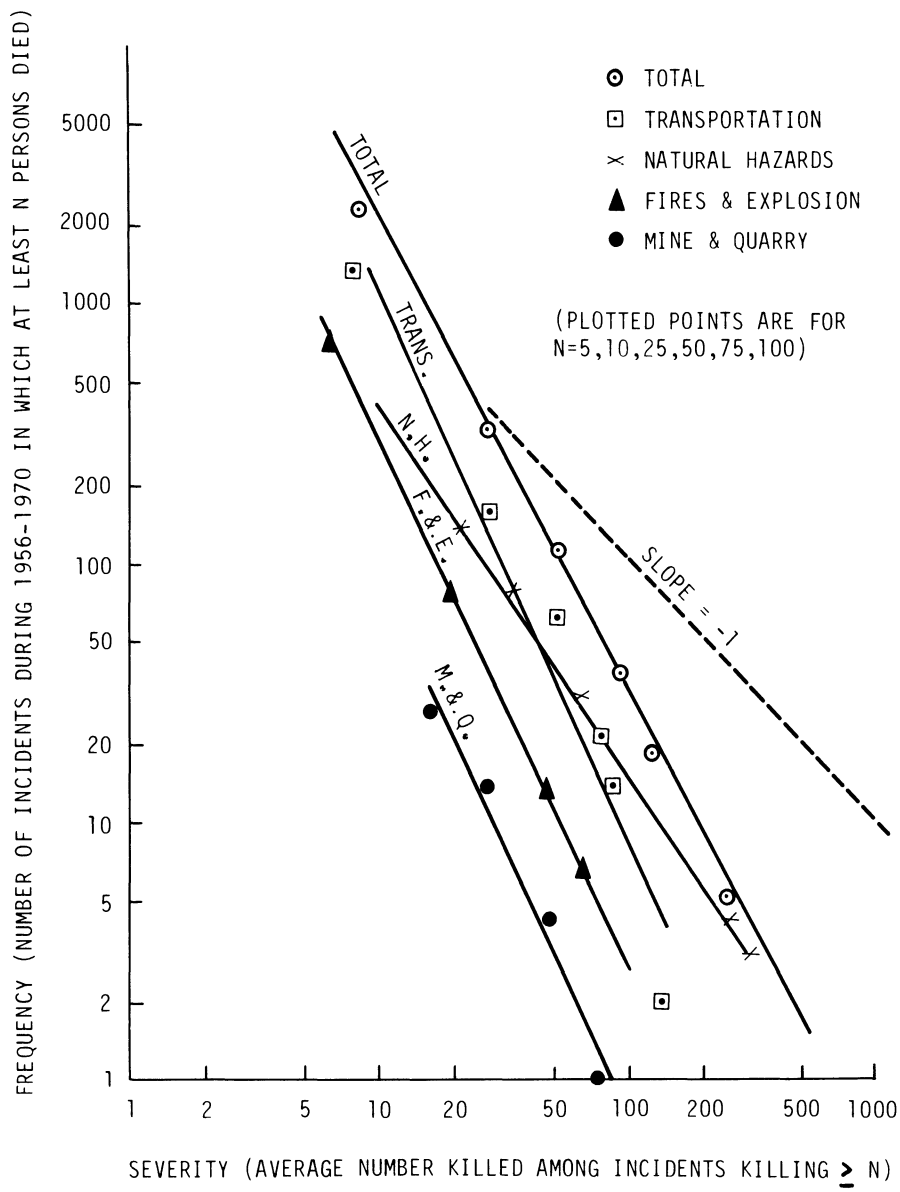

Figure 4. Cumulative accident frequency versus severity distribution, continental United States, 1956–1970. Transportation includes commercial and civil aviation, motor vehicle and bus, railroad, and water transport. Military aviation is excluded. Natural hazards include tornadoes, hurricanes, and floods. The only major earthquake during this period occurred in Anchorage, which is outside the study area (Ferreira and Slesin, 1976).

Similarly, Table 3 exhibits the results of Comar and Sagan (1976) obtained from a survey of the results of many other studies. The ranges of estimates of the fatality risks in terms of premature deaths per year associated with the operation of 1000 megawatts-electric (MWe) power plants employing different fuels are shown as they derive from various sources. Lave and Freiburg (1973) have looked more deeply into health risks, and they arrive at similar results.

Second, and more generally, the risks and benefits of an activity can be compared in some common terms, and the risks be deemed acceptable if, in these terms, they are not

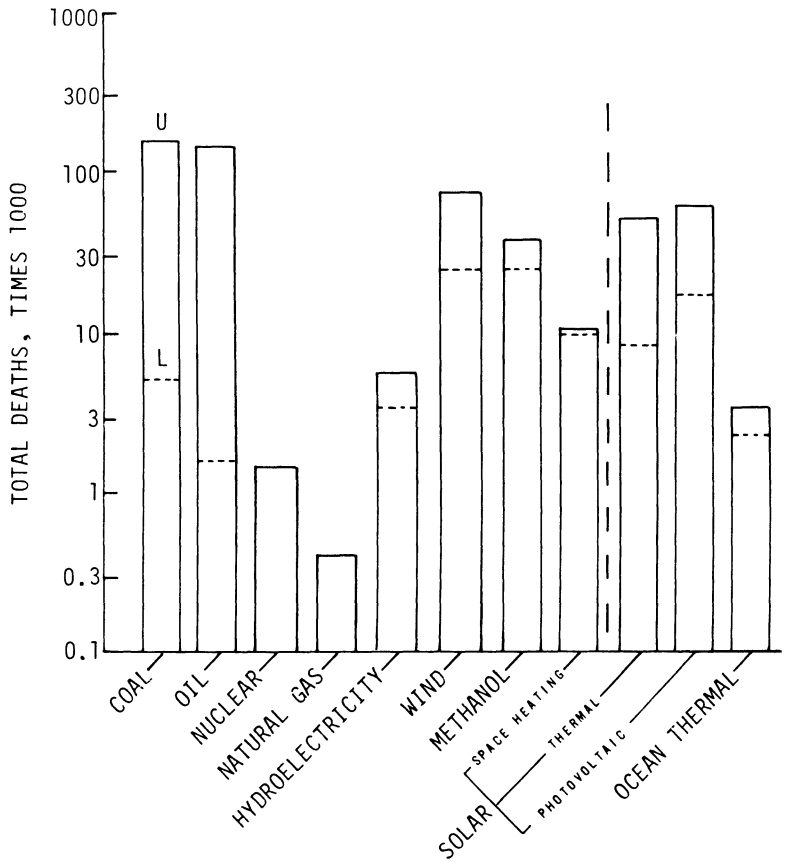

Figure 5. Upper (U) and lower (L) bounding estimates of total deaths (public and occupational), times 1000, per megawatt-year, as a function of energy system (total fuel cycle) (Inhaber, 1979).

greater than the benefits. This is referred to as the balancing of risks and benefits. (Again, costs are assumed able to be neglected or subsumed as negative benefits.)

Third, and most applicable to a risk management process employed in the optimization of a hazardous system's design and/or operating procedures, resources can be applied to safety improvements until the value of the marginal risk decrease attained for an additional unit cost becomes less than the cost. The residual risk remaining, when optimality is reached, is then deemed to be the acceptable risk level, in the sense that it would be an inefficient use of resources to attempt to reduce it further. This argument is best made when resources are limited and several hazards are competing for them, so that it is clear that they must be employed efficiently.

It is to be noted that the implementation of the second or third process requires a common scale of measurement of risks, benefits, and costs. This has given rise to many attempts to establish a dollar "value-of-a-life" or, because of the evident problems in this, a dollar value of some risk of loss of life. Alternatively, the application of utility theory has been attempted in order to assess risks, benefits, and costs on a common scale provided by a "decision maker's" utility function.

Linnerooth (1975) and Zeckhauser (1975) have surveyed the published work on the value-of-a-life problem. Thaler and Rosen (1975) have discussed the assessment of the "willingness to pay" to avoid a given risk. They developed an estimate of the average amount

Table 3. Premature Deaths per Year Associated with Operation of a 1000-MWe Power Plant (Values are Lowest and Highest Estimates from Various References)[a,b]

	Coal	Oil	Natural gas	Nuclear
Occupational				
Extraction				
Accident	0.45–0.99	0.06–0.21	0.021–0.21	0.05–0.2
Disease	0–3.5	—	—	0.002–0.1
Transport				
Accident	0.055–0.4	0.03–0.1	0.02–0.024	0.002
Processing				
Accident	0.02–0.04	0.04–1	0.006–0.01	0.003–0.2
Disease				0.013–0.33
Conversion				
Accident	0.01–0.03	0.01–0.037	0.01–0.037	0.01
Disease	—	—	—	0.024
Subtotals				
Accident	0.54–1.5	0.14–1.3	0.057–0.28	0.065–0.41
Disease	0–3.5	—	—	0.039–0.45
Total	0.54–5.0	0.14–1.3	0.057–0.28	0.10–0.86
General public				
Transport	0.55–1.3	—	—	—
Processing	1–10	—	—	—
Conversion	0.067–100	1–100	—	0.01–0.16[c]
Total	1.6–111	1–100	—	0.01–0.16
Total occupational and public	2–116	1.1–101	0.057–0.28	0.11–1.0

[a] *Source:* Comar and Sagan (1976).
[b] Dashes indicate no data found; effects, if any, are presumably too low to be observed; and no theoretical basis for prediction.
[c] For processing and conversion.

workers in a wide range of occupations would be willing to pay to avoid a small increase in the chance of death per individual per year. Kalelkar and Brooks (1978) have attempted an application of utility theory in the context of hazardous materials transportation; Smith et al. (1978) have initiated such an attempt as part of evaluating the concept of underground siting of nuclear power plants, and Keeney (1980) has published an extensive development of a utility analysis and its application to hazardous facility siting decisions. It should be noted, however, that Kahneman and Tversky (1979, 1981) have argued that the standard application of utility theory is not valid because of certain human psychological factors that arise in the subjective estimation of probabilities. They suggest a major revision that they call "prospect theory" that accounts for these factors through a generalization of the probability weights involved in expected utility calculations (analogous to standard utility theory's generalization of value to utility).

SYNTHESES OF NUMERICAL ACCEPTANCE CRITERIA

Rather than seeking some public consensus on acceptable risk levels, a number of individuals in the United Kingdom, Switzerland, Germany, and elsewhere, as well as in the United States, have attempted to develop numerical criteria that they then seek to have adopted by sufficient authority. Leaders in the area in this country are Okrent, chairman of the Reliability and Probabilistic Analysis Subcommittee of the Nuclear Regulatory Com-

mission's Advisory Committee on Reactor Safeguards, and his coauthor, Whipple (1977); Rowe (1975); and, of course, Starr (1971b). Otway and Erdmann (1970) also made early efforts in this area. The Nuclear Regulatory Commission (1980) has now published proposed acceptable risk criteria or "safety goals," which society as a whole, however, may or may not entirely agree to. Farmer (1967), Gibson (1977), and Bowen (1975) have developed criteria that are used in the United Kingdom. Schneider (undated) has developed such criteria for explosives safety in Switzerland. Of interest also are U.S. Army (1979) and Navy (1973) explosives criteria that have been established as safety management guidelines.

All of these criteria are based on rational comparisons with ambient risks "accepted" in the past or present, with, in some cases, added weightings reflecting confidence in risk estimates or the ordinary-versus-catastrophic character of the risks concerned. Some examples follow.

Okrent and Whipple propose that Congress consider acceptable levels of (1) 1 or 2×10^{-4} expected fatalities per year at 90% confidence for "essential" hazardous technologies; (2) 10^{-5} for "beneficial" technologies; and (3) 2×10^{-6} for technologies not generally beneficial to society.

The stringent confidence requirement imposes a heavy penalty in an effective acceptable risk level decrease if significant uncertainty is present in the estimation of the technology's risks (e.g., a well-understood technology might have an acceptable risk of, say, 5×10^{-4}, while a poorly understood one might require a level of 10^{-3}). Other criteria proposed especially for nuclear plants are shown in Tables 4 and 5.

In the United Kingdom, Gibson (1977) and Bowen (1975) discuss the Fatal Accident Frequency Rate (FAFR) criterion for the chemical processing industry. Gibson's ambient risk data that he employs to justify mitigating to an acceptable FAFR of 2 for chemical plant employees are exhibited in Table 6.

Bowen's approach is more complex. He considers the risk of a plant having an accident that causes off-site loss of life rather than the risk in terms of fatalities, although he translates to this ultimately. He proposes an acceptability criterion of 10^{-5} accidents per plant per year for events that cause any off-site fatalities, with increasing confidence in the estimate required (so a lower effective acceptable risk level) for plants with potential for increasingly catastrophic events. (It is understood that Bowen has more recently increased his criterion to 10^{-4} for some cases.)

Table 4. Some Proposed Numerical Values for Individual Risk Criterion[a]

NRC–RES	10^{-5}/year unacceptable
	10^{-6}–10^{-5}/year warning range (case-by-case evaluation)
Wilson	10^{-5}/year near site
	10^{-6}/year next township
Okrent	2×10^{-4}/year essential activity
	10^{-5}/year beneficial activity
	2×10^{-6}/year peripheral activity
	Assess risk at 90% confidence level
Conkerton et al. (CEGB)	10^{-5}/year public
	10^{-4}/year worker
WASH 1400	8×10^{-7}/year
German Risk Study	1×10^{-6}/year
AIF	10^{-5}/year

[a] Source: O'Donnell (1980).

Table 5. Some Proposed Numerical Values for Population Risk Criterion (Implied from Risk Curves)[a]

Levine	0.2	Fatalities/year
WASH 1400	0.02	Fatalities/year
German Risk Study	0.4	Fatalities/year
AIF	0.1	Fatalities/year

[a] Source: O'Donnell (1980).

Bowen's 10^{-5} value derives from a loose balancing of the plant-caused loss of life expectancy with the plant's contribution to national income, which then is associated with an increase in life expectancy. He notes that if life expectancy is increasing at a faster rate in relation to income, as in the U.S. relative to the U.K., then a higher acceptable risk level results. The plant's income increment is associated with a larger life expectancy increment. Thus, the plant's greater "benefit" in terms of a larger increase in life expectancy balances a larger loss of life expectancy due to its hazards.

CONCLUSIONS

After a risk accruing from an existing or proposed activity hazardous to health or safety has been estimated, a decision must be made on whether it should be accepted, or some alternative action taken that will mitigate the risk. This alternative action may require the additional use of limited resources or may induce risks elsewhere. Whether it is possible to decide if the original risk is acceptable may depend on whether it is small relative to ordinarily accepted "ambient" risks; whether the benefits in accepting it are sufficiently great (which may be able to be assessed by direct comparison of the risk and benefits in common terms, or by comparison to risk–benefit preference relationships in the past); or whether other risks accruing from not accepting the original risk may exceed it. Whether, on the other hand, some alternative action should be decided upon may depend on whether its cost is justified by the risk decrease that it would provide. To determine the best such alternative, the trade-off between risk decrease and cost among all available alternatives may need to be assessed. The considerations involved may apply to a specific case or to a population. Risks and benefits may directly accrue differently to different individuals and groups, and also may accrue indirectly to others as well, including the decision maker, such as an activity operator,

Table 6. Fatal Accident Frequency Rate[a] *for Some Industrial Activities*[b]

		FAFR
British manufacturing industry	1971–1974	2
Chemical industry	1971–1974	4
Construction industry	1971–1974	9
Mining and quarrying	1971–1973	10
Air crews	1964–1973	200[c]
Professional boxers	1963–1974	20,000[c]

[a] Per 10^8 exposure-hours, or 1000 men's average working lifetimes.
[b] Source: Gibson (1977).
[c] Calculated for the time actually exposed.

a regulator, an insurer, the government, and society as a whole, insofar as harm to affected individuals could detract from its present and future values.

This review has largely been limited to fundamentals in the approaches to these questions. It has attempted to illuminate several rational approaches to the development of criteria that may aid in resolving in a decision process the questions of fundamental concern and, with varying effectiveness, such added complexities as have been noted. The refinement of these approaches to generally accepted means of support to governmental decision making is essential to the future utility of risk analysis in public policy development.

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REFERENCES

Baldewicz, W. et al., "Historical Perspectives on Risk for Large Scale Technological Systems," UCLA-ENG-7485, November 1974.

Bowen, J., "The Choice of Criteria for Individual Risk, for Statistical Risk, and for Public Risk," *Risk–Benefit Methodology and Application: Some Papers, Presented at the Engineering Foundation Workshop,* Asilomar, California, 22–26 September 1975, UCLA-ENG-7598, December 1975.

Cohen, B.L., "Society's Valuation of Life Saving in Radiation Protection and Other Contexts," *Health Physics,* v. 38, pp. 33–51, January 1980.

Cohen, B.L. and I.-S. Lee, "A Catalog of Risks," *Health Physics,* v. 36, pp. 707–722, June 1979.

Comar, C.L. and L.A. Sagan, "Health Effects of Energy Production and Conversion," *Annual Review of Energy,* v. 1, 1976.

Coppola, A. and R.E. Hall, "A Risk Comparison," Prepared for the Nuclear Regulatory Commission, Brookhaven National Laboratory, NUREG/CR-1916, February 1981.

Farmer, F.R., "Siting Criteria—A New Approach," *Proceedings of a Symposium on the Containment and Siting of Nuclear Power Plants,* International Atomic Energy Agency, Vienna, 3–7 April 1967.

Ferreira, J. and L. Slesin, "Observations on the Social Impact of Large Accidents," Technical Report No. 122, Operations Research Center, Massachusetts Institute of Technology, October 1976.

Gibson, S.B., "Major Hazards—Should They Be Prevented at All Costs?" Paper presented to the Institute of Management Sciences, Athens, July 1977.

Harriss, R.C. et al., "Our Hazardous Environment," *Environment,* September 1978.

Inhaber, H., "Risk of Energy Production," Atomic Energy Control Board, Canada, AECB-1119/Rev. 2, November 1978. Also see "Risks from Energy from Conventional and Nonconventional Sources," *Science,* v. 203, pp. 718–723, 23 February 1979.

Kahneman, D. and A. Tversky, "Prospect Theory: An Analysis of Decision Under Risk," *Econometrica,* v. 47, no. 2, March 1979.

Kahneman, D. and A. Tversky, "The Framing of Decisions and the Psychology of Choice," *Science,* v. 211, 30 January 1981.

Kalelkar, A.S. and R.E. Brooks, "Use of Multidimensional Utility Functions in Hazardous Shipment Decisions," Arthur D. Little, Inc., March 1978.

Keeney, R.L., *Siting Energy Facilities,* Academic Press, 1980.

Kletz, T., "The Risk Equation—What Risks Should We Run?" *New Scientist,* 12 May 1977.

Lave, L.B. and L.C. Freiburg, "Health Effects of Electricity Generation from Coal, Oil and Nuclear Fuel," *Nuclear Safety,* v. 14, no. 5, September–October 1973.

Linnerooth, J., "The Evaluation of Life-Saving: A Survey," International Institute for Applied Systems Analysis Research Report RR-75-21, July 1975.

Miller, B. and R.E. Hall, "Index of Risk Exposure and Risk Acceptance Criteria," Prepared for the U.S. Nuclear Regulatory Commission, Brookhaven National Laboratory, NUREG/CR-1930, February 1981.

Nuclear Regulatory Commission, "Plan for Developing a Safety Goal," *Federal Register,* v. 45, no. 209, pp. 71023–71028, 27 October 1980.

O'Donnell, E., "General Considerations on Use of PRA in Regulatory Process," Presented to the ACRS Subcommittee on Reliability and Probabilistic Analysis, Los Angeles, July 1980.

Okrent, D., "A General Evaluation Approach to Risk–Benefit for Large Technological Systems and Its Application to Nuclear Power," Final Report, UCLA-ENG-7777, December 1977.

Okrent, D. and C. Whipple, "An Approach to Societal Risk Acceptance Criteria and Risk Management," UCLA-ENG-7746, June 1977.

Otway, H.J. and J.J. Cohen, "Revealed Preferences: Comments on the Starr Benefit–Risk Relationships," International Institute for Applied Systems Analysis Research Memorandum RM-75-5, March 1975.

Otway, H.J. and R.C. Erdmann, "Reactor Siting and Design from a Risk Viewpoint," *Nuclear Engineering and Design,* v. 13, pp. 365–376, 1970.

Philipson, L.L., "The Systems Approach to the Safety of Liquefied Natural Gas Import Terminals," Prepared for the California Energy Resources Conservation and Development Commission, May 1977.

Rasmussen, N.C. et al., "Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400, Nuclear Regulatory Commission, NUREG 75/104, October 1975.

Rothschild, N.M.V., "Coming to Grips with Risk," *The Wall Street Journal,* 13 March 1979.

Rowe, W.D., "Development of Approaches for Acceptable Levels of Risk," *Risk–Benefit Methodology and Application: Some Papers, Presented at the Engineering Foundation Workshop,* Asilomar, Calif., 22–26 September, 1975, UCLA-ENG-7598, December 1975.

Sage, A.P. and E.B. White, "Methodologies for Risk and Hazard Assessment: A Survey and Status Report," *IEEE Transactions on Systems, Man and Cybernetics,* v. SMC-10, no. 8, August 1980.

Salem, S.L., K.A. Solomon and M.S. Yesley, "Issues and Problems in Inferring a Level of Acceptable Risk," Prepared for the U.S. Department of Energy, Rand Corporation Report R-2561, August 1980.

Schneider, T.H., "Vorschlag für die Bewertung von Personenrisiken," Basler and Hofman Consulting Engineers, Zurich, Undated Diagrams on Explosives Accidents Risks Acceptance.

Smith, J.H. et al., "An Application of Multiattribute Decision Theory to the Underground Siting of Nuclear Power Plants," *Proceedings of the Meeting on Probabilistic Analysis of Nuclear Reactor Safety,* Los Angeles, May 1978.

Starr, C., "Social Benefit Versus Technological Risk," *Science,* v. 165, 19 September 1969.

Starr, C., "Benefit–Cost Studies in Sociotechnical Systems," *Proceedings of a Colloquium on Perspectives on Benefit–Risk Decision Making,* National Academy of Engineering, 26–27 April 1971a.

Starr, C., "Benefit–Cost Studies in Sociotechnical Systems," *Proceedings of the Conference on Hazard Evaluation and Risk Analysis,* Houston, Texas, 18–19 August 1971b.

Starr, C. and C. Whipple, "Risks of Risk Decisions," *Science,* v. 208, pp. 1114–1119, 6 June 1980.

Thaler, R. and S. Rosen, "The Value of Saving a Life: Evidence from the Labor Market," Chapter in *Household Production and Consumption,* Columbia University Press, New York, 1975.

U.S. Army, Office of the Project Manager for Munitions Production Base Modernization and Expansion, Dover, New Jersey, "PBM Operating System Manual No. 385-1, Change 1, System Safety Program for Modernization and Expansion Projects," 1 August 1979.

U.S. Navy, Ordnance Systems Command, "Weapon System Safety Guidelines Handbook," Part 1, NAVORD OD 44842, 1 May 1973.

Wilson, R., "The Costs of Safety," *New Scientist,* v. 68, pp. 274–275, 30 October 1975a.

Wilson, R., "Example in Risk–Benefit Analysis," *CHEMTEC,* v. 6, October 1975b.

Wilson, R., "Analyzing the Daily Risks of Life," *Technology Review,* February 1979.

Zeckhauser, R., "Procedures for Valuing Lives," *Publicc Policy,* v. 23, no. 4, Fall 1975.

III

Risk Management

Public concern over technological hazards has led to substantially increased government involvement in risk management. In the last two decades, at least 25 major pieces of legislation to regulate technological hazards have been passed by the U. S. Congress. This increase in government risk management activity has been paralleled by the growth of scholarly literature on risk management.

A number of significant problems have been raised by the increasing emphasis on government regulation of technological hazards. First, laws and regulations are often inconsistent. Second, government agencies often use different approaches to risk management. Third, it is extremely difficult to design standards and regulations that are appropriate for all the various forms which a hazard may take. Fourth, the collection and evaluation of data overwhelm the resources of the agency. Fifth, the economic costs of regulation may exceed the economic benefits. Sixth, regulation may inequitably allocate the costs, risks, and benefits among various subpopulations. Finally, increased reliance on regulatory solutions may be ultimately detrimental to society's management of hazards if not adequately balanced against alternatives, including reliance on private-sector risk management, on the provision of more and better information to the public, on personal good judgment, and on after-the-fact claims for damages. Each of the papers in this section addresses one or more of these and other related topics in the area of risk management.

14

Alternatives to Government Regulation for the Management of Technological Risks

Michael S. Baram and J. Raymond Miyares

INTRODUCTION

Before the creation of the various health, safety, and environmental regulatory programs of the 1960s and 1970s, there already existed a number of legal mechanisms with the potential to stimulate proper risk management on the part of those who generate risk. These mechanisms commonly operated in a *laissez faire* fashion and, taken together, did provide some incentive for risk management—for example, to avoid future liability or other economic consequences. This risk-deterrent effect, however, was often ponderously slow and indirect.

Indeed, a repeated justification for regulation of risk-generating activities has been that the effects of unregulated "marketplace" mechanisms are so attenuated that, on balance, the wrong incentives are given to those who generate risk: without regulatory requirements, it is less costly to ignore or externalize risks than to undertake voluntarily the measures necessary for their proper management, even if the probability of ruinous economic consequences is thereby increased by some small increment. Certainly the practical preregulatory experience with respect to technological risks to health, safety, and the environment was that such risks were not being properly managed. In fact, economic forces often seemed to preclude proper risk management by placing the socially responsible firm at an economic disadvantage compared to its less squeamish competitors.

Our nation's road to risk regulation thus began with the first perception that traditional incentives were not adequate to effect proper risk management. The threat of liability for harms created by industrial activity was simply too remote to have genuine impact. Insurance coverage was often written on so aggregated a level that variations in safety practices had little impact on premiums. The marketplace was sufficiently manipulated by the corporate giants that consumer preferences for clean air, pure food, and safe products were not capable of proper expression. Contract agreements were not readily adaptable to multiparty negotiation over diffuse and incremental risks.

Michael S. Baram and J. Raymond Miyares • School of Public Health and School of Law, Boston University, Boston, Massachusetts 02118.

All of these factors combined to support the call for regulation. The limits of traditional risk management incentives, however, do not establish the case for regulation by themselves. Certainly, for example, the development of the common law in the past two decades has demonstrated its considerable capacity to adapt in response to the litigants and risk situations presented to it.

In the early days of health, safety, and environmental regulation, however, neither this development nor similar ones in other areas had yet occurred. For example, insurance rating practices were still rather crude, and often unrelated to loss experience or expectations. Similarly, the types of health, safety, and environmental concerns that were to dominate the regulatory agenda of the 1960s and 1970s were not perceived as susceptible to negotiation. Thus, by the 1960s, the precedents and standard rationale for regulation were established. Each time Congress enacted a regulatory program, it recited essentially the same objectives: (1) to meet its affirmative duty to protect the public; (2) to remedy economic incentives thought to operate against proper health, safety, or environmental risk management; (3) to provide for coordinated and parallel functioning of related health, safety, and environmental laws; to promote consistency in the federal approach; and to avoid one program's working at cross purposes with another; (4) to provide necessary uniformity among the states; and (5) to assure that the information necessary for proper risk assessment and management was collected, disseminated, and utilized.

These themes were apparently repeated so often that new regulation was, by the second half of the 1970s, the virtually automatic congressional response to every health, safety, and environmental risk it confronted. Today, regulatory agencies exercise wide authority, delegated by Congress, to manage some aspects of virtually all private and federal activities and, increasingly, to influence state and local decisions.[1]

Health, safety, and environmental risk regulation thus consists of a complex matrix of legislation, agency rules, permit procedures, judicial decisions, and other elements. The particularized effects of a single regulatory program can be immediate and significant in its required costs, institutional changes, and dislocations; these are to be expected from any regulatory attempt to achieve new societal goals. However, the aggregated effects of several regulatory programs that converge on a particular sector can be even more difficult to accommodate. For example, the convergence on small chemical companies of several programs to control toxic substances (Occupational Safety and Health, Toxic Substances Control, Hazardous Wastes Management, Right-to-Know) can lead to an overwhelming array of requirements which may ultimately solve the problem of toxic risks, in part, by completely eliminating the businesses that generate them.

Thus, responding to even valid societal and special interest needs by regulation inevitably involves costs, dislocations, loss of independence, and the growth of government bureaucracy. Some commentators also attribute inflationary problems, unemployment, and the loss of American industrial competitiveness to the growing regulatory enterprise. While these assertions have not been adequately proven, the need for reform in the nation's approach to the management of risks to health, safety, and the environment is apparent.

The most important regulatory reform option available today consists of an increased reliance on the properly structured use of alternatives to regulation. Greater reliance on alternatives to regulation does not violate the assumption that government is ultimately responsible for managing health, safety, and environmental risks effectively. The major health, safety, and environmental statutes in existence generally provide a sufficient framework for carefully designing both regulatory and nonregulatory approaches to meeting this responsibility.

Several categories of alternatives exist. All are of limited, but proven, efficacy, and

none rely on extensive and complex government intervention. Each has the potential for more efficacious use. Nevertheless, no attempt has heretofore been made to assess why these nonregulatory options succeed in some respects and fail in others, and what can realistically be done to remedy their failings so that they can become more effective and acceptable as risk management tools.

Further, no attempt has yet been made to structure a role for the government regulator, in which agencies would regulate only as a last resort, and only if the problem or need remains real and substantial after the agency has (1) fully considered the available nonregulatory options, (2) made a good faith effort to improve the efficacy of the more promising of the nonregulatory options, and (3) made a satisfactory effort to trigger the working of the best of the nonregulatory options in its new, more efficacious mode.[2]

This chapter presents the results of research on three key questions: (1) Which alternatives to regulation demonstrate the greatest potential for managing technological risks to health, safety, and the environment? (2) Can the federal government harness and use these alternatives, consistent with the present legal framework and public expectations for risk management? (3) What principles should govern federal reliance on alternatives to regulation for purposes of risk management?

In a broader sense, however, this chapter is about new possibilities for using alternatives to regulation and for changing the role of the regulator. The research described here was conducted in full cognizance of the many weaknesses of the nonregulatory options and the difficulties facing the regulator in the new role suggested. It is not an attempt to deny the need for health, safety, or environmental regulation by government, and it assumes the government's continuing responsibility for effective management of such risks. Instead, this chapter opens up, for full consideration, a new approach to health, safety, and environmental risks, consistent with both the need to manage such risks and the growing dissatisfaction with further routine application of current regulatory practice.

Many problems with pursuing this course of reform are identified here and discussed; few are resolved. But, the need emerges to establish a more coherent process for dealing with risk by regulation and by alternative means, and to establish a more fully structured role for the regulatory agencies in society.

IMPORTANT PREVIOUS WORK

Despite the panoply of regulatory programs enacted over the past two decades and the regulatory implementation efforts of federal and state officials, health, safety, and environmental problems continue to plague the nation. The reasons for this persistence include (1) the wide range of existing and potential risks to health, safety, and the environment; (2) technical uncertainties as to the nature and magnitude of these risks; (3) financial limitations on federal and state activities, and economic burdens imposed on the private sector by regulation; and (4) inflexibility in most federal regulatory programs and the consequent lack of innovative state, local, or private risk management initiatives.[3]

The wide range of existing and potential hazards to health, safety, and the environment across the nation militates against the type of regulatory effort that exists in most federal programs. Hundreds of thousands of risk generators, dispersed throughout the nation, pose a virtually impossible management problem for the federal rule-making approach. Compounding this problem is the great variability of circumstances where health, safety, or environmental hazards exist or may occur. Each risk has its own physical, chemical, and biological attributes, and human and environmental exposure conditions vary. This variability

tends to undermine any uniform federal "cookbook" approach to risk management which does not permit consideration of specific circumstantial differences.

In addition, risk analysis is a difficult process with uncertain results, especially where there is a lack of data on fundamental issues such as cause and effect. Thus, establishing the findings of fact necessary to support regulatory action on a nationwide and generic basis is a complex task, particularly when the action seeks to manage risks in the distant future. The resulting set of rules may not be optimal for any particular case to which it is addressed.

Efforts to manage risks by federal regulation are also costly, with the economic burden falling eventually on the taxpayer and consumer. Regulatory costs to government and compliance costs to industry can be very large and difficult to bear, especially for local units of government and small businesses. Significant fiscal and human resources must be committed to implementation of the monitoring, reporting, enforcement, adjudication, and other functions of a regulatory program. In addition, generic and uniform rules may be perceived as imposing excessive costs, in comparison to the risk management objective they are designed to achieve.

Finally, federal regulation offers little incentive—or even justification—to states, local governments, or the private sector to develop cost-effective programs to meet their own risk management needs. While substantial uniformity in approach may be needed with respect to some aspects of health, safety, and environmental risk management—so as to avoid discriminatory impacts or disruptions of interstate commerce, for example—uniformity is often of value only as a convenience for some affected parties, rather than as a genuine benefit to public health and safety or the environment.

Thus, even if current uncertainties and forces in opposition to regulation were to diminish, there is now sufficient evidence to indicate that health, safety, and environmental hazards are too large, too variable, and too costly for the federal rule-making approach alone. Nevertheless, the public still expects these hazards to be properly managed and risks to health, safety, and the environment to be reduced.

Critics of regulation have sponsored a wide variety of reform proposals. Some of these have been designed to affect specific regulatory programs and were conceived in response to grievances arising from the impacts of those programs on particular interests. Others, however, have been designed and fostered as generic proposals which cut through all, or a particular category of, regulatory programs.[4] Many of these have met with opposition because they would affect the interests of those (often including regulated parties) who perceive themselves to benefit from present regulatory policies. Especially concerned, however, have been those who believe that health, safety, and environmental regulation is threatened by these generic reforms—indeed, that such regulation is the intended target of the reforms.

The policy of examining the effectiveness of rule-making activity before adopting a new rule is reflected in President Reagan's Executive Order 12,291. That order calls on executive agencies to conduct a "regulatory impact analysis" prior to promulgating a "major rule." Similar requirements existed under the Carter administration's Executive Order 12,044. In practice, these requirements have led the agencies to conduct formal cost–benefit analyses as a part of their rule-making procedures.[5]

Implementation of these executive orders has also resulted in considerable involvement of the executive office in agency decision making. This has raised Constitutional questions about the separation of powers because, in some cases, it is impossible for an agency to carry out its statutory responsibilities effectively while concurrently being in compliance with the executive orders. In the executive office alone, the president's Office of Management and Budget, Council of Economic Advisors, Council on Wage and Price Stability, Office of Science and Technology Policy, Regulatory Analysis Review Group, and Regulatory

Council have had roles over the past decade in reviewing agency actions and exerting pressure on the agencies to reduce certain initiatives under their statutory mandates. Since much of this pressure has been exerted off the official agency record for decision making, new problems involving potential procedural violations have also arisen. Therefore, the net result of these presidential initiatives has been the reduction of certain vigorous agency initiatives (e.g., EPA's ozone standard, OSHA's cotton-dust rules) and the apparent delay and stalling of new agency regulatory initiatives.

Other major approaches to regulatory reform remain in the hypothetical or proposal stage. Some would provide for an economic impact "budget" to govern the complete regulatory program of any agency, a presidential or congressional veto function over agency rules,[6] increased authority for the courts to deny agency regulations a presumption of validity, "sunset" review of agency programs, and a host of new economic analytic requirements for agencies to conduct in reaching their regulatory decisions (e.g., small business impact assessment, competition impact assessment, comparative risk–benefit assessment, innovation impact assessment).[7] Further reform proposals have sought to change the selection and duties of administrative law judges, redesign the Administrative Conference of the United States and the Office of Management and Budget to provide for better congressional and executive oversight of agency activities, to fund certain forms of citizen participation in agency proceedings, or to implement other modifications of agency procedures.

Most of these proposals involve incremental changes within the framework of regulation, and seek "better" regulatory outcomes (softer economic impacts of the rules eventually promulgated, or greater flexibility in the compliance demanded) or more "rational" outcomes, based on quantitative assessment of their supposed impacts. None of these proposals recognize, however, the practical, inherent limitations of regulation noted above. If regulation cannot do the whole job, then alternatives to regulation are needed.

CURRENT RESEARCH

Which Alternatives Demonstrate the Greatest Potential for Use in Risk Management?

The Available Alternatives. The most obvious of the available alternatives is industrial self-regulation. Private firms invest considerable resources each year in developing and revising internal health and safety standards to govern their own activities. Often these firms rely on industry-wide or professional association technical standards specifically developed to provide guidance to product or system designers, manufacturers, sellers, and users. In addition, a variety of organizations outside of industry and the professions have sought to develop "consensus" standards, with the participation of environmental, health, and safety interest groups.[8] Perhaps as many as 60,000 separate nongovernmental standards are currently in use in American industry.

Many federal agencies have traditionally relied extensively, in their rule-making processes, on standards developed in the private sector. Because such regulations require of industry no more than what it requires of itself, it is logical to suggest that private standards need not be promulgated as regulations, but can affect industrial risk management without any regulatory action. To the extent that private standards define acceptable product quality and design, or appropriate practice in a particular industry, nonconforming products and practices will be rejected in the marketplace.

The threat of liability may sometimes be a significant enough factor to stimulate a firm

to adopt voluntary risk management standards. Thus, private actions at common law can be regarded as a second alternative to regulation. Today, modern tort suits pose a far greater threat to potential defendants than their earlier counterparts. Liberalization of pretrial "discovery" rules, which permits litigants to learn about the evidence other parties intend to produce at trial, has given plaintiffs access to the benefit of defendants' research and evaluation of their own activities. This information can greatly facilitate the proof of the risk management decision made and of the necessary casual link between the activity complained of and the injury alleged.

Judicial certification of class actions, to vindicate in one proceeding the claims of large numbers of plaintiffs exposed to similar risks, has also contributed to the efficacy of the common law as an alternative to regulation. When a firm knows that it may be made to internalize costs approaching the actual harms it has imposed on all consumers, neighbors, or the society at large, its internal balance of risks and benefits is likely to be altered far more than it is affected by the possibility of a single claim of liability.

The proliferation of damage suits against product manufacturers in the last two decades is by now well known. Many product design improvements and many new product warnings on proper use are directly attributable to actual tort judgments or the prospect of such judgments. Unsafe products have been driven from the market (or "voluntarily" withdrawn) because of the fear of liability even before regulators could act.

Clearly, then, the common law can motivate those whose conduct involves risk to adjust their activities to avoid potentially ruinous liability. This effect will occur even though the common law may not provide a specific standard of conduct, such as might appropriately be promulgated in a regulatory proceeding, by which to evaluate the conduct. Indeed, the lack of such a standard may actually add to the efficacy of the threat.

Insurance, a third alternative to regulation, is perhaps the oldest institution that formally addresses the problem of risk. Insurance against marine perils existed as early as the 12th century. Fire insurance was first sold in the 17th century, and general liability insurance appeared late in the 19th century. It was also late in the 19th century that product liability insurance was first written.[9]

Insurance underwriting practices have historically advanced as insurers strove to adjust the rates they charge for coverage to reflect more precisely the risks being insured. Today, insurance underwriting involves an assessment of the characteristics of the product or activity being insured, the ways in which it poses risks, the probability and magnitude of the harms thereby produced, various rules of law, and the economic context of insurers. This process can serve as a substantial, if imperfect, incentive for risk management by insureds, since it encourages insureds to seek to adjust these factors to make their risks acceptable to underwriters.

Clearly, as insurers strive to adjust the rates they charge for coverage to reflect more precisely the risks being insured, the focus of their concern is increasingly on risk management goals. Their efforts can be expected to continue to increase as federal agencies replace substantive regulation with "financial responsibility" requirements, compelling the purchase of liability insurance by those engaged in activities involving risk.

A fourth alternative to regulation is the provision of information. Some economists assert that many imperfections in the market's allocation of resources to reflect the preferences of participants derive from an imbalance between sellers and consumers in the level of information on such matters as health or safety.[10] Individual consumer transactions can reasonably be expected to be made in consideration of their environmental consequences or health and safety risks only if the information necessary for such consideration is available

to consumers. Clearly, then, the way to achieve a more optimal level of risk management is to assure that such information is provided.

Contract negotiation is a fifth alternative to regulation. In theory, if not always in practice, every health, safety, or environmental risk that can be defined can be the subject of negotiated agreement between those whose activities create the risk and those upon whom the risk will fall.[11] If the risks are understood and all the parties affected participate in the negotiations, the result could be a risk management plan satisfactory to all.[12]

Finally, since the federal government is both the largest employer and largest consumer in the United States, its influence on risk management decisions made in the economy can also be a substantial alternative to regulations. Federal procurement restrictions have often been used to pursue social goals beyond the immediate objectives of the particular procurement.[13]

Federal influence is also exercised by other nonregulatory means. Even an announcement of federal interest in a particular risk management problem, e.g., an advanced notice of proposed rule-making, can serve as an important stimulus to private resolution of the problem. Merely by focusing federal attention on a particular issue, the government can create the necessary impetus for others to resolve it.

Societal and Technical Attributes of Risk. In considering the use of these alternatives, a valuable starting point is to determine the societal and technical factors that have shaped congressional regulatory initiatives. These factors, imbedded in the legislative histories of health, safety, and environmental legislation, can be viewed as the parameters and goals that would govern any use of alternatives to regulation, to assure that the alternatives would be at least as acceptable as the regulatory programs now being used.

The legislative histories of four regulatory programs [the Occupational Safety and Health Administration (OSHA), the Consumer Product Safety Commission (CPSC), the National Highway Traffic Safety Administration (NHTSA), and the Hazardous Waste Management program of the Environmental Protection Agency (EPA)] suggest generally that risks exist in either a consumer, a workplace, or an environmental risk context. Since many alternatives to regulation involve private arrangements, the recognition of "risk context" facilitates the identification of the private parties involved, their rights and duties, and the historical patterns of problem solving without reliance on government regulation.

Beyond these risk contexts, however, many of the risks addressed by Congress have shared common societal and technological attributes.[14] Thus, the legislative histories reveal that the impetus for congressional establishment of regulatory approaches to risk management has often been based on three societal factors: trends showing an increase in the incidence and magnitude of certain adverse effects on particular interests from technological activities or developments, growing public dissatisfaction with industry responses, and loss of confidence in the corrective effect of the preregulatory mechanisms for risk management. Further, in some cases, the impetus for regulatory solutions also came from the industrial sector, due to its concerns about tort liability or other economic consequences, technical uncertainties, lack of insurance at reasonable rates, or the vagaries of state law.

As noted, the nexus between impetus (the factors which drew Congress to the problem) and response (the congressional rationales and subsequent legislative actions opting for regulatory solutions) has often been tenuous. Regulation was certainly not the only feasible response in each case. Nor was it necessarily the most cost-effective, equitable, or efficacious response to the societal concerns presented. Indeed, comparison of the regulatory records of the four agencies (only a few standards achieved and defended at great cost over the past decade) with the possible outcomes of the nonregulatory or alternative approaches that

Congress could have taken, approaches which might also have been responsive to the societal impetus and consistent with congressional rationales for action, could lead to the conclusion that the regulatory approach was inferior on grounds of cost, fairness, and even efficacy. Thus, if the societal attributes of risk do not necessarily call for a regulatory response, and will support alternative approaches as well, these attributes must be examined and understood in the development of any approach which would rely on nonregulatory alternatives.

The risks under congressional consideration in these four programs also often shared certain technical attributes: (1) the significance of the risk, usually measured in terms of incidence and magnitude, but also in terms of the degree of certainty of effect on specific individuals or resources; (2) the technical uncertainty attending the risk, in terms of low confidence in probabilistic risk analysis, difficulty in establishing causation, difficulty in grappling with the implications of differential sensitivities or proclivities of receptors to risk, and synergistic factors; (3) the temporal characteristics of the risk, the time spans between exposures, symptoms, and disease or other adverse effects; (4) the susceptibility of the risk to timely management, the extent to which risks are susceptible to optimal management for purposes of preventing effects at particular points in time only; and (5) the social role and economic factors of the risk-generating activity, upon which the acceptability of risk is, in part, determined.

These technical attributes of technological risk were often used by Congress to justify the legislation of regulatory programs, but, as with the social attributes noted above, the regulatory response was not necessarily dictated by these attributes. Nor was regulation necessarily the most effective, efficient, or equitable option. Nevertheless, if these technical attributes of risk can be used to justify alternative risk management approaches, then they must be considered in the development of any such approach.

Matching Alternatives to Risk Attributes. A second step in considering the use of alternatives to regulation is to evaluate their historical operation, as well as current trends and proposed reforms, in each of the three risk contexts noted above. For example, traditional modes of industry self-regulation and professional licensure have historically served protectionist or anticompetitive purposes as well as health, safety, or environmental risk management objectives. Even where industry codes and licensing procedures have incorporated significant safety components, the resulting standards were often tempered with a deference to industry costs and related interests. More modern self-regulation practice, in contrast, has attempted to correct this problem and improve the fairness of the ultimate standards achieved, by establishing greater consumer or public access to the private standard-setting process.[15] The resulting standards may well be an improvement over corresponding regulatory promulgations, because industry efficiency will be accounted for in ways that regulators often cannot be expected to replicate.

On the other hand, industry self-regulatory and self-licensing mechanisms generally do not address risk areas of significant technical uncertainty where no consensus concerning appropriate risk management has been reached. Rather, industry standards have tended to incorporate features upon which industry members can agree, and to be silent where there is no agreement. The common result is that many important health, safety, and environmental risks are left unaddressed. Where this problem is compounded by uneven industry adherence to self-regulatory standards, the further problem of enforcement is presented.

Of course, even a single firm's development and use of its own internal health or safety standard can be an improvement in risk management. Nevertheless, such internal standards work only through the good faith of the individual firm and may contribute little to the risk

management practices of a firm with priorities other than health, safety, and environmental protection.

Historical experience with the common law as a risk management mechanism has been replete with examples of ineffectiveness and inequity. Still, the common law has been responsible for many improvements in risk management—better product design, reduced environmental impairment, improved protection of health, and more effective warnings of risks. In recent years it has developed as a powerful instrument of consumer protection, and it is being relied on increasingly in cases involving environmental impairment. In the workplace, the common law was virtually replaced by the worker compensation system in the early 20th century. Today, however, a variety of exceptions to the exclusivity of worker compensation have been established so that common law remedies for workplace injuries and disease are increasingly common. Nevertheless, the common law continues to present problems in its lack of uniformity and consistency, in its insistence upon proof of actual causal pathways, in its operation well after harms occur, in its reluctance to credit scientific evidence in areas of technical uncertainty, and in its relatively high transaction costs.

Insurance and similar compensation mechanisms often blunt risk management incentives created by regulation, the common law, or other systems, but the existence of insurance or related mechanisms such as bonds and escrow accounts can also provide a level of financial responsibility essential to the effectiveness of other risk management incentives which operate by economic means. Thus, for example, the threat of potential liability may not be meaningful to risk generators and risk managers if the level of potential liability is out of proportion to the risk generator's capacity to respond. In addition, where insurance underwriting is based on loss experience or technical assessments of the insured's activities, it can be an independent stimulus for proper risk management.

Recent experience, however, has shown a tendency for important health, safety, and environmental risk problems to be manifested as insurance crises of availability, affordability, or capacity. Product liability insurance rates skyrocketed and fluctuated wildly in the 1970s; environmental impairment liability insurance was limited to sudden occurrences until recently; and the nuclear industry could not obtain private insurance until the federal government intervened through the Price-Anderson Act. In circumstances where federal policy has mandated a mechanism to speed and assure compensation for victims of occupational disease (black lung) or natural disaster (flood), substantial premium subsidies—which may promote undesirable risk generation—were required.[16]

Finally, as noted, the federal government is both the largest employer and largest consumer in the United States. Because federal employment and procurement practices are often in direct competition with those of the private sector, improvements in federal workplace safety or purchasing requirements have tended to stimulate corresponding measures among competing firms. In addition, announcements of federal interest in particular risk management problems have sometimes stimulated private resolution of those problems. Agency or congressional hearings on particular risks have sometimes induced private remedial action by putting those affected on notice that their existing practices were under scrutiny and would be regulated if the need were shown.

The operation of subregulatory mechanisms has generally been haphazard and unsystematic, however. The results, in turn, have been uneven, especially where technical uncertainty limits industry's ability to respond to the government stimulus. Moreover, because subregulatory mechanisms do not operate in well-defined channels, public access to the process, a principal guarantor of fairness in the outcome, may be limited.

The history and current operation of alternatives to regulation indicates that a number

of central issues concerning their operation recur: (1) efficacy of the alternative in producing a sound preventative approach to risk by the risk generator; (2) efficiency or cost-effectiveness of the alternative vis-à-vis regulatory options; (3) equity attributes of the alternative in terms of fairly allocating costs and benefits, and in terms of affording due process and reasonable outcome predictability to all interested parties; (4) evidentiary feasibility of the alternative in terms of allocating the burden of proof, providing for presumptions and other methods of coping with technical uncertainty, and the evidentiary burdens imposed on all interested parties; (5) institutional simplicity of the alternative, in terms of ease of access to the alternative system of risk management by all interested parties, the simplicity of the risk management process involved, and the uniformity of outcomes; and (6) credibility of the alternative, in terms of confidence instilled in the interested parties that the alternative provides for objectivity and rationality, adequate remedies, and procedural fairness.[17]

CASE STUDIES

Four case studies of the actual or potential application of alternatives to regulation to technological risk problems (automotive design, carcinogenic chemicals in the workplace, high-voltage electric transmission lines, and hazardous waste management) demonstrated the utility of the six evaluation criteria noted above, the sensitivity of the conclusions drawn to the particular risk attributes addressed, and, ultimately, the feasibility of using an approach to risk management which employs the consideration of multiple alternatives.

In the consumer risk sector, the experience with automotive design indicates the widespread influence of the common law. Although the common law has not provided perfect incentives for safety in the industry, and has begun to function as an effective stimulant to proper risk management only after relatively high societal losses have been incurred, the fact remains that the large and growing volume of automotive design cases have become an important factor in risk management decision processes. Because automotive design defects produce harms that are often readily understood and involve little technical uncertainty, the common law functions at its best in providing an efficient stimulus for proper risk management.

A second alternative to regulation, first-party insurance rating, could operate to supplement the incentives of the common law. This insurance alternative would require that insurance rates be high enough and the spread in rates be wide enough to be a determining factor in a significant number of new car purchases. In addition, public education and the availability of information would have to be improved. Neither the common law nor the insurance alternative to regulation prescribes conduct or safety standards before the regulated product or activity begins, but both do provide assurance that unacceptable performance will be dealt with afterwards.

For the context of workplace risk from carcinogenic chemicals, a principal alternative to regulation is the worker compensation system. Like other compensation schemes, worker compensation has struggled to expand its scope to include a wider range of workplace risks and occupational diseases. However, its overall functioning as an incentive for proper risk management is limited by the modest compensation benefits recoverable in the system and by the relatively low portion of insurance premiums that are experience-rated.

As a result, there has been a recent trend toward expanding exceptions to the exclusivity of worker compensation and greater reliance on third-party tort litigation (against toxic chemical manufacturers, for example) as a remedy for workplace harms. While such litigation is subject to exactly the same limitations as a risk management incentive as is reliance on

the common law in other contexts, the fact that litigation is increasingly being used by those who suffer workplace harms indicates that they perceive the common law as a more equitable source of compensation. Worker compensation does establish a no-fault standard of recovery, however, which would theoretically stimulate risk generators to internalize all harms they produce into their risk-decision processes.

In the environmental risk context, common law remedies and indemnification mechanisms may be a more efficient and less costly means for preventing or remedying possible injuries from the operation of high-voltage electric transmission lines and for deterring significant risk taking by the operators of such systems. The various deficiencies of the common law described above, of course, limit the availability of tort actions to provide a remedy for environmental harms, however. For example, the cost of litigation can be a significant barrier to its use in deserving cases, particularly since expert testimony is necessary on technical issues. In the case of high-voltage transmission lines operating at 765 kV or higher, the cost of providing testimony or technical data necessary to maintain a cause of action may act as an inequitable disincentive for all actions except those involving major damages or injuries, where the possible recovery would exceed the cost of litigating. However, at least with regard to risks that result in manifest harm in the short term, common law remedies may provide an effective and efficient incentive to proper risk management.

Indemnification mechanisms such as bonding, escrow, or restoration funds also provide considerable economic incentives to minimize the possible risks of high-voltage lines. These mechanisms are particularly well suited to regulated public utilities whose continuing maintenance of the indemnification mechanisms can be assured. Thus, the fact that public health harms from high-voltage lines may be manifest only after long exposure periods may be less of a problem than in other contexts where indemnification mechanisms might be tried. On the other hand, the existence of such mechanisms does not necessarily reduce any of the evidentiary barriers or cost problems associated with common law actions for environmental impairment by high-voltage lines.

Similar alternatives to regulation may be considered for a second environmental risk context, hazardous waste management.[18] Again, the common law alternative to regulation seems to be most appropriate for determining short-term risks due to fires, explosions, and poison gas emissions, because the causes and injury effects would be most clear in these instances. The problems which limit the effectiveness and equity of the common law generally will also apply specifically to the hazardous waste management context. These problems seem most acute in cases involving damage to groundwater sources and human health which may arise after the risk-generating activity (operation of a hazardous waste facility) has ended.

Ensuring financial responsibility following closure of a hazardous waste facility can be effectively achieved, but only for a limited period, through the use of trust fund mechanisms. After that time has elapsed and the remaining sums in the postclosure trust fund have been refunded, no further financial responsibility can be expected. Certainly, the risks to groundwater and health beyond the trust period will not be subject to the economic influences on the facility owner or operator created by a trust fund. The trust fund mechanism may be effective during the period it is employed, however, in conjunction with the common law mechanisms, at least where the source of injury is ascertainable and the extent of the injury is immediately apparent.

In addition, environmental liability insurance can be a primary force for guaranteeing owner or operator financial responsibility and, in combination with the common law devices, a secondary force in creating appropriate economic incentives for proper risk management through the relation of facility loss experience to premium costs. Again, as with the trust

fund mechanism, there is a direct correlation between the limitations on the effectiveness of the common law remedies and the limitations on the effective use of the conventional liability insurance policy. Moreover, a national manifest system that tracks hazardous wastes throughout their life cycle, such as that now mandated by EPA regulation, is a key element which must remain in place if the common law, trust fund, and insurance mechanisms are to function in a manner which motivates hazardous waste facility owners or operators to proper risk management.

Can the Federal Government Harness and Use These Alternatives, Consistent with the Present Legal Framework and Public Expectations?

The Federal Role in Reforming Alternatives. Reforms necessary to improve the operation of alternatives to regulation could, of course, simply be mandated at the federal level. Alternatively, substantive federal regulatory action could be conditioned on the failure of such reforms to be adopted. However, since many of the alternatives under consideration here are currently subject to state law, federal efforts to coerce or preempt state action would be controversial. Thus, less invasive approaches for influencing state development of necessary reforms on a voluntary basis should be considered. These may include the promulgation of "model codes" for state consideration and voluntary adoption, and reliance on "bellwether" states for leadership on certain needed reforms.

In the case of auto design defects, the provision of federal data and inspection reports as a means of reducing product liability litigation costs, the elimination of the doctrine of "mutuality of estoppel" so that a manufacturer is permanently bound by a judicial determination of defectiveness, and the acceptance of evidence of recalls as admissions of defects are other possible federal reforms. Federal premarket motor vehicle testing may also be tried as a means of facilitating insurance underwriting based on vehicle safety characteristics.

With respect to hazardous waste management, preservation and expansion of existing record-keeping requirements, such as the hazardous waste manifest, may be essential to the functioning of common law incentives. The loosening of federal requirements for state compliance with EPA regulations will be necessary if state revamping of common law liability theories and state installation of insurance and tax measures are to be fostered. Also needed would be a restructuring of a residual federal role for technical fact-finding and federal regulation of reporting requirements and interstate activities.

Individual reforms of alternatives in particular contexts, however, are less central to their implementation than is the development of a generic framework for agency decision making in choosing and fostering alternatives. Such a framework must consist of a process and the criteria or considerations for agencies to use when confronting a specific risk or generic class of risks that fall within their statutory authority, for purposes of selecting which alternatives to pursue; determining the types of information and findings needed to support agency implementation of the selected alternatives (in light of potential legal challenges to agency action); and eventually taking implementation actions.

Generic Framework for Federal Use: Process and Criteria. A generic framework for choosing and fostering alternatives to regulation, consisting of a simple process and specific criteria, will stimulate a qualitatively consistent approach to the use of alternatives in agency risk management and promote fairness through the predictability or certitude that would become apparent to all affected interests.[19] One such framework consists of the following process and criteria: (1) *identification of risk:* e.g., by petition to agency or by various agency initiatives for "discovering" the risk; (2) *measurement of risk:* by agency

data collection and analysis, leading to findings of fact as to the significance of the risk attributes, to determine which attributes are to be acted on; (3) *agency notice of intent to act on the risk:* e.g., by use of Advanced Notice of Agency Rule-Making, published in the *Federal Register;* (4) *agency evaluation of responses to advanced notice:* as such responses apply to agency measurement of risk, affected interests, and the efficacy of rule-making and alternative systems for managing the risk; (5) *agency identification of regulatory (rule-making) options and potentially feasible alternative options:* and use of a matrix approach illustrated in Table 1[20] for subsequent comparative analysis (in step f); (6) *agency evaluation of regulatory and alternative options:* by applying the specific criteria and the matrix format presented in Table 1 as part of a publicly available record; (7) *agency selection of one or more options to implement:* based on use of criteria and described in a publicly available record with public notice in the *Federal Register;* (8) *agency implementation of selected options:* the process of implementation of regulatory and alternative options should be integrated in one publicly available record and in all required or appropriate public notices. Thus, notices of *Proposed Regulatory Action* should contain all relevant information on the array of selected regulatory and alternative options being implemented. The regulatory options would follow the normal procedures of the Administrative Procedure Act, Executive Order 12,291, and other applicable law and policy. The alternatives would be similarly treated, although successful conclusion of the alternatives would not be reached, in many instances, until after the APA process, particularly where final decision making on the alternatives is vested in institutions or organizations other than the agency (e.g., state or federal legislatures, industrial trade associations); and (9) *agency monitoring and corrective measures:* agencies would finally be responsible for monitoring implementation efforts and

Table 1. Matrix Approach: Case of Hazardous Waste Management

Risk management options	Key risk attributes of hazardous waste management		
	1. Generator (storage) health/ groundwater	2. Transporter (handling) health/ spills	3. Disposal facility proprietor (mgmt.) health/ groundwater
A. Regulatory			
B. Alternatives 1. Common law			
2. Industrial self-regulation			
3. Insurance and other compensation systems			
4. Negotiation or contractual methods			
5. Subregulatory actions			

for taking necessary regulatory actions and other corrective measures to rectify problems encountered in implementing the alternatives.

Each of the cells of the matrix illustrated in Table 1 is, to a large extent, unique. Some alternatives present obvious shortcomings for certain risks and can be discarded without detailed analyses. Others, however, pose more subtle difficulty and call for extensive analytic effort. The job of regulators or legislators will be greatly facilitated if they are provided with criteria to guide the evaluation of alternatives.

What Principles Should Govern Federal Reliance on Alternatives to Regulation for Managing Risk?

Within the proposed structure for congressional and agency consideration of alternatives, what principles or criteria should be considered by Congress and agency officials to assure selection of appropriate risk management options—regulation and alternatives to regulation? The criteria may be organized as follows:

1. Efficiency: will the options under evaluation be cost-effective vis-à-vis other methods of risk management?
2. Equity: will the options under evaluation be fair in terms of the allocation of costs and benefits over time, and afford substantive due process to all affected, legally recognized interests?
3. Institutional feasibility:
   a. Evidentiary considerations—will the options function without imposing unrealistic evidentiary burdens on the parties with interests at stake? Will they be workable on the basis of the findings of fact which are technically and economically achievable?
   b. Consistency and uniformity—will similar risks be dealt with in similar fashion? Will the options be relatively uniform in operation in all jurisdictions, so as to prevent risk generators from "forum shopping" and subsequent inequitable outcomes?
   c. Accessibility to the parties—will the options enable the parties to have access to the risk management fora in which the options are to be applied? In other words, will the options provide for procedural due process?
4. Efficacy overall: will the options under evaluation achieve socially desired "preloss" levels of risk reduction and risk prevention, and provide socially desired "postloss" remedial measures?

Efficiency. Efficiency is defined in terms of minimizing social costs, the sum of the costs incurred in the risk-generating activity, the losses imposed by it, the costs of avoiding those losses, and the transaction costs associated with shifting costs from one party to another. Efficiency can be contrasted with equity, which is concerned with the profile and acceptability of income distributions resulting from a set of risk management strategies, the ability of affected parties to be heard in the course of each strategy's implementation, the extent of individual choice, the potential for abuse of any arrangement, including avoiding costs, and the extent to which affected parties are protected during the transition from the current system to some new system.

Table 2[21] summarizes, in a qualitative way, the desirability of several risk management methods available to federal agencies. The tabulation is more an indication of a helpful method and relevant attributes than a firm judgment of the value in each cell.

Table 2. Qualitative Desirability of Risk Management Methods

Attributes	Market regulation		Federal government regulation	Voluntary standards	Strict product liability
	A[a]	B[b]			
Efficiency—minimize social cost	H[c]	L	L	H	M
Cost to producers	H	H	M	M	L
Cost to rich consumers	H	L	M	H	H
Cost to poor consumers	H	H	M	M	M
Delays	H	H	L	M	H
Equity	M	L	H	M	M
Chance to be heard	L	L	H	M	L
Individual choice	H	H	L	H	M
Abuse potential	L	L	M	M	H
Protection during interim	M	L	L	L	H
Transactions costs					
Implementation costs	H	H	L	M	M
Implementation time	H	H	L	M	H
Implementation personnel	H	H	L	M	H
Information collection and dissemination	L	L	M	M	M
Plausibility	M	L	H	M	M

[a] No important externalities of information asymmetries.
[b] Important externalities or information asymmetries.
[c] The entries in the table refer to the social desirability of each method of managing social risk in terms of the attributes specified: High, Medium, or Low.

Equity. The classic legal concept of equity is that the courts have a responsibility to promote justice and fairness which the literal application of law cannot achieve. This concept reflects the societal recognition that something is missing or lost in the formal application of law and policy, and that what is missing is some sort of fairness. For present purposes, the concept of equity can be disaggregated into two main parts: (1) fairness of risk management outcomes in terms of the distribution of costs and benefits over time, and (2) the affording of substantive due process to all legally recognized interests at stake in a particular risk management problem context.

Both parts of the concept of equity can be applied as measures of risk management alternatives. Among the attributes of equity to be considered in such an evaluation are (1) the justness of the cause of the parties: morally or constitutionally improper objectives should not be advanced by the application of societal risk management options; (2) the public interest: particular activities of a risk generator may be critical to the support of public welfare and individual rights to such an extent that the rights of a person exposed to a hazard must yield to the public interest fostered by the risk generator's actions; (3) the congruence between fairness in process and fairness in outcome: whereas it is possible to have an unfair process that nonetheless produces equitable results, both process and outcome are important, and one should not overwhelm the other; (4) the proper weighting of respective interests at stake: in considering options for risk management, the weights to be accorded the different

interests at stake in a particular risk management problem should be defined in terms of current measures; and (5) the consistency of government action with the rights and autonomy of the private parties involved: although government must not unduly interfere in the private sector, government action may be needed to reinforce or protect the value of individual dignity and autonomy.[22]

Institutional Feasibility. Institutional feasibility consists of three main elements: the element of evidence or information necessary to reach a decision that would be deemed valid in the context of the risk management option under consideration, the element of consistency and uniformity in dealing with risk in the multiple fora for risk management that some of the options entail, and the element of access to the decision process for purposes of presenting one's interests and confronting opposing interests and evidence.

Risk management decision making necessarily relies, to a considerable extent, on whatever evidence of risk characteristics is before the decision maker. The evidence may pertain to the actual or potential injury to certain interests, the causal connection between risk generator and risk receptor, the risk attributes of certain activities or substances, the reasonableness of the risk-generating activity vis-à-vis industry-wide custom or standards, and other matters. Rarely is such evidence direct or conclusive on its face; instead, it often includes information of arguable relevance, data which are incomplete, and unproven or contested analytic methods. Thus, action on technological risks is usually taken on the basis of considerable technical uncertainty, particularly when the action to be taken is designed to prevent future injury or reduce the probability that a current risk will lead to manifest harms.

The quality of the risk management decision will therefore depend, in part, on the quality of such evidence, on the ability of affected parties to produce such evidence, and on the ability of the decision maker to receive, evaluate, and act on that evidence. Thus, to evaluate alternatives to regulation, it is essential to examine and compare the respective capacities of courts, insurance underwriters, and general business fora to receive, evaluate, and use evidence to ascertain whether these can credibly accept the risk management role they have been, or would be, assigned, as a part of a strategy to rely on alternatives to regulation. Particular fora may differ widely in terms of the respective role of the participants and the forum itself in producing, introducing, and evaluating the evidence; the allocation of burdens for producing the evidence and using it to persuade; the levels or weights of the evidence needed to reach findings of fact and support the ultimate decision; special evidentiary attributes arising from the temporal aspects of alleged risks and harms; the role of risk analysis and the receptiveness of the fora and weights accorded probabilistic information; the use of experts; the presence and vitality of protocols or generic rules for screening evidence offered to determine whether it is to be introduced and how it is to be weighted; and evidentiary considerations when emergencies and imminent harms are at issue.[23]

Consistency of approach (to risk) and consistency of outcome are important criteria in assessing the capability for risk management alternatives to handle recurring risks of a similar nature. Consistency enhances the efficiency of the management option and promotes its due process and other features. Uniformity of process and uniformity of outcome may sometimes be important for similar reasons but, in general, uniformity is principally important to large industrial risk generators, since it enables them to utilize more systematic and efficient risk/loss planning and management strategies. The demand for uniformity, of course, undermines the development of creative risk management approaches.

Problems of consistency and uniformity inhere in those risk management options which fall under state authority. However, as states increase their activity in health and safety regulation, several factors operate to promote uniform legislation and regulation in the states.

First, competition for business and industry among the states may act to ensure some uniformity of health and safety standards. Indeed, there may be a conscious effort by states to enact legislation and regulations which will not differ substantially from other jurisdictions. A second factor is improved communication among states through meetings of national organizations such as the National Safety Council, National Governors Association, and the National Conference of State Legislators. These groups act as clearinghouses for information on the activities of state governments, and thereby foster consistency among their risk management efforts. Finally, the availability of new computer data bases which track state legislation and regulation and new state issues newsletters published by private companies enhance communication among different states and will serve to increase uniformity of state action.[24]

In addition, federal authority can be used to delegate risk management functions to state government, and then to impose constraints on state implementation of the functions which would promote consistency and uniformity.[25] However, whether Congress can force the states to act when they do not want to or cannot afford to is a delicate question requiring the application of a new legal doctrine that is still in its formative stages. Certainly, Congress cannot force the state to act in ways that deny the fundamentals of state sovereignty and hence violate principles of federalism.[26]

Several other forces also work toward uniformity, however.[27] These consist chiefly of organized efforts by organizations such as the American Bar Association, the National Conference of Commissioners on Uniform State Laws, and the American Law Institute. Others include industrial firms in interstate commerce and their trade associations, labor unions, and consumer and environmental groups.

Even in the absence of such efforts, however, the "bellwether" phenomenon is likely to produce substantial uniformity among the states. Simple economics dictate that any producer wishing to market products or services on a mass basis must meet the conditions of the most attractive market. For the most part, activities of similar kinds are attracted by favorable conditions and those conditions are not usually universally present.

Thus, assuming that marketing of a product is important and that population generally is a factor, New York and California are potential bellwether states for regulation. (There are obviously others.) The point is that the drive for uniformity is very much influenced by the behavior of certain important legislatures. For mine safety it might be Pennsylvania and West Virginia. For safety in the lumber industry, it may be Georgia and Washington. Regardless, the presence of dominant states having special influence because of critical positioning in the scheme of things or because of special experience and hence expertise is influential and critical in efforts to obtain uniformity.

A third aspect of the institutional feasibility criterion for choosing among alternatives is the extent to which, and the ease with which, all affected or interested parties have access to the decision makers.[28] Under the common law, access is formally available to those parties who have standing to sue. However, two problems serve to constrict or obstruct access in practice. The first is the disparity between the resources of the individual plaintiff (risk receptor) and a powerful corporate defendant (risk generator). The second is the statute of limitations, which may bar action taken many years after a plaintiff's exposure to a hazard. This has been a particularly troublesome obstacle in cases involving chronic health hazards, with their long time-span between exposure to hazard and manifestation of symptoms or injury itself.

The class action is a device to overcome the disparity of resources problem, since it enables individual plaintiffs to act together to sue in federal and state courts. Further, the courts have started to recognize that, in certain types of actions, defendants should also be dealt with as a class. As a result, several courts have used enterprise liability or joint tort-

feasor theories, or acted to certify defendants as a class to enable the joinder of numerous defendants, thereby bolstering the ability of plaintiffs, under the common law, to gain redress for serious injuries with complex origins.

As for statutes of limitations, courts have moved to liberalize the application of such statutes in many states. Thus, current statutes of limitation would not, as a general proposition, impede or render unconscionable a carefully thought out strategy in which the common law is given greater responsibility for reducing health, safety, and environmental risks.

Access to other risk management decision processes poses other problems.[29] For example, at their best, industrial standard-setting procedures compare favorably with federal Administrative Procedure Act rule-making procedures. This is especially so for private consensus standards. Some private standard-setting organizations even provide in-house appeal procedures. Not all industry standards are set so openly, however.

With respect to professional business, despite the presence of ample procedural safeguards for *de minimis* protection of parties at interest, and the availability of judicial review, the selection or membership of licensing boards is critical for assuring that such procedural safeguards are meaningfully implemented. Thus, opening up board membership to ensure that diverse interests are represented and that professional self-interest will not dominate proceedings is essential if professional business is to be relied on for purposes of risk management.

State authority to control insurance decisions theoretically provides access to interested parties, depending on state legislative enactments and the vitality of state oversight. However, the lack of rights of appeal in many states, and judicial deference to agency expertise in states with judicial review, leads to less than desirable access and procedural fairness. Moreover, most states become involved in rate-making only when rates filed with them are felt to be "clearly excessive." Statutes requiring prior approval of rates are more effective in affording timely access and procedural safeguards. In addition, a possible regulatory improvement is the structuring of consumer/safety interest representation within the cognizant state agency.

Efficacy Overall. The final criterion—efficacy overall—is required to determine if the nonregulatory options under assessment can reasonably be expected to achieve results, such as a level of risk reduction, which (1) are at least equivalent to the probable results of using regulations to manage the risks, and (2) are consistent with societal risk management objectives. If both tests for efficacy are met by certain nonregulatory options, and the application of all other criteria leads to favorable results, then the nonregulatory options can be chosen and their use considered responsible and defensible.

The "equivalency to regulatory outcomes" test can readily be conducted by agency officials assessing both regulatory and nonregulatory options, since the regulatory process normally entails the setting of some of the risk management objectives to be achieved. These objectives may include, for example, certain quantified levels of emission reduction or reduced exposure to hazards, or reduced injuries or other losses, and desired time-frame and degree of reliability considerations. Statutory provisions may, in some cases, provide guidance to regulatory officials as to what these goals must be; but in the usual case, it can be expected that such guidance will be general and permissive, and not quantitative or mandatory. In any case, agency selection of goals or targets, and agency assessment of regulatory and nonregulatory means of reaching these goals, must rest on agency findings of fact and reasonable estimates of what can be achieved in order to be legally defensible.

The "consistency with societal risk management objectives" test is designed to assure that nonregulatory options will not be chosen unless they meet the societal goals expressed

in the statute which governs the agency approach to a particular risk, where such other goals may not have been fully considered or articulated by the agency in applying the "equivalency of regulatory outcomes" test.

IMPORTANT ISSUES FOR FUTURE RESEARCH

The application of generic criteria such as these to the facts assembled by an agency for each case in a structured procedure will constitute the core of agency decision making in the choice of alternatives. Agency use of chosen alternatives will then depend on the highly particularized circumstances surrounding the specific risk problem being addressed and the ability of the agency to ensure that the alternatives chosen will actually work (or can be improved to work better as necessary).

The possibilities are many, and the necessary agency efforts will not be small. The alternatives route will be complex and fraught with difficult choices and implementation responsibilities. Further research can help to illuminate these choices and responsibilities. For example, research on the efficiency properties of particular alternatives may identify their social costs, transaction costs, equity implications, and information asymmetries. Analysis of the equity of alternatives to regulation may focus on defining justice and equity in risk management interests; articulating the public interest in loss control; and assigning proper weights to health, safety, and environmental values in competition with the societal values, such as privacy and human dignity. Research on the institutional criteria for evaluating alternatives to regulation may address the element of evidence or information necessary to reach a decision that would be deemed valid in the context of the risk management option under consideration, the element of consistency and uniformity in dealing with risk in the multiple fora for risk management that some of the options entail, or the element of access to the decision process for purposes of presenting one's interests and confronting opposing interests and evidence.

Other research will be needed to develop integrated regulatory and alternative strategies for specific risk problems of significance. Perhaps separate frameworks will be needed for the three risk contexts—consumer, worker, and environmental—identified here. Perhaps the generic framework suggested here can be refined upon further study and experience. As aspects of the alternatives framework are incorporated into the thinking of regulators, evaluation research will be needed to assess the experience. Finally, ongoing research aimed at reforming, streamlining, and improving alternatives to regulation—to increase their benefits and reduce their costs—will need to continue.

CONCLUSION

This chapter has sought to define a new, broader framework for risk management by government officials than the traditional agency rule-making approach heretofore employed. It has developed substantive information, and applied this information to particular risk cases, and thereby established the plausibility of greater societal reliance on the use of alternatives to regulation for managing risk. In addition, it has developed information on procedures which enables the approach to be put to use by government officials in a manner that is consistent with applicable law. Finally, it has suggested a way to assure that uses of alternatives to regulation will be reasoned and responsible by identifying and defining the basic criteria to be employed in future decision making on technological risks.

At the outset, each risk management problem which an agency attempts to address in the suggested framework will be unique and consume considerable agency resources. Nevertheless, if health, safety, and environmental risks are to be dealt with adequately, the alternatives-to-regulation approach, utilized in a systematic and judicious manner, deserves testing and use now. Even if its successes are few and achieved with difficulty at first (new regulations frequently take three to five years of considerable agency effort), it could begin to represent a new model or system for dealing with risks that ultimately could be fine-tuned and made more efficient and effective. Thus, a new role for regulators will ultimately evolve.

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NOTES

1. *See* M.S. Baram, *et al.*, *Alternatives to Regulation*, Lexington Books, D.C. Heath Co., Lexington, MA (1982).
2. *See* D. Sandberg, "A New Role for Regulators," unpublished paper presented at the annual meeting of the American Association for the Advancement of Science (Toronto; January 5, 1981).
3. Baram & Miyares, "Expanding the Policy Options for the Management of Hazardous Waste" 104, Report to the U.S. Congress, Office of Technology Assessment (1982).
4. For a thoughtful survey and assessment of the major regulatory reform proposals of a generic nature, *see* American Bar Association, *Federal Regulation: Roads to Reform,* Final Report and Recommendations of the Commission on Law and the Economy (1979); and American Enterprise Institute, *Government Regulation: Proposals for Procedural Reform* (1979).
5. For extensive discussion, *see* Baram, "Cost–Benefit Analysis: An Inadequate Basis for Health, Safety and Environmental Regulatory Decision-Making," 8 *Ecology L.Q.* 473 (1980).
6. The congressional veto was recently declared unconstitutional by the U.S. Supreme Court. *See Immigration and Naturalization Service v. Chadhar,* 103 S. Ct. 2764 (1983).
7. *See* American Bar Association, "Proceedings of the National Conference on Federal Regulation: Roads to Reform," 32 *Ad.L. Rev.* (2) (Spring 1980). Baram, "Testimony on H.R. 3441: The Risk Analysis Research and Demonstration Act of 1981," 3 *Env. Professional* 201 (1981).
8. *See* R. Hamilton, "The Role of Non-governmental Standards in the Development of Federal Standards Relating to Safety of Health" I-1 (report prepared for the Committee on Licenses and Authorizations, Administrative Conference of the United States).
9. N.H. Hollenshead, J.R. Miyares & R.M. Singer (eds.), First World Congress on Product Liability *Program materials* C-37 (London; January 19–21, 1977).
10. Beales, Croswell & Salop, "The Efficient Regulation of Consumer Information," 24 *J.L. and Econ.* 491 (1981).
11. *See* R. Coase, "The Problem of Social Cost," 3 *J.L. and Econ.* 1 (1960).
12. *See* L. Bacow, *Bargaining for Job Safety and Health* (1980).
13. *See* Caruso, "Socio-Economic Clauses and Policies," in American Bar Association, *Developments in Government Contract Law* 229 (1975).
14. *See* Baram & Miyares, "The Legal Framework for Determining Unreasonable Risk for Carcinogenic Chemicals," Report to the U.S. Congress, Office of Technology Assessment (1981).
15. Baram, *et al.*, "Managing Risks to Health, Safety and Environment by the Use of Alternatives to Regulation," 16 *N.Eng. L. Rev.* 657 (1981).
16. *See, e.g.*, Baram & Miyares, "Managing Flood Risk: Technical Uncertainty in the National Flood Insurance Program," 7 *Colum. J.Env.L.* 129 (1982).
17. Baram, *supra* note 1, at 153–155.
18. Baram & Miyares, *supra* note 3, at 23–51.
19. *Cf.* Baram, *supra* note 5, 8 *Ecology L.Q.* at 515–23.
20. Adapted from Baram & Miyares, *supra* note 3, at 19–21.

21. From L. Lave, "Economic Implications of Shifting from Federal Regulation to its Alternatives," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
22. R. Hesse, "Ethical and Equity Considerations of Alternatives to Regulation," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
23. J.R. Miyares, "Evidentiary Issues of Risk Management and the Use of Alternatives to Regulation," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
24. C. Marraro, "Problems of Uniformity Among State Health and Safety Regulatory Programs," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
25. C. Marraro, "The Effects of the Federal Supremacy Doctrine and the Commerce Clause on State Power to Manage Health, Safety and Environmental Risks," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
26. D. Sandberg, "Federal Preemption Limitations on State Control of Health, Safety and Environmental Risks," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
27. C. Marraro, "Problems and Mechanisms for Uniformity in State Laws Dealing with Health, Safety and Environmental Risks," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
28. D. Sandberg, "Special Consideration of Increased Use of the Common Law: Class Action Suits and Statutes of Limitations," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).
29. D. Sandberg, "Public Participation and Adjudicatory/Appeal Procedures in Industrial Self-Regulation, Professional Licensure and Insurance Ratemaking," paper prepared for the Project on Alternatives to Government Regulation, Boston University Law School (NSF Grants PRA-8007227 and PRA-8117640) (1982).

15

Alternative Risk Management Policies for State and Local Governments

David Okrent

INTRODUCTION

Scope of Study and Definition of Terms

The last decade has seen a very rapid expansion of activity by the federal government with regard to societal hazards and risks. Although federal regulatory decisions have tended to avoid quantifying the question "How safe is safe enough?" there is growing attention, on the federal level, to efforts to quantify risks and to examine various policies concerning "acceptable" or "assumable" risk. However, matters pertaining to many hazards and risks fall under the direct control of state, county, or municipal government. While there exists much current effort on risk quantification and risk management at the federal level, little information is available on the extent and magnitude of risks subject to local control. In addition, little has been done to examine the ramifications of various possible risk management policies at the state or municipal level.

This chapter reviews current practice at the state and local level with regard to management of risk to public health and safety and describes some proposals for possible improvement in current practices. Only risk management in the preventive mode, as distinct from the emergency response mode, is considered, and only involuntary risks, as distinct from occupational or voluntary risks, are considered. Risk management, in our usage, is also distinguished from insurance management in that the latter anticipates financial liabilities arising from nonfeasance or malfeasance affecting both lives and property. Therefore, risk management is viewed here as being unconcerned with fault in the legal sense and tries to anticipate losses to life and health as a means of devising corrective strategies. Neither loss of property nor investment risk will be considered in the discussion which follows.

The study of current practice included unstructured interviews and a questionnaire posed to a limited sample of state and local officials. It also included two case studies, one of

David Okrent • Department of Mechanical, Aerospace, and Nuclear Engineering, University of California at Los Angeles, Los Angeles, California 90024.

seismically substandard buildings in Los Angeles, and another involving risks from drinking water exposed to the disposal of hazardous chemical wastes. The detailed results of this study, which was supported by the National Science Foundation Grant PRA 79-10804, were published in a series of seven reports (see Appendix).

In order to facilitate the discussion several terms require definition:

Risk. While the term *risk* is used in the literature in many ways, this study will refer to risk as the likelihood per unit time of death, injury, or illness to people. This will usually be represented in terms of the product of the frequency (or probability per unit time of an event) multiplied by the consequence of the event, summed over all relevant events. However, it is sometimes argued that this compression of many possible contributing events, having a wide range of frequencies and/or consequences, loses much information, and that a proper description of risk will display a curve of frequency versus consequence.

The term *risk* may also be used when the results are uncertain. For many of the matters of interest to this study, the likelihood of death, illness, or injury to an individual or to society will be quite uncertain. We would call it a risk, however, even if it were known without a doubt that 50,000 people will be killed in automobile accidents next year. The fact that the risk is usually not known precisely will be treated or alluded to in terms of some level of uncertainty in our results or in terms of confidence limits.

Hazard. The term *hazard* shall be used to describe a source of risk. Thus, a dam poses the hazard of drowning should it fail. However, the risk of drowning because of dam failure depends on the likelihood of failure per year and the conditional probability that a particular individual (or each individual downstream) will drown, given that the dam has failed.

Risk acceptance and risk acceptability. A distinction can be made between accepted risks and acceptable risks. Thus, a risk may be accepted by an individual or by society, even though the risks fail to "pass" when compared against some standard of acceptability. Many risks are "tolerated" rather than "accepted." Many are accepted in the belief that they are much smaller than they actually are.

Risk analysis or risk estimation. These terms indicate the process of attempting to quantify a risk.

Risk management. Risk management is the act of attempting to identify all significant hazardous activities, including obtaining information concerning the nature of their risks (e.g., their magnitude and frequency) and benefits, and developing and adopting actions to deal with the risks as judged appropriate. Much of the existing activity with regard to risk management within state or local government relates to preparation for emergencies such as flood, fire, and other reactive kinds of action. In this study, the preventive aspect of risk management will be emphasized.

Risk manager. The risk manager is envisioned as a person, or group of people, who undertakes the tasks of risk management, except that of adopting actions such as new ordinances, which would be the task of the elected officials. The risk manager may also oversee the adequacy of the job being done by those responsible for observing or enforcing applicable laws or ordinances.

Hazards and Risks in Society

Society has available a large body of information of a fairly general nature concerning hazards and risks. However, except for those limited things covered by actuarial statistics, society is remarkably deficient in its knowledge of the hazards and risks to which it is exposed. For example, there are thousands of large dams in the United States, many with

large numbers of people living in their inundation plain, but there exists little information on the safety standards in force at the time in which these dams were built.

No report exists which deals quantitatively with the risk from these dams collectively, and only for a few individual dams is information available on the maximum hazard or on the estimated risks. The same is true with regard to the storage of large quantities of dangerous chemicals, although the transportation of dangerous chemicals is somewhat better off with regard to the quantification of risk, in that a limited set of studies on safety standards, hazards, and risks has been performed.

Despite the large gaps in our knowledge mentioned above, the hazard from accidents, with its attendant risk of attributable death, is easier for society to deal with than the hazards arising from chronic pollution and contamination of our air, water, and food. There is a fairly general acceptance that 60 to 90% of all cancer is environmentally produced, including effects found naturally in the environment (Doll, 1977). This acceptance, when coupled with the fact that all accidents, including those related to motor vehicles, cause only about 5% of deaths, suggests that far more attention should be given to chronic effects. Here, as for large accidents with low probability, there are major gaps in societal knowledge, with no clear path to obtaining the desired knowledge, even if a huge amount of resources is made available for the task. Hence, most decision making involving risk, whether by individuals, regulators, political representatives, or representatives of advocacy groups, is being made with inadequate knowledge of the factors under consideration. This is particularly true when the decision involves chronic risks rather than accidents. By comparison, much more is known about occupationally related deaths due to accidents than those due to an illness such as cancer, which usually cannot be unequivocally attributed to a single source of exposure. And, while only about 5% of our total death rate is due to accidents, it is primarily these latter which receive attention by the news media, possibly resulting in an undue emphasis on such events by those responsible for risk management.

Drinking Water and Hazardous Chemical Waste Disposal. The matter of disposal of hazardous chemical waste, as it represents a potential local source of hazardous emissions and as a pollutant of drinking water or food, is rapidly becoming one of the major public issues in the United States. In this regard, one might pose several questions as a partial focus for further consideration: (1) What are the average effects on health of the currently used drinking water? Where do health effects occur which are much larger than average? How large are they? Why do they occur? What are the uncertainties and the gaps in our knowledge in this regard? What constitutes adequate knowledge and when and how can we get it? (2) What are the potential future effects on drinking water, and thus on health, of the wastes which were dumped or otherwise disposed of in the past? Has this been quantified? Can it be quantified? In assessing health effects arising from these wastes, do we need to consider other uses, e.g., for irrigation? Are there synergistic effects? (3) How should federal regulation agencies such as the Environmental Protection Agency (EPA), the states, and other interested parties judge the appropriateness of controls that EPA has promulgated or is planning to promulgate on the disposal of hazardous wastes and on the quality of drinking water?

Almost all of about a dozen epidemiological studies show an association between cancer rates and organic contaminants in drinking water (Kimm, 1980). Two epidemiological studies of the whole population of 88 Ohio and 64 Louisiana counties suggest that contaminated surface water is responsible for approximately 8% and 15% respectively, of the cancer mortality rate (Page, 1976; Harris, 1977). This is a large effect, if true.

In its final rule on control of trihalomethanes in drinking water, the EPA (1979b)

summarizes many of the risk estimates made for this carcinogen, and arrives at a lifetime incremental risk of 4×10^{-4} for cancer. This figure assumes that an individual drinks two liters of water daily containing 0.10 mg/liter, the newly promulgated maximum level for this contaminant for community water systems serving more than 10,000 persons. However, while a lifetime risk of 4×10^{-4} seems to be a tolerable number, at least at first glance, this rule does not address the potentially large quantity of chemicals to which one may be exposed. In addition, other possible health effects, including reproductive effects, remain to be understood (CEQ, 1981).

What is the magnitude of hazardous waste disposed of annually? The EPA estimates that approximately 75 million tons of the 380 million tons of liquid and solid industrial waste generated in the United States in 1978 were hazardous wastes and that about 80% of these hazardous wastes were improperly disposed of in land fills or lagoons, thus posing the threat of groundwater contamination (EPA, 1980a). From their surface impoundment assessment, EPA estimates that 5,000 to 6,000 industrial impoundments may contain hazardous wastes. Few of these land disposal sites are lined, and virtually no monitoring of groundwater is conducted to detect contamination beneath the sites. Almost one-third have the potential to contaminate usable aquifers, and one-third may endanger water wells.

Industrial waste, of course, is not the whole story. Agriculture and mining provide potentially large, additional sources of contamination of drinking water.

EPA has recently promulgated cradle-to-grave regulations for hazardous wastes (EPA, 1980b). However, implementation of these regulations is left primarily to the states. The magnitude of the source is so large, diverse, and complex that compliance is made difficult. Equally important, quantitative knowledge of the magnitude of the current and future risk does not now exist and is difficult to obtain. Cohen (1977) has estimated that the toxicity of hazardous chemical wastes generated annually in the United States is large compared to that of the radioactive waste generated by a 1000 MWe nuclear reactor.

A type of hazard and risk which has received insufficient attention in the past is the source of local air and ground pollution (EPA, 1978; Sharma, 1980). Such hazards come to public attention only after serious real or potential adverse effects on health and safety have come to light, e.g., the Kepone release in Virginia, an asbestos mine in Arizona, and a lead smelter in Idaho.

Seismic Effects on Our Cities. The prediction of the likelihood of occurrence of damaging earthquakes involves very large uncertainties. That this is the case for all portions of the United States is graphically illustrated in a survey of seismic experts (Okrent, 1975). Seven experts independently assessed the likelihood of increasingly severe earthquakes at 11 sites distributed around the United States. For each location, these experts usually differed in their estimates of likelihood for severe earthquakes by a factor ranging from 100 to 1000. Such a large uncertainty in the likelihood of severe earthquakes poses safety questions for essentially all of our cities, for dams, for storage facilities for hazardous chemicals, and so forth. Except for nuclear power plants and some dams, seismic design requirements are usually rather modest for most structures.

The problem of seismically substandard buildings is clearly acute for the city of Los Angeles and for many other communities in California. Even in Los Angeles, only part of the problem is being addressed, namely pre-1933 masonry buildings which contain many dwelling units or are frequented by large numbers of people. There may be similarly high individual risks to people living in smaller and/or older masonry buildings. And there may be many post-1933 buildings whose design is inadequate for the substantial seismic shaking

which is likely to occur during the coming years. It should be noted that this problem is not unique to Los Angeles, San Francisco, and a few other cities in California; earthquakes can and do occur almost anywhere in the United States.

SOME PRIOR WORK PERTAINING TO THIS STUDY

The United Kingdom and Canvey Island

One of the most interesting and significant accident-risk studies available is from the Health and Safety Executive (1978) of the British government entitled "Canvey: Summary of an Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area". Canvey Island lies in the Thames River and is about 9 miles long and 2.5 miles wide. It is populated by about 33,000 residents; there are seven large industrial complexes, including a petroleum plant, an ammonium nitrate plant, and a liquefied natural gas (LNG) facility.

The study indicates that the largest risk of death to Canvey residents arising from an accident at one of the industrial facilities was estimated to be about 1.3×10^{-3} (one in 800) per year for some of the nearest residents. This risk is about five times as large as the average risk of dying in an automobile accident in the United States. The average risk of death arising from an accident at these industrial installations was estimated to be about 5×10^{-4} (one in 2000) for all the island's residents. This is about twice the risk in the United States of death from an auto accident. The chance of 1500 people being killed in a single accident was given as more than 1 in 1000 per year. The chance of 18,000 being killed in a single accident was given as 1 in 12,000 per year. These estimates were stated to probably err on the side of pessimism by a factor of 2 or 3, but probably not by a factor of 10.

The U.K. Health and Safety Executive recommended that improvements be made to reduce the likelihood of each of the above estimates by a factor of 2 or 3. With these changes, the Health and Safety Executive judged that the risk would be acceptable. It is of interest to note that in a follow-up study which included the results of modifications made to improve safety, somewhat lower, but still significant, risks were reported (Health and Safety Executive, 1981).

The Canvey Island study is a direct outgrowth of substantial efforts within the United Kingdom during the 1970s to improve risk management for hazardous installations. In 1972 a committee of inquiry under the chairmanship of Lord Robens issued a report (1972) which commented on the then existing fragmentation of administrative jurisdiction and recommended the establishment of a national authority for safety and health at work. In 1974 the Health and Safety at Work Act established two new bodies, the Health and Safety Commission and the Health and Safety Executive, the latter being responsible for day to day operational matters. This act places general duties on employers to ensure so far as is reasonably practical the health and safety of both work people and the general public.

While Canvey Island represents a location with a high concentration of industrial complexes, there is good reason to believe that the general hazards and risks posed there are not unique, either in the United Kingdom or in the United States. Except for a few recently proposed facilities for the importation of LNG, there has not been published in the United States a risk analysis of a chemical installation similar to that performed for Canvey Island. Nor does the United States have a regulatory approach for acute hazards to the public from chemical installations similar to that being developed in the United Kingdom and in Western Europe.

On Storage of Hazardous Chemicals in the United States

Some insight into the status of regulation of hazardous chemical storage facilities by states and local communities in the mid-1970s is provided in the brief study by Solomon et al. (1976). Letters were written to the governors of all 50 states asking for information concerning the means used by their state for regulating and evaluating risks from the storage of potentially hazardous chemicals. In general, the knowledge and regulation of such hazards appeared not to be very detailed and frequently minimal. Two cities in California (Los Angeles and El Segundo) were then surveyed with regard to measures employed in regulating the construction and use of facilities to store hazardous materials. Of particular interest in this study was whether there were, in proximity to a relatively high housing density, places where hazardous chemicals might be used, and, if so (1) What safety criteria were used in evaluating the adequacy of container design? (2) What magnitude of risk was considered to be acceptable? (3) What controls were exercised and by whom? (4) How were the safety evaluations made? (5) What magnitude of risk actually exists?

For these two cities the fire and building departments impose certain requirements. However, no detailed hazard or risk evaluations are made and the knowledge and regulation of hazardous chemicals appear to be less than complete. One interesting aspect that arose in the survey of these two cities is that an industrial area in one city may be located next to a heavily populated region in a neighboring city without any systematic recognition of this juxtaposition. In addition to sudden accidental death, another risk issue arises from hazardous chemical storage facilities, namely, delayed health effects arising either from a large accidental spill or from chronic releases. Little has been published on this matter.

Some Proposals Concerning Vulnerability Assessment and Hazard Movement

Gabor and Griffith (1980) discuss the problem posed by hazardous chemicals manufactured, stored, and transported in the United States and review some existing qualitative vulnerability models. They argue that part of the problem stems from lack of recognition of the hazards by the community personnel most responsible for their mitigation and recommend the identification of these hazards through risk assessments to provide objective confirmation of their existence. They also recommend that emergency planners concern themselves not only with the recognition of the hazard itself, but also with the existing state of preparedness of the assessed area; that is, its vulnerability. Finally, they discuss a more detailed rating system for emergency planning, which in the hazard identification stage, could also have application in preventive measures.

Beranek (1979–1980) discusses methods by which state governments might improve their ability to handle information concerning hazardous chemicals, whether through the governor's office, the legislature, or designated agencies. His suggestions include the following: (1) access to national and international technical information networks;(2) exchange of chemical information with an emphasis on the development of individual contacts with counterparts at the federal, state, and local level and with appropriate members of the academic and corporate community; (3) establishment of an office of chemical risk for the state board of health; (4) development of a mechanism for obtaining information about potential problems from industry; (5) review of state regulations, in particular for inadequacies in intrastate operations; (6) establishment of reliable chemical testing laboratories; and (7) enactment of whistle-blower legislation.

Whittaker and Ketchum (1982) recommend the use of hazards analysis for emergency

management. They define hazards analysis as the systematic identification, investigation, and subsequent analysis of hazards in terms of the interrelationships of their physical properties, their probability of occurrences, the vulnerability of the elements-at-risk to these hazards, and the maximum threat, as well as the risk reduction and the local conditions that affect their impacts. They suggest a five-step process, as follows: (1) planning and coordination at state and county levels, and adoption of standardized incidence reporting; (2) data identification, collection, and compilation and risk mapping; (3) state and county hazard profile development; (4) comparative methodology development; and (5) cross hazards evaluation and ranking.

This process is based on the premise that there are seven factors that must be considered in analyzing hazards, and that each has one to six descriptive and quantifiable indicators. They are listed in Table 1.

ON CURRENT RISK MANAGEMENT PRACTICES IN LOCAL COMMUNITIES (Meyer, 1982; Bordas, 1982)

This research (Okrent, 1982) began from the premise that risks to life and health, other than occupational risks, fall, at least in part, within the purview of local government, and that the mitigation or prevention of these risks is, or ought to be, a key concern of local decision makers. A number of assumptions might flow from this premise. One is that a generic concept of risk informs the local official's approach to problems, and that policies are directed as much toward reducing risk as they are toward response to emergencies. Another assumption is that alternative risk management strategies might be devised and an optimal mix developed so that more rational, cost-effective risk management practices can be implemented.

These assumptions were rendered suspect by a series of informal interviews of city officials as well as a limited, structured survey of state and local officials in Oregon and California. Risk management, if used at all, usually appeared on the organization charts of

Table 1. Factors to be Considered in Analyzing Hazards

Factors	Indicators
Incidence	Occurrences over past three years.
Severity	Deaths over past three years. Injuries over past three years. Dwelling units 85+% destroyed. Businesses 85+% destroyed. Persons unemployed 30+ days. Per capita.
Probability	Chances per year that average event will occur.
	or
	Chances per year unexperienced event could occur.
Maximum threat	Estimated greatest percentage of harm from single event.
Vulnerability	Risk to population.
	Risk to property.
	Risk to area economy.
	Risk to quality of life.
	Risk to environment.
Risk reduction	Mitigation measures minimizing hazard.
	Preparedness measures minimizing hazard.
Local conditions	Climatic, geographical, or structural conditions that increase–decrease hazard.

finance departments to designate individuals or units responsible for fiscal, as opposed to personal, risk. Initial interviews not only show the concept of risk to be foreign or extremely limited in local government, but they also reveal the near absence of formal risk management activities. Formal risk management entails the following: (1) a suspected source of risk is identified; (2) the degree of hazard posed by the source is estimated from either experimental or observational evidence and the level of exposure to the hazard is calculated so that an overall risk estimate can be made; (3) this level of risk is compared to previously established risk acceptance criteria; (4) policies are developed and implemented so that the risk does not exceed acceptable levels; and (5) a system of monitoring is set in place to ensure the effectiveness of the policy. The terms *identification, analysis, acceptance, policy,* and *monitoring* describe these steps; each is dependent upon the prior one.

Little resembling this rational model of risk management surfaced in our first conversations with local officials. Where we did find risk management at the local level, it was at the end rather than at the beginning of the sequence. Identification of specific hazards posing risk does not normally occur at the local level. When it does, it is sporadic and usually the result of a highly publicized incident such as a major fire or a toxic spill. Substances or activities posing substantial hazards are not actively sought. Quantification of risk is rare at the local level, and determination of acceptable levels is all but nonexistent. There is, of course, political determination of which hazards are tolerable and which are not, but this is far different from setting quantitative standards for acceptability. Specific policies for managing risks are sometimes enacted locally, usually at the behest of state and, in turn, federal authorities, and are only infrequently due to local initiatives. The monitoring of hazards is, however, frequently a local function, undertaken, again, mainly at the behest of state and local authorities.

Types of Local Risk Management

Three types of local risk management emerged from the initial conversation with city, county, and state officials. One type we call management by reaction, the second is management by compliance, and the third is analytic or formal risk management.

Risk management takes place by reaction when life-threatening situations or events causing loss of life lead to measures intended to prevent their recurrence. These measures are implemented swiftly and in most cases without careful analysis of their probable costs and benefits.

Risk management occurs by compliance when rules, codes, standards, and statutes govern decisions affecting life and health. Compliance is distinguished from reaction in that it is orderly rather than *ad hoc*. The same standards, more or less, apply to all similar cases.

Risk management analysis combines most of the elements of the formal risk management model discussed above. Specifically, there is an effort to confine overall levels of risk within the bounds of what is believed acceptable, however the latter is determined. The analytic approach is distinguished from reactive risk management in that it involves quantification and estimation of risk prior to decisions. Analysis is distinguished from compliance in that it does not automatically accept standards set elsewhere that determine allowable levels, if not acceptable levels, of risk.

Overall, local government entities tend very much toward risk management by reaction and compliance, and relatively little toward analytical techniques. The bulk of local, and to a lesser extent state, expenditures are for public protection, emergency response services—police, fire, acute medical care—and planning for emergency response. Expenditures for risk mitigation generally support enforcement of codes and regulations applying to very

specific kinds of hazards such as storage of flammable materials, contaminants in drinking water, and the like—but not analytical studies aimed at identifying, quantifying, and comparing risks.

Problems in Risk Management

One limitation to local risk management is historical. Traditionally, the functions of local governments have been limited to service delivery, and localities have not had a mandate to protect their citizens from all conceivable risks to life and health. There are also political limitations affecting management of risk of low visibility or salience since short-term benefits from analytic approaches to risk are likely to be invisible, and the costs will be substantial.

Another limitation to local risk management is cognitive. It is well documented that public perceptions on the relative riskiness of different kinds of hazards is not congruent with the ranking of risk according to its consequences. Generally, risks associated with hazards that are sensationalized in the press, such as earthquakes, tornadoes, major fires, and crime, tend to be overestimated as are risks of death due to causes that are statistically rare but dramatic, such as botulism and rabies. By contrast, the riskiness of chronic hazards affecting many people tends to be underestimated. In the absence of public perception that a hazard poses substantial risk, local action is difficult, if not impossible. On the other hand, in the absence of local action when public perception of a risk is high, discontent will be produced. This perception of magnitudes of risk, however, is but one element of the problem, and perhaps the minor element. To the extent that the public's understanding of risk is conditioned by the media, considerable volatility will exist in what is perceived hazardous and what is not. Hence, where action is demanded and where there is indifference varies.

A third, and probably most important limitation on local risk management arises from political and fiscal weaknesses. The mandates and resources available to local and even to state governments to formulate and execute long-term policies of any kind are modest compared to those of the federal government. Such incapabilities stem from a variety of sources in the institutional structure of local government codes in that "home rule" charters and the like rarely make explicit provision for the management of unspecified and often unknown hazards.

The Survey of Risk Managers

Several broad issues arose out of our survey of state and local risk managers. One is the extent to which the full spectrum of risk management activities are carried out in local government. Another is the adequacy of existing scientific and technological information, manpower, and legal authority with which to manage hazards effectively. A third topic is the adequacy of current organizational arrangements among federal, state, and local authorities concerned with risks, as well as the desirability of a centralized risk management office in each locality.

While firm conclusions cannot be drawn from the survey of 19 informants, as their representativeness for all risk managers cannot be guaranteed, some of the more striking results do give pause. Identification of new hazards and quantification of risk are not features of local government, except incidentally. Therefore, priorities in dealing with risks are not based on assessments of riskiness. Almost all policy making is incremental, based on past practice rather than on formal quantitative analysis of risks.

The information and other resources available to local agencies to do what they are now doing may or may not be adequate; the pattern is ambiguous.

There is overwhelming agreement, however, that additional quantification of hazards would be of assistance in local decision making. At the same time, at least from the perspective of city, county, and regional agencies, coordination among the various bodies charged with risk management is inadequate. There are frequent complaints about both substantive and jurisdictional issues arising due to combined state and federal supervision of local risk management practices.

CASE STUDIES

The two hazards chosen for case studies differ widely in their characteristics. As a result, they lead to contrasting conclusions concerning the proper role of local government.

Drinking water poses a small, difficult to quantify risk to essentially all members of the community. The risk is chronic, not catastrophic, and quite common. The contaminants which are likely to be harmful have not all been identified, are usually invisible, and are not easy to measure. The federal government has prescribed standards for "safe" water, but the risks at these or higher levels of contamination are multiple and not readily managed. Therefore, a better scientific resolution of the risks from drinking water is beyond the capabilities of local government. Furthermore, management of this hazard conflicts with, rather than augments, the traditional service delivery function of local government.

It is concluded that these characteristics tend to diminish the local role in risk management. Since chronic risks of low magnitude do not ordinarily stimulate immediate demands for protection, risks common to many localities and concentrated in none are not viewed as principally local problems. Hazards eluding easy detection exceed the technical capacity of local governments. Finally, highly uncertain risk estimates pose political perils for local officials, as when risk management practices impede or increase the cost of service delivery.

It is concluded that local government can usually do little beyond monitoring federally identified contaminants (unless the local government happens to be in a position to regulate potential polluters of its own water supply). While the responsibility for controlling contamination of drinking water appears to fall on state government, their resource limitations require a major federal role in providing the necessary scientific information, and in performing cleanup of existing dangerous disposal sites.

Seismically substandard buildings, on the other hand, introduce a significant risk primarily to an identifiable subset of the total population. The risk is catastrophic. At least in Los Angeles, the risk to these individuals is substantially larger than that posed by drinking water to any individual in the same city. Also, the risk may be large compared to other accidental risks. This is a risk which can be and has been evaluated by local governments in line with their responsibility for building safety. However, the risk from earthquakes is not unique to residents of Los Angeles or even California. It may be less in most other parts of the country, but whether the matter has been evaluated, and on what basis judgment concerning the need for seismic upgrading would be made, is uncertain.

Drinking Water

Solomon et al. (1982a) estimated the likelihood of cancer from drinking water, using data from an EPA survey of organic contaminants (1977) together with results derived from experiments on animals, and compared these estimates with the results of several published

Table 2. Summary of Risk Estimates from Animal and Epidemiologic Studies

Animal tests	Cancers/million population/year
New Orleans	10–23
Miami	18–19
Epidemiologic studies	Cancer deaths/million population/year
Ohio counties (Surface versus groundwater)	140
Louisiana counties (Mississippi River versus groundwater)	250
80-cities survey (250 ppb chloroform)	45–110
New York counties (Chlorinated versus nonchlorinated)	240–340

epidemiological studies (see Table 2). Although all these estimates are highly uncertain, the epidemiological studies suggest a substantially higher risk than do the animal studies.

Recent research has demonstrated that organic contaminants potentially harmful to human health are ubiquitous in America's drinking water. Over 700 such contaminants have been identified, yet they represent only about 15% (by weight) of the total organic matter in drinking water (NAS, 1977). Many contaminants cannot be identified or quantified given present analytical methods. Primary sources of these contaminants are solid waste disposal facilities. Only a small fraction (less than 10%) of the known contaminants have been adequately tested for adverse health effects. Twenty-three chemicals have been identified as known or suspected carcinogens, while a few others are known or suspected as either mutagens or tumor promoters (NAS, 1977).

Unfortunately, the extent to which cancer is caused by organic contaminants in drinking water is extremely difficult to determine (NAS, 1977; EPA, 1979b; NCHS, 1977). The currently developed means of assessing cancer risks all have considerable limitations.

Reducing contamination from industrial waste seems to be particularly complex. The very large number of potential chemical products, the inadequate information on waste effluents, the high cost of identifying and analyzing the contaminants, the difficulties in ascertaining their health risks, and the potential for synergistic effects combine to make this a difficult problem, even with the resources that might be expended at the federal level.

The Role of Local Government. Three systems exist at the federal level for regulating contamination of drinking water. One is the National Pollutant Discharge Elimination System, for which authority is provided in the 1977 Clean Water Act. Responsiblity for the implementation and enforcement of this act is divided between the federal government (EPA), the states, municipalities, and interstate and intermunicipal agencies.

A second system is the set of regulations governing disposal of hazardous wastes promulgated by the EPA as authorized by the 1976 Resource Conservation and Recovery Act. A third system is direct regulation of drinking water quality by the EPA's Office of Drinking Water. The water pollution standards identify specific contaminants, maximum contaminant levels, and acceptable procedures for ascertaining levels of contamination. Cost–benefit analysis and other forms of risk assessment were involved in formulating these regulations, which were based on a National Academy of Sciences study of risks associated

with known contaminants, and set maximum permissible levels for a large number of contaminants (NCHS, 1977). The EPA's hazardous waste disposal regulations, by contrast, are much less specific, classifying wastes only by relative degree of toxicity, and were formulated without quantitative estimates of risk.

Normally the EPA does not directly enforce regulations regarding water pollution, hazardous waste disposal, and drinking water quality. Instead, enforcement is left to the state and local units. Implementation of EPA standards remains with local water suppliers; local agencies responsible for maintaining the purity of rivers, lakes, and streams (in California, the Regional Water Quality boards); and, in the case of hazardous wastes management, with a panoply of local agencies whose configuration is inchoate, and cannot be fully described. (See, e.g., Chapter 18.) The principal responsiblity of local agencies is, then, compliance with state and, ultimately, federal standards. It is not the identification or quantification of risk, and it is not the comparison of the extent of risk with the overall level of risk deemed desirable or mandated externally.

Therefore, the capacity to assess risk associated with drinking water, and, thereby, to manage it with appropriate policies, does not exist at the local level, and it is unlikely that such capacity will exist in the foreseeable future. The reasons for this include lack of expertise, lack of resources, and inadequate coordination of functions at the local level (EPA, 1973). A wide range of potential risk management options exists in principle for local government, but as a practical matter local agencies may be able to move little beyond current capacities and practices. Local government is hampered in managing risk associated with water because of the lack of resources and expertise, and, in some instances, lack of jurisdiction. Additionally, the service delivery practices of local governments preempt activities aimed at long-term mitigation.

Any proposal to delegate the management of risk associated with carcinogens in drinking water wholly to local government agencies would be costly because duplication of effort would result, and ineffective because service delivery would take precedence over hazard mitigation. This does not mean that there is no room for improvement in local risk management practices, but it does mean that improvements may be confined largely to facilitating concrete activities. Hazard monitoring or identification capacities of local governments might be enhanced somewhat through pooling or sharing of information about previously unknown or unsuspected contaminants. The capacity of local governments to prevent contamination might also be improved somewhat as preventive measures are many times cheaper than purification in most instances. Prevention requires long-term cooperation of water "retailers" with agencies supervising discharges in the water supplies as well as agencies overseeing disposal of hazardous wastes. The processes through which such cooperation is to be achieved cannot be specified here, but such efforts necessarily extend beyond the jurisdiction of any single unit of local government.

The states do not suffer the same resource constraints as local entities. Although they have far fewer resources than the federal government, their health and environmental agencies are capable of risk analyses and policy formulation to a limited extent. Jurisdictional issues do not arise as frequently at the state level as between local governments. Indeed, precisely because states have the power to preempt local ordinances, especially land use regulations, state governments can compel cooperation among local entities when disputes arise concerning protection of watersheds and siting hazardous waste dumps. State-level agencies can potentially regulate most of the use and disposal of hazardous chemicals. These powers are rarely vested in any single local entity because enforcement of construction and fire codes, highway and traffic laws, and disposal regulations are vested in different jurisdictions.

A strengthening of the state role in management of hazards associated with water contamination is thus indicated.

Risk from Seismically Substandard Buildings in Los Angeles (Sarin, 1982)

Los Angeles, like many other cities in the state and nation, has a large number of existing hazardous buildings. These buildings were built before earthquake standards were incorporated in the building codes. In case of a major earthquake, these buildings are most susceptible to collapse, causing death and injuries to the occupants. Sarin (1982) specifically deals with the unreinforced masonry buildings that were built before 1933—prior to code requirements designed to withstand earthquakes—and performs a social decision analysis, examining the points of view of city, owner, renter, and society.

Sarin observes that the risk to the occupants of the unreinforced masonry buildings is significant. Using expert opinion as to the likelihood of a severe earthquake in the region during the next 10 years (about 40%) and plausible assumptions on the damage produced, he estimates that if no upgrading of these buildings is undertaken, an individual occupant faces approximately a 5-in-1000 chance of death, and a 25-in-1000 chance of serious injury due to earthquake in the next 10 years. This risk is about 10 times the risk due to fire and about 40 times the risk of electric shock in the home during the same time period. Moreover, this risk would be 5 times higher if he assumes that a 90% collapse of the building would cause deaths to 25% of its occupants, instead of only 5%. These are large risks and raise ethical questions for societal consideration. His social decision analysis led to the following conclusions: (1) The estimated total cost of upgrading the old buildings the least costly amount (called Masonry B) is approximately $400 billion. Upgrading these buildings would result in a lower property damage to the owners of these buildings ($125 million saving), but this gain clearly does not offset the costs involved. A policy that does not account for the owner's interests would appear to have low likelihood of success. Besides, the cost of implementing a policy that disregards the owner's interests would be tremendous. This is because unwilling owners will find all sorts of ways (legal, political, unethical) of not complying with the policy. (2) Class I buildings such as schools, hospitals, fire stations, etc., should be upgraded to current standards. The net benefit of upgrading found in this analysis does not include the benefits to the general public due to uninterrupted operation of emergency facilities in the event of an earthquake. (3) Residential buildings should be upgraded to Masonry B standard. The net benefit of this policy is positive if an individual occupant is willing to pay $16/month for the reduced risk. The owner should be allowed to increase rents to partially offset the cost of upgrading. Approximately a $10/month/dwelling increase in rent is a fair cost sharing by the owners and the tenants. This is because the owner receives other benefits—e.g., tax advantage, increase in the life of the building, increased property value, protection against lawsuits, insurance benefits—that are not included in the calculations. The city should also ensure that adequate financing through conventional channels is made available to the owners for undertaking the upgrading. (4) Sarin does not recommend that the city should simply post signs to make the residents aware of the hazard on the belief that the market mechanism will determine the optimal action. This is because, for an average resident, it is relatively difficult to assess the risks involved. Besides, because of the housing shortage in Los Angeles, in the short run, the residents may not have a real choice of paying a higher rent for a safer building. An ordinance based on a cost-sharing scheme between the tenants and the owners would reduce the resistance

of the owners to upgrading. Such a scheme would therefore be beneficial to both the owners and the tenants.

ON THE METHODOLOGY OF RISK MANAGEMENT

From the decision analysis of the case of seismically substandard buildings, one can derive a series of questions to help guide the management of an identified risk. They are as follows: (1) Is the risk significant? (2) What are the mitigation alternatives? (3) What are the costs and benefits? (4) What are the legal, social, and political ramifications? (5) What are the enforcement and implementation issues?

Of course, there are many risks of potential interest and not all are well recognized. We investigated several different approaches to the classification of risks and concluded that no single taxonomy is likely to be most useful for the task of risk management (Solomon 1982b). We believe that multiple taxonomies, developed in reasonable detail and quantified as practical risk profiles, would provide a portion of the framework needed for decision making by identifying a more complete array of risks and by profiling these risks for several geographic regions and subregions.

We also argue that a set of appropriate risk taxonomies and profiles may introduce persons responsible for risk management to a new way to quantitatively represent risk. The favored risk classification approaches include the following: (1) situation in which the hazard or risk is encountered (e.g., transportation, occupation); (2) cause of the hazard or risk (e.g., virus, explosive); (3) kind of hazard or risk (e.g., cancer, poison); and (4) geographic division of risk management responsibility (e.g., within city, by state).

We recommend the development of a national risk management information system. We believe that there is a need for risk classification not only to help accumulate and retrieve information, but also to help think about risks. We feel that classification permits comparison, ensures that some categories of risk are not altogether ignored, and is a prolegomenon to systematic thinking about risks.

We believe that the responsibility for initiation of a national risk management information system must fall on the federal government, since no state or local community has the requisite authority or resources. The existence of a national risk management information system could overcome several of the weaknesses of local government in dealing with hazards by providing local governments the information wherewithal on which to base risk management decisions. Thus, the federal government would reinforce the political process in states, counties, and cities. We do not argue that this would or should necessarily lead to a more nearly uniform approach to risk management among the states.

We take the point of view that while the elected representatives will ultimately need to make the policy decisions concerning risk, the structuring of the alternatives and the assessment of the probabilities of uncertain outcomes is largely a highly technical enterprise and should be done by a technically competent agency (possibly an Office of Risk Management). We conclude that the task is too formidable for local government and is inappropriate for the federal government, and that hence, the management of risk must start at the state level with the possibility of strong regional offices which would interact both with the central office and with local officials.

There will exist a need for criteria by which such a technical agency can judge whether a hazard requires attention. The setting of such criteria will involve sociopolitical decisions. Given the necessary leadership and support by the state, one can envisage a possible functional model for the office of risk management of a large city, assuming that the office was

given responsibility for trying to prevent or reduce unnecessary yet significant risks and has a reasonable amount of resources available to perform its tasks. The outline of such a function might be as follows: (1) Develop tentative threshold criteria for action appropriate to identification of potential sources for each catagory of hazard or risk. For example, for health effects from pollutants in drinking water, there might be several thresholds for each chemical or pollutant. Some threshold quantity of waste disposed of per year would require notification of the responsible agency, including means of disposal. For a larger quantity of a chemical, a risk evaluation would be required to be provided by the disposer to the agency. Each chemical that could pose a threat to drinking water in an accident would require notification of an agency. For each of these, some larger quantity might require a risk evaluation. (2) Develop ordinances to identify hazard and risk sources which meet threshold criteria. (3) Formulate a basis whereby governmental entities can, in practical ways, assess risks that may exceed "acceptable" limits. (4) Prepare evaluation processes, methodologies, etc., whereby source identification methods can be checked for adequacy. For example, how would PCB containing transformers be detected; how would asbestos in buildings, specifically schools, be thought of as a possible source of air pollution; and how would the use of uranium tailings for home building material be identified and detected? (5) Arrive at a methodology for determining other attributes which may be relevant to decision making for risk sources which exceed threshold criteria. For example, such factors would include the benefit associated with the technology responsible for the risk, the dollar cost of reducing the risk, and various political factors. (6) Suggest methods for acquiring appropriate information about other attributes. (7) Identify and bring forth factors which will potentially enter in judgment on risk acceptance and risk management. (8) Formulate a proposed risk management policy for each hazard class.

SYNTHESIS AND CONCLUSIONS

Some Introductory Comments

In view of the many difficulties facing the development of a significantly improved approach to risk management at the state and local level, it becomes relevant to ask whether there are strategies that might be effective in leading to measures that are meaningful, workable, and cost-effective.

It may be useful first to restate some general points: (1) The terms state and local government encompass a very wide range of governmental entities ranging from large, industrialized states with very large budgets to poor, sparsely populated localities with minimal resources and personnel, mostly committed to public protection. Not only do these governmental entities differ in resources, they also vary widely in their attitudes toward regulation of industry, agriculture, mining, etc. Such diversity renders any single risk management strategy unsuitable for all states or local governments; (2) Many hazards and risks are still poorly known or understood by society. Others are understood in a generic sense, but are very difficult to evaluate in specific instances. One such example is the probable future risk from drinking water due to disposal of hazardous chemical wastes that, decades later, creep into an aquifer used as a source for a city water supply. (3) Society is not and cannot be made risk-free. Nevertheless, there are some risks that can be prevented, removed, or reduced cost-effectively. There have been many risks that, once identified and quantified, were judged to have been intolerable. (4) Risks vary widely in their nature and seriousness. Risks also interact. Mitigation of one risk may exacerbate another. For example, the use of

Tris to reduce the flammability of children's sleepwear appears to have exposed many children to a potential carcinogen. (5) The benefits society derives from activities which act as sources of risk vary widely. (6) There is a paradox with regard to the quantification of risk. Elected officials at the state and local level appear to prefer categorical statements that something is "safe" to quantitative estimates of risk (coupled with an opinion that the particular risk is low enough to be acceptable). On the other hand, quantitative risk estimates are needed to perform meaningful analyses to determine whether acceptable levels of risk have been exceeded, and, if so, to choose from among various corrective actions. (7) Although some risks are ubiquitous, others are quite localized; for example, asbestos fibers in drinking water from a large industrial point source of contamination.

A fundamental finding of this study is that a quantitative grasp of risk seldom exists in state and local government. The information that is available to society as a whole is frequently not part of the background of responsible local officials, and the concept of managing risk to reduce ill effects on health and safety is sometimes foreign to local governments which are organized to respond only to crises.

A second important finding is that the different nature of various risks strongly affects the potential role of state and local government. Drinking water introduces a small, difficult to quantify risk affecting all members of the community, having the following characteristics: (1) the hazard is chronic, not catastrophic; (2) the hazard is widespread, not localized, although levels and types of contaminants vary across localities; (3) the hazard is in some instances unknown or undetectable, in other cases not known although visible (e.g., turbidity); (4) substantial, rather than moderate, uncertainty is associated with risk estimates; and (5) management of the hazard conflicts with, rather than augments, the traditional service delivery and public protection functions of local government.

We conclude that all these characteristics tend to diminish the local role in risk management. Chronic risks of low magnitude do not stimulate immediate demands for protection. Risks common to many localities and concentrated in none are not viewed as principally local problems. Hazards eluding easy detection exceed the capacity of local governments to identify or detect them. Highly uncertain risk estimates pose political perils for local officials, and risk management practices impeding or increasing the cost of service delivery may also be perilous for the official. Thus, for the management of the risk from carcinogens and other dangerous contaminations in drinking water, we do not advocate a significant responsibility or changed role for local government. We place a principal responsibility on the federal government for identifying dangerous contaminants and setting "safe" levels. The states should take an active role in overseeing action by local communities, in monitoring for contaminants, and in preventing future contamination, as practical.

Seismically substandard buildings, on the other hand, introduce a risk primarily to an identifiable subset of the total population. At least in Los Angeles, the risk to these individuals is substantially larger than that posed by drinking water to any individual in the same city. Indeed, the risk may be large compared to other accidental risks. In Los Angeles, the city government has employees knowledgeable in the detailed technical aspects of seismic risk, employees who not only understand the situation but are able to formulate possible alternatives and to evaluate (with the assistance of consultants) both the direct costs and the likely benefits (via risk reduction) of various alternatives. Hence, this is a risk which can be identified and evaluated by the local government involved. Furthermore, the responsibility for building safety clearly lies with the local government.

If risks from seismically substandard buildings can and should be managed by Los Angeles, should the same conclusion automatically be drawn for all governments, not only in California, but throughout the United States? If not, what are the factors that might militate

against such risk management? It may be readily ascertainable in many communities that the risk from earthquakes does not require the attention of a risk manager. Conversely, some local communities may need the equivalent of a full-time risk manager to guard their water supplies, contrary to the conclusion of Solomon et al. (1982a). This situation could exist in localities where (1) a single, irreplaceable source of water supply exists; (2) there are identifiable sources of possible water contamination; and (3) there is a nontrivial probability of contamination by these sources. With such a situation it would behoove the local government entity to take the necessary action, unless it was clear that a higher governmental group, say the state, was acting definitively in their behalf on a continuing basis. Thus, one may need to exercise care in generalizing prescriptively from either of the two case studies.

On Policy Alternatives

Improved risk management decision making at the state and local level will depend upon overcoming numerous, interrelated technical, institutional, and cognitive obstacles. Practically speaking, these are inseparable in a policy context. Debates over technical issues, for example, often become a vehicle for introducing wider social concerns about policy. A local demand for banning the transport of nuclear waste through a municipality can simultaneously be a technical, political, and cognitive issue.

The complexity of the problems facing state and local decision makers does not mean that remedial efforts cannot be made to upgrade risk management policy. There must be, however, a broad recognition as to the nature of extant policy, and the way state and local activities fit into the overall framework of risk management.

In trying to formulate possible alternate models of management, we have postulated several constraints which should guide the formulation, as follows (Meyer, 1982): (1) Risk judgments are comparative and comparison entails quantification; (2) risk judgments may vary across localities; (3) risk judgments need legitimacy; (4) risk judgments may need revision in light of information concerning new hazards and new information concerning the riskiness of known hazards; and (5) the costs of obtaining the information needed for risk management judgments can be high and should be distributed equitably.

We then define for purposes of consideration several possible models of risk management, as follows: (1) the existing system, which is largely dominated by the federal government; (2) the "weak" risk manager, in which the existing system is buttressed by strengthening local capacities to utilize professional judgment in managing diverse risks; (3) the network of risk managers, whereby relatively weak offices at the state and local level tie into a network that facilitates sharing of data on hazards, risks, risk acceptance criteria, and risk policies; (4) the "strong" local risk manager who is charged with the full spectrum of risk management activities, from risk identification to policy and implementation; (5) a radical decentralization of risk management, whereby *prima facie* evidence of riskiness above a low threshold compels the source of risk to obtain appropriate risk studies showing the acceptability of the safety of proposed activities before proceeding with them; (6) an incentive system in which the cost of risk is transferred to the one producing the risk; (7) internalization of the cost of risk via a risk tax; and (8) reliance on legal avenues for those who suffer harm.

At the local level, we believe there is merit in studying further the approach involving a network of "weak" risk managers. The basic elements of such a network approach would involve a system of classifying risks, central storage of risk information, means of developing needed information, the maintenance of risk profiles for localities, and risk managers trained in the utilization of the information.

We caution that the network concept is novel and relies upon information technologies not heretofore utilized. Developmental work would be required prior to its implementaton and studies would be needed of the appropriate changes in federal role and policy.

For the states we favor a major role in risk management employing an approach lying somewhere between the "strong risk manager" and the network of "weak risk managers." While the states have some resources to devote to the task and should take a strong leadership role, the overall task of developing methodology, data, and criteria, and of performing complex analyses is too large for any state, and will require a wide variety of assistance from the federal government as well as the benefit of cooperation and the interchange of information among the states.

The usefulness of improved or full liability insurance for attributable risks appears to warrant further examination because, where property rights or liabilities are poorly defined, risk is transferred from the liable party to the public at large.

Baram (1982) has recently discussed a wide variety of alternatives to regulation of managing risks to health, safety, and the environment. These include common law alternatives, private voluntary self-regulation, insurance, and other compensatory plans, and government influence. Baram examines these in the context of three case studies, including that of hazardous waste. Baram finds that alternatives to regulation seem to be most appropriate for deterring risk due to fires, explosions, and poison gas emissions, because the cause and injury effects would be clear in these instances. However, in his opinion, long-term, postclosure dangers of fire, explosion, and poison gas emissions warrant regulation to supplement common law and insurance mechanisms, because of their limitations despite the provision of incentives to responsible practice. Baram concludes that the hazardous waste problem creates certain risks that are too severe in their impacts to leave entirely to non-regulatory devices. Baram does not examine the risk tax as an alternative to rules and regulations, an alternative which may at one and the same time internalize the cost of risk and provide an incentive for the source of risk to reduce the risk in a cost-effective fashion. We recommend that serious study be given to the formulation of pragmatic approaches to a risk tax.

By way of some specific steps which should be of value in advancing the task of risk management, we also recommend the following: (1) the development and use of multiple risk taxonomies to serve as a background information source and as a working tool for an office of risk management to inform state and local officials and to provide a mechanism for discussing alternative approaches with those involved, and (2) the holding of workshops on risk management to inform state and local officials and to provide a mechanism for discussing alternative approaches with those directly involved.

If the network approach is to receive serious consideration, several studies may be appropriate as a next step, including a policy study to identify changes in federal regulations needed for an effective network; an effort to construct alternative models of information systems; and an experimental effort aimed at determining the likely utilization and effectiveness of a risk management information network.

Each state will have its own special risks to consider, as well as its own strengths and its own limitations on resources. One cannot expect to deal with all of those contingencies simultaneously. However, a joint examination of the feasibility and desirability of a network approach by several state and local governmental entities, together with an examination of the implications for a changing federal role, could provide the necessary information for a judgment on whether there is merit in some version of the network alternative to risk management. It seems that studies such as these might best involve groups like the National Conference of State Legislatures and National Governors' Association.

An important finding, which is central to an improvement in local risk management, is the need for introducing quantitative conceptions of risk at the local level, to complement the traditional political and social conceptions. The absence of thinking of risk in quantitative terms, of necessity, limits the adequacy of the information which enters the decision-making process. This must be remedied if an improved approach to risk management at the local level is to be developed. Although we have generally found that many, if not most, governmental bodies at the local level do not deal with quantitative risk concepts or preventive risk management, there are, of course, situations which illustrate the converse condition. For example, a risk management plan has been drawn up for the Port of Long Beach (1981) in accordance with a requirement of the California Coastal Commission. Similarly, it is clear that some agencies of state government do take quantitative approaches to the management of specific risks. For example, in connection with the contamination of water supply wells with trichloroethylene, the Department of Health Services of the State of California drew up quantitative guidelines in 1980 in terms of the excess lifetime cancer risks attributed to various exposure levels.

Nevertheless, even a large state like California has not addressed all risks in this fashion or organized a truly systematic approach to preventive risk management. An equivalent, albeit different, effort should be devoted to the identification, categorization, and measure of the benefits associated with the societal activities which introduce these risks. This is a field in which relatively little solid information exists.

A considerable number of specific issues which require further study has been raised during this project. Seven of these are discussed briefly below:

1. How should state and local governments approach the question "How safe is safe enough?" for those hazards for which they have responsibilty and for which guidance has not been provided by federal regulatory agencies or other recognized authoritative groups? Benefits and societal needs, among other attributes, may enter into a judgment that something is "safe" or "unsafe." Thus, there will not be a unique definition of "safe." Nevertheless, decisions are continually being made by state or local governments which directly involve an imposition of risk on their constituents. And, frequently, by acts of omission, they permit risks later judged to be intolerable to be imposed on their constituents. How should society ascertain whether the upper threshold of acceptable risk is being violated for some of the people? At what point would resources expended to do this exceed the benefit obtained? Are there risks which are flatly unacceptable and which require a mechanism to assure their identification and correction?

2. British law imposes a requirement on owners and operators of technological facilities to keep them as safe as practical. Should there be a similar requirement in the United States, and, if so, how should it be instituted? Would such a requirement provide the appropriate incentives for risk management, or is it limited to "attributable effects"? Is there a workable mechanism which achieves the transfer of the cost of risk from the public to the liable party for nonattributable risks?

3. Is there a mechanism for achieving a more cost-effective expenditure of societal resources committed to risk reduction? Should cost-effective expenditures for risk reduction be a goal of state and local government, or should sociopolitical factors dominate?

4. The safety of the storage of large quantities of hazardous chemicals appears to be the responsibility of local government for the most part. This is largely handled via regulations imposed by the fire and building departments, or their equivalent. Experience in the United States and elsewhere indicates strongly that catastrophic accidents are rarely evaluated in this process, and that the risks to individuals living or working nearby can vary widely and sometimes be quite large. If local governments generally lack the resources and expertise

to regulate adequately the storage of large quantities of hazardous chemicals, what, if anything, should be changed? Should a federal or state approach similar to that under adoption in the United Kingdom be pursued?

5. Are the current federal regulations with regard to the disposal of hazardous wastes and to local sources of ground, water, and air pollution adequate? If not, how should they be changed? If adequate in principle, do they work in practice? What does it take at the state and local levels to assure the necessary compliance?

6. How should limitations on total available societal resources be factored into risk management at the state and local level? Can analysis provide meaningful answers on when further expenditures on direct risk reduction may lead to a net increase in societal risk because of economic or political disruptions? Are such considerations of importance only in a national sense, or do they apply at the state and local level? If so, how?

7. If the state has jurisdiction and responsibility for managing risks that can impact strongly on a local government entity, from the point of view of either health or economics (e.g., the cost of cleanup, or of alternate and expensive facilities such as new wells made necessary because of contamination of the old ones), how should local government assure itself of the adequacy of the steps taken by others on its behalf?

The problems in developing a more systematic and more nearly optimal approach to risk management at the state and local level are difficult, to say the least. Nevertheless, the continuing series of episodes of local ground, air, and water pollution reported frequently in the media are only one piece of evidence that all is not well in this regard. There has been considerable sentiment in the United States House of Representatives for the introduction of a coordinated program for improving and facilitating the use of risk analysis by federal agencies concerned with scientific and technological decisions related to human life, health, and protection of the environment, as evidenced by HR 3441, introduced by Congressmen Ritter of Pennsylvania, Fuqua of Florida, and Brown of California, and passed by the House of Representatives during the 97th Congress. A Congressional examination of the feasibility and usefulness of steps by the federal government to assist the development of improved risk management at the state and local level may warrant consideration.

Appendix: Reports Emanating from Study Entitled "Alternative Risk Management Policies for State and Local Governments"

National Science Foundation Grant PRA 79-10804 (David Okrent, principal investigator).

Final Report, Alternative Risk Management Policies for State and Local Governments	UCLA-ENG-8240
Executive Summary, Alternative Risk Management Policies for State and Local Governments	UCLA-ENG-8241
Risk Management Practices in Local Communities: Five Alternatives, Meyer, M.W. and K.A. Solomor	UCLA-ENG-8242
Management of Risks Associated with Drinking Water at the Local and State Levels, Solomon, K.A., M.W. Meyer, P. Nelson, J. Szabo, and R. Tsai	UCLA-ENG-8243
Risk Management Policy for Earthquake Hazard Reduction, Sarin, R.K.	UCLA-ENG-8244

Classification of Risks, Solomon, K.A., M.W. Meyer, P. Nelson, and J. Szabo — UCLA-ENG-8245

Problems of State and Local Risk Management: An Overview, Bordas, W. — UCLA-ENG-8246

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REFERENCES

Baram, M.S., *Alternatives to Regulation,* Lexington Books, 1982.

Beranek, W., "Chemical Information for the State Governments," *Toxic Substances Journal,* Vol. 1, pp. 61–68, 1979/80.

Bordas, W., "Problems of State and Local Risk Management: An Overview," UCLA-ENG-8246, 1982.

CEQ, *Chemical Hazards to Human Reproduction,* Council on Environmental Quality, January 1981.

Cohen, B.L., "High-Level Waste from Light Water Reactors," *Reviews of Modern Physics,* pp. 1–20, 49(1), 1977.

Doll, Sir Richard, "Strategy for Detection of Cancer Hazards to Man," *Nature,* 265, February 17, 1977.

(EPA, 1973) Environmental Protection Agency, EPA National Env. Research, *Annual Report,* 1973.

(EPA, 1977) Environmental Protection Agency, *National Interim Primary Drinking Water Regulations,* 1977.

(EPA, 1978) Environmental Protection Agency, "Carcinogen Assessment Groups, Primary Report on Population Risk to Ambient Coke Oven Exposure," 1978.

(EPA, 1979a) Environmental Protection Agency, Subtitle C; Resource Conservation and Recovery Act of 1976; Draft Environmental Impact Statement, January 1979.

(EPA, 1979b) Environmental Protection Agency, "National Interim Primary Drinking Water Regulations; Control of Trihalomethanes in Drinking Water; Final Rule," *Federal Register,* Vol. 44, No. 231, November 29, 1979.

(EPA, 1980a) Environmental Protection Agency, *Planning Workshops to Develop Recommendations for a Ground Water Protection Strategy,* Washington, D.C., 1980.

(EPA, 1980b) Environmental Protection Agency, *Federal Register,* 45, 33066–33588, May 19, 1980.

Gabor, T. and T.K. Griffith, "The Assessment of Community Vulnerability to Acute Hazardous Materials Incidents," *Journal of Hazardous Materials,* Vol. 3, pp. 323–333, 1980.

Harris, R.H., T. Page, and N.A. Reiches, "Carcinogenic Hazards of Organic Chemicals in Drinking Water," in *Origins of Human Cancer,* H.D. Hiatt, D. Watson, J.A. Winsten (eds.), Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y., 1977.

Health and Safety Executive, *Canvey: An Investigation of Potential Hazards from Operations in the Canvey Island/Thurrock Area,* London, H.M.S.O., 1978.

Health and Safety Executive, *Canvey, A Second Report,* London, H.M.S.O., 1981.

Kimm, V.J., A.M. Kuzmack, and D.W. Schnare, *The Questionable Value of Cost–Benefit Analysis: The Case of Organic Chemicals in Drinking Water,* EPA, March 1980.

Lord Robens, "Safety and Health at Work," Report of the Committee, (1970–1972), H.M.S.O., London, 1972.

Meyer, M.W., and K.A. Solomon, "Risk Management Practices in Local Communities: Five Alternatives," UCLA-ENG-8242, 1982.

(NAS, 1977) National Academy of Sciences Safe Drinking Water Committee, *Drinking Water and Health,* Washington, D.C., 1977.

(NCHS, 1977) National Center for Health Statistics, *Vital Statistics of the United States,* U.S. Department of Health, Education and Welfare, 1977.

Okrent, D., *A Survey of Expert Opinions on Low-Probability Earthquakes,* School of Engineering and Applied Science, University of California, Los Angeles, UCLA-ENG-7515, 1975.

Okrent, D., *Alternative Risk Management Policies for State and Local Governments,* UCLA-ENG-8240, June 1982.

Page, T., R.H. Harris, and S.S. Epstein, "Drinking Water and Cancer Mortality in Louisiana," *Science,* 139, pp. 55–77, 1976.

Port of Long Beach, "Risk Management Plan: Amendment to the Certified Master Plan," 1981.

Sarin, R.K., "Risk Management Policy for Earthquakes Hazard Reduction," UCLA-ENG-8244, 1982.

Sharma, R.K. et al., *Health and Environmental Effects Document for Batteries,* ANL

ES-105, prepared for the Office of Health and Environmental Research, U.S. Department of Energy, 1980.

Solomon, K. et al., *On Risks from the Storage of Hazardous Chemicals,* Chemical, Nuclear and Thermal Engineering Department, University of California, Los Angeles, UCLA-ENG-76125, December 1976.

Solomon, K.A., M.W. Meyer, P. Nelson, J. Szabo, and R. Tsai, "Management of Risks Associated with Drinking Water at the Local and State Levels," UCLA-ENG-8243, 1982a.

Solomon, K.A., M.W. Meyer, P. Nelson, and J. Szabo, "Classification of Risks," UCLA-ENG-8245, 1982b.

Whittaker, H. and J. Ketchum, "An Approach to Hazard Analysis in Comprehensive Emergency Management" (Draft), Center for Policy Research, Office of State Services, National Governors' Association, 1982.

16

Institutional Mechanisms for Converting Sporadic Agency Decisions into Systematic Risk Management Strategies

OSHA, the Supreme Court, and the Court of Appeals for the District of Columbia

Arthur Oleinick, Lynn D. Disney, and Karen S. East

INTRODUCTION AND PROBLEM STATEMENT

The explosive growth of federal responsibility for risk management in health and safety areas is generally well known. Table 1 illustrates the broad statutory responsibilities of three major federal agencies,[1] the Occupational Safety and Health Administration (OSHA), the Consumer Product Safety Commission (CPSC), and the Environment Protection Agency (EPA), none of which existed before 1970. An estimate[2] of the work load imposed by OSHA, CPSC, and EPA on the federal appellate judiciary[3] is given in Table 2. In the case of the Courts of Appeal, no less than 1.3% of all cases with a published opinion involved OSHA, CPSC, or EPA. In view of the enormous controversy surrounding the passage of the laws administered by these agencies, it is perhaps not surprising that these three agencies would account for such a comparatively large share of the appellate work load so soon after their creation. Moreover, the percentages by themselves underestimate the amount of work involved because, at least in the cases involving challenges to standards, the courts have had to review massive[4] records containing highly technical information from the fields of medicine, toxicology, engineering, and economics. Quite clearly, risk management problems have had a major impact on both the executive and judicial branches.

In general, the agencies indicated have implemented their statutory responsibiilties by enacting risk management strategies through the informal standard or rule-making process,[5] or through a functional equivalent,[6] and a substantial number of these standards have under-

Arthur Oleinick, Lynn D. Disney, and Karen S. East • Department of Environmental and Occupational Health, University of Michigan, Ann Arbor, Michigan 48109.

Table 1. Selected Federal Agencies and Their Health and Safety Risk Management Responsibilities[a]

Agency	Year created	Major statute(s) administered	U.S. code reference	Subject matter covered
Occupational Safety and Health Administration (OSHA)	1970	Occupational Safety and Health Act	29/651	Workplace safety and health
Consumer Product Safety Commission (CPSC)	1972	Consumer Product Safety Act	15/2051	Dangerous consumer products
		Federal Hazardous Substances Act	15/1261	"Toxic" household products
		Poison Prevention Packaging Act	15/1471	Packaging of products dangerous to children
		Flammable Fabrics Act	15/1191	Flammability standards
		Lead-Based Paint Poison Prevention Act	42/4801	Use of lead paint in federally assisted housing
Environmental Protection Agency (EPA)	1970	Clean Air Act	42/7401	Hazardous air pollutants
		Federal Water Pollution Control Act	33/1251	Toxic water pollutants
		Safe Drinking Water Act	42/300F	Drinking Water contaminants
		Noise Control Act	42/4901	Noise abatement
		Federal Insecticide, Fungicide, and Rodenticide Act	7/136	Pesticides
		Toxic Substances Control Act	15/2601	Allows evaluation of existing chemicals and requires evaluation of new chemicals
		Resource Conservation and Recovery Act	42/6901	Hazardous wastes
		Comprehensive Environmental Response, Compensation, and Liability Act	42/9601	Funds federal response to hazardous materials release

[a] Adapted from *EPA Journal*, July–August 1979, @15

Table 2. Distribution of Total Agency and Total Appeals Court Cases by Circuit, 1971–1983[a]

Circuit	Total *N* agency[b] cases, 1971–1983	Total *n* circuit cases 1971–1983[c]	*N* Agency cases per 1,000 circuit cases
1	46	2,779	17
2	75	7,565	10
3	112	6,459	17
4	61	4,130	15
5	148	19,777	7
6	72	6,851	11
7	76	8,257	9
8	70	6,714	10
9	116	9,527	12
10	60	3,605	17
D.C.	210	3,394	62
Total	1,046	79,058	13

[a] Chi-square test for independence: all circuits, $\chi^2_{[10]} = 1213, p < 0.001$, significant; excluding D.C. circuit, $\chi^2_{[9]} = 85.5, p < 0.001$, significant. Chi-square values are based upon mutually exclusive frequency distributions.

[b] Agency cases were identified by LEXIS search on name of the agency or an equivalent in the case title and either agency name—Environmental Protection Agency (EPA), Occupational Safety and Health Administration (OSHA), or Consumer Product Safety Commission (CPSC)—or the enabling statute appearing in the opinion.

[c] Total number of circuit cases were identified by a LEXIS search for an F.2d citation by circuit. The resultant numbers estimate the number of published opinions, including a small proportion officially designated as "Not for Publication" by the circuits.

gone judicial review. Sufficient experience has now accumulated so that it seems appropriate to investigate the extent to which the judiciary's contribution to federal health and safety risk management decisions is systematic[7] and whether it can be collected and classified in a catalog in ways which would be useful to legal and science policy makers. Stated differently, an important research question is the extent and manner in which prior court decisions contribute to a cognizable, coherent federal risk management scheme.

The present effort to identify such a judicial contribution to a coherent federal risk management scheme focuses on that subgroup of court decisions that involve some aspect of the standard-setting process, rather than on all opinions involving an agency. This focus was selected because rule making involves risk management decisions that are the product of the broadest technical input and have the widest impact. As Table 3 indicates, between 100 and 300 Circuit Court and 8 Supreme Court cases from the three agencies have been decided which involve one or more aspects of risk management arising during the standard- or rule-making process.

While concentration on court decisions obviously provides a limited perspective on federal risk management practice, there are important reasons for beginning with such material. First, the judicial review process, which is itself highly structured, provides a ready-made classification scheme for the various problem types encountered in a disputed risk management decision which facilitates, rather than hinders, their consideration. Thus, all disputed elements in an agency decision are recast by the legal process into one of five types of questions[8] when they are presented to the court for resolution. Disputes are characterized either as legal policy questions (constitutional issues[9] or issues involving intra- or interbranch relationships[10]); legal questions (the scope and/or meaning of statutory terms[11]); legislative fact or policy questions ("policy judgments where no factual certainties exist or facts alone do not provide the answer. . . .[12]); fact questions; or procedural questions.[13]

Table 3. Standard-Setting Cases involving Risk Management Disputes,[a] Total Agency Cases, and Prevalence Rates per 1000 Supreme Court and Circuit Court Cases for OSHA, CPSC, and EPA, Fiscal Years 1971–1982

Study cases criteria[g]	OSHA[b] Standards Regulations Emergency temporary standards	CPSC[c] Standards Regulations (including banned hazardous substances)	FIFRA[d] Registration: Cancellation Suspension Emergency orders	TOSCA[e] Standards	Total[f]	Total	Per 1000 cases
Number of risk management cases (June 1970–July 1982)							
Supreme Court	3	0	0	0	5[h]	8	2
Court of Appeals	31	16	14	3	57–302[i]	121–366	1–4
Number of total agency cases (June 1970–July 1982)							
Supreme Court[j]	5	2	0	0	22	29	8[k]
Court of Appeals	330	28	29	4	630	980	12

[a] Though generic risk management disputes arise occasionally in the course of adjudication, cases involving various risk management issues in rule making were initially selected for analysis because rule making involves decision making with the broadest public input and potential impact.
[b] 29 U.S.C. Sect. 651, *et seq.*
[c] 15 U.S.C. Sect. 2051, 15 U.S.C. Sect. 1261, 15 U.S.C. Sect. 1191, *et seq.*
[d] 7 U.S.C. Sect. 135, *et seq.*
[e] 15 U.S.C. Sect. 2601, *et seq.*
[f] Includes TOSCA and FIFRA, plus:
Clean Air Act 42 U.S.C. Sect. 7401, *et seq.*
Federal Water Pollution Control Act 33 U.S.C. Sect. 1251, *et seq.*
Noise Control Act 42 U.S.C. Sect. 4901, *et seq.*
Resource Conservation and Recovery Act 42 U.S.C. Sect. 6901, *et seq.*
Safe Drinking Water Act 42 U.S.C. Sect. 300F, *et seq.*
[g] An attempt was made to include any case involving a challenge to the rule-making activity indicated e.g., initiating the process, challenges to statutory authority (see figure 1).
[h] All Supreme Court cases were reviewed for inclusion.
[i] Estimated value based upon fractions for CPSC (48% of all agency cases involved risk management as defined) and OSHA (9% of all agency cases involved risk management as defined).
[j] Includes summary judgements as well as cases with full text opinions (cases decided on the merits).
[k] Denominator consists of all appellate docket cases for term 1970–1981. Taken from *Harvard Law Review*.

Once classified in this fashion, the published opinions indicate that the questions are resolved, some would argue that they are rationalized,[14] by resort to one or more judicial analytic processes: *stare decisis*[15] or the application of legal principles derived from precedents or previously decided cases, canons, or rules of statutory construction[16] and, in the case of legislative fact or fact questions, by reliance on the "substantial evidence" or "arbitrary, capricious, . . . abuse of discretion" review standards.[17] The identification of question type and the analytic processes used to decide the question comprise what is referred to as structural analysis in this paper.

The usual interactions between question type and analytic process are shown in Figure 1. In the two-dimensional judicial decision matrix created by the type of question/judicial analytic process classification scheme, each question decided by the courts serves to define the boundaries of acceptable risk management decisions for that particular statute. A systematic judicial contribution to federal health and safety risk management policy, either intra- or interagency (to the extent permitted by the various statutes), would then be char-

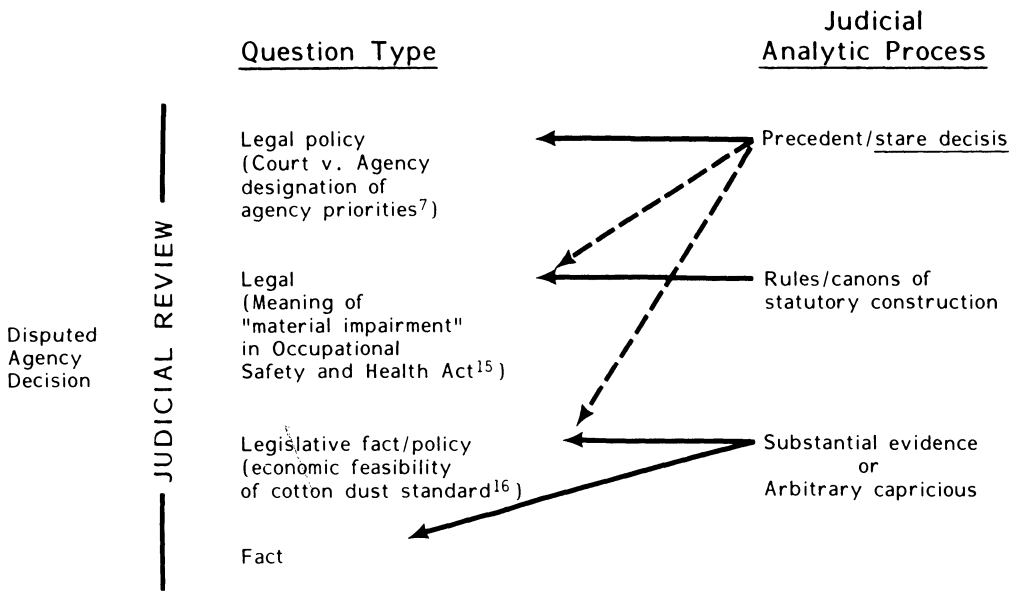

Figure 1. Judicial analytic process by question type: judicial review of federal agency risk management decisions.

acterized by the production of consistent decisions in the various Circuits for closely analogous disputes through the application of the various judicial analytic processes.

Moreover, an understanding of the principles governing the resolution of disputes in the legal system is essential for understanding even those standards and other related agency risk management actions which are never challenged legally. The legal perspective pervades the standards' development process in the person of standards lawyers who often function as the major repository of each agency's institutional memory.[18] These lawyers ensure that current agency decisions are consistent with prior court mandates, though such lawyers generally lack formal scientific training and may miss the full scientific implications of prior decisions. The current diminished federal regulatory role, coupled with a reduction in agency legal personnel as part of a decrease in government employment, could ultimately lead to a loss of such institutional memory. Reports such as the present one ensure the continued availability of the information and supplement the agency lawyer's role by organizing the material from both the scientist's and lawyer's perspective.

Another reason for analyzing federal court decisions is the opportunity it provides to undertake simultaneously an empirical study of the determinants or correlates of judicial decision making; that is, the relationships between type of legal question and judicial analytic process. Such empirical studies of the judicial decision-making process comprised the central element of the realist mode of jurisprudence, a mode which flourished during the period 1920–1940[19] and then declined, either because the criticism that it lacked "pervasive moral ideals"[20] was sufficient to dissuade a new generation of legal scholars or, perhaps, because empirical methodology has never been effectively integrated into law school curricula. The current dearth of empirical legal studies[21] is incomprehensible from a modern scientific perspective. In any event, an additional characteristic of a systematic judicial contribution to federal health and safety risk management policy might include, not only consistent outcomes for similar disputes, but also consistent relationships between judicial process and outcome.

Structural analysis of the type just discussed is now complete for 9 of the 46 study

population cases identified in a prototypic risk management agency, the Occupational Safety and Health Administration. This report presents results for cases from the Supreme Court and the Court of Appeals for the District of Columbia, and is focused on their review of the health risk assessment component of challenged agency risk management decisions. Specifically, data in this report address the following issues: (1) the type of health risks falling within OSHA's statutory authority, (2) the type of evidence characterized as "substantial evidence" supporting an agency finding or conclusion, (3) the statutory construction techniques employed to determine whether a health risk falls within OSHA's authority, and (4) the nature of the judges' review of scientific evidence.

JUDICIAL REVIEW CRITERIA FOR SCIENCE-BASED DETERMINATIONS IN AGENCY RULE MAKING[22]

The essential characteristic of science-based determinations which underlie agency decisions regarding health standards is that, invariably, one or more of those determinations involves an issue on the "frontiers of science"[23] for which proof, in the usual sense, is unavailable. Scientific uncertainty may arise because the issue is one which science is incapable of answering though the question is framed in scientific terms (a transscience question), there are insufficient data or inadequate studies available at the time of decision, there are varying interpretations of what the data actually show, or there is disagreement regarding the inferences that the data will support.[24] Where, to use the powerful imagery of Justice Clark, the "factual finger points [but] does not conclude . . ."[25] and the legislature has directed an agency such as OSHA not to await definitive studies,[26] the agency must make decisions which are "essentially legislative"[27] in character and not purely scientific.

Though initially disputed,[28] it is now well established that the substantial evidence review standard governs the judicial review of both factual and legislative-fact determinations which underlie a health standard promulgated by OSHA.[29] In those cases where the agency has not promulgated a standard, disputed health risk determinations are governed by the arbitrary/capricious review standard.[30] Some judges have indicated that these two standards of review do "tend to converge,"[31] while J. Marshall has indicated that the substantial evidence test requires review "more stringent"[32] than contemplated for the arbitrary/capricious standard.

Nevertheless, in spite of J. Marshall's admonition, the historical development of the meaning of these two review standards strongly indicates that the criteria for the two standards mandate very similar reviews of agency fact or legislative-fact determinations. In the lead case construing the substantial evidence test,[33] J. Frankfurter indicated that the review standard requires the court to review all the evidence in the record, not just that which supports the agency position,[34] to assure that the agency's decision is reasonable.[35] In fulfilling these functions, courts were cautioned not to displace the "[agency's] choice between two fairly conflicting views, even though the court would justifiably have made a different choice. . . ."[36]

In comparison, the lead case construing the arbitrary/capricious review standard[37] indicates that agency action continues to enjoy a presumption of validity[38] and requires reviewing courts to conduct a "searching and careful" inquiry into the facts but not to "substitute its judgment for that of the agency."[39] In a subsequent case,[40] the Court indicated that the arbitrary/capricious review standard requires affirmance if the agency has a rational basis for its decision. In addition to the obvious similarities in court function implied by the words

reasonable and *rational,* the courts have treated the review criteria as interchangeable by citing cases decided under one standard to determine the scope of review under the other standard.[41] It seems established that there is but a single federal judicial review standard for disputed science-based fact and legislative-fact determinations involved in health standards. Moreover, no systematic empirical studies establish that the courts have more than one review standard.

Within the broad strictures laid down by the Supreme Court, the Circuits have implemented this policy by requiring "a careful identification by [OSHA] . . . of the reasons why [it] chooses to follow one course rather than another."[42] In a later case, the District of Columbia Circuit indicated that the agency's reasons would have "to identify relevant factual evidence, to explain the logic and the policies underlying any legislative choice, to state candidly any assumptions on which it relies, and to present its reasons for rejecting significant contrary evidence and argument."[43] However, the requirement that agencies fully articulate the reasons for their decision does not specify the level of complexity at which such reasons should be specified nor the level at which judges will scrutinize the agency's work.

It is precisely over this issue that the judges of the District of Columbia Circuit have "engaged in a lively debate. . ."[44] On one end of the spectrum of possible solutions is senior Circuit Judge Bazelon's suggestion that the courts' proper role in review of agency fact-finding decisions is "to monitor the agency's decisionmaking process—to stand outside both the expert and the political debate and to assure that all the issues are thoroughly ventilated."[45] On the other end of the spectrum is the late Circuit Judge Leventhal's belief that

> [O]ur present system of review assumes judges will acquire whatever technical knowledge is necessary as background for decision of the legal questions . . . Congress . . . has proceeded on the assumption that we can both have the important values served by generalist judges and rely on them to acquire whatever technical background is necessary.[46]

Judge Wright appears to be closer to Judge Leventhal than Judge Bazelon in the following quotation:

> There is no inconsistency between the deferential standard of review and the requirement that the reviewing court involve itself in even the most complex evidentiary matters; rather, the two indicia of arbitrary and capricious review stand in careful balance. The close scrutiny of the evidence is intended to educate the court. It must understand enough about the problem confronting the agency to comprehend the meaning of the evidence relied upon and the evidence discarded; the questions addressed by the agency and those by-passed; the choices open to the agency and those made. The more technical the case, the more intensive must be the court's effort to understand the evidence, for without an appropriate understanding of the case before it the court cannot properly perform its appellate function. But that function must be performed with conscientious awareness of its limited nature. The enforced education into the intricacies of the problem before the agency is not designed to enable the court to become a superagency that can supplant the agency's expert decision-maker. To the contrary, the court must give due deference to the agency's ability to rely on its own developed expertise. The immersion in the evidence is designed solely to enable the court to determine whether the agency decision was rational and based on consideration of the relevant factors.[47] [Citations omitted].

Interestingly, McGarity[48] has noted that, though Judges Bazelon and Leventhal disagreed on the standard of review, their votes on cases on which they have served on the same panel have been identical except that their reasons differ, that is, Judge Bazelon finding procedural error when Judge Leventhal found substantive defects, and the reverse.

The present report provides data illustrating the current practice of selected courts in implementing their duty to determine whether OSHA has provided substantial evidence for its findings or conclusions.

CURRENT RESEARCH DESIGN

The study employed a three-level, full-text search of words and phrases[49] of the LEXIS federal case library to identify the study cases for OSHA. The search strategy is given by level in Part A of Table 4. In addition to the cases identified in level 3, all the remaining cases in level 2 and a 10% sample of cases in level 1 were screened for appropriateness. Review of the 47 level 3 cases provided 33 cases to the final study population of 46 cases. Six additional cases were found in levels 1 and 2. An additional 7 cases identified from other sources[50] complete the 46 case study population.

Cases are included in the final study population which contain one or more risk management disputes arising in the course of the standard-setting process. Risk management disputes have been identified to date in the following stages in the development of a rule, including activities which precede and follow the actual informal standard-setting process itself: (1) initiation of agency risk management activity by petition; (2) issues in making a rule: determination of scope of risk management authority, relationship between type of rule employed and scope of risk management authority, risk control issues, emergency risk control; (3) modifying existing risk management decisions: correcting ministerial errors; interpretation; and (4) challenges to agency risk management decisions in the adjudicatory framework. Risk management disputes are seen to occur both before and after the actual standard-setting process itself. The project's focus on the entire range of the standard or rule-making experience of the agency reflects the fact that risk management decisions with the broadest impact occur throughout the process.

To analyze each case, all types of legal questions in the opinion, excluding purely procedural questions, have been identified and linked to the analytic processes ostensibly relied upon in the opinion to resolve them. In addition, the scientific materials cited by the

Table 4. LEXIS Search Strategy for Study Population Cases

A.	Search strategy		
	Reference population: All district court, court of appeals and Supreme Court cases		
	Level 1		
	Identify all OSHA and Occupational Safety and Health Review Commission cases and exclude Federal Mine Safety and Health cases.		
	430 cases		
	Level 2		
	Identify cases that discuss standard setting, using a variety of synonyms and the sections of the act conferring standard-setting authority.		
	80 cases		
	Level 3		
	Eliminate all cases which are challenges to Review Commission decisions.		
	47 cases		
B.	Evaluation of effectiveness search strategy at Level 3		
	Sensitivity[a]	= 33/42[b]	= 78.6%
	Specificity[c]	= 374/388	= 96.4%
	Positive predictive accuracy[d]	= 33/47	= 70.2%

[a] Defined as percent of study cases correctly identified by LEXIS search.
[b] Total study population (N = 46), less challenges in the course of adjudication, *Louisiana Chemical Association v. Bingham* (DC WD Louisiana, 11/5/82) and *Auchter v. Public Citizen Health Research Group* (D.C. Cir., 3/15/83) [decided after search was conducted] (N = 4).
[c] Defined as percent of cases correctly eliminated by LEXIS search.
[d] Defined as percent of cases identified by LEXIS search that are in study population.

judges in their determination of whether substantial evidence supports the findings have been tabulated. The intensity of the judges' scrutiny of the evidence has been determined by comparing the judicial, agency, and party descriptions of the data. The current report includes data from all three relevant Supreme Court cases and the six of eight cases from the District of Columbia Circuit, which included a challenge to the agency's decision on scientific, technical, or economic grounds. Where indicated, nonsystematic material from the Fifth Circuit is footnoted to demonstrate divergent Circuit positions.

Since the search strategy developed for OSHA was meant to serve as a prototype for identifying cases involving comparable standard-setting disputes in other agencies,[51] an evaluation of the methodology, using standard concepts and terminology from medical screening tests and information retrieval studies,[52] was employed. A complete report of the evaluation of the search strategy is in progress.[53] The summary evaluation statistics are shown in Part B of Table 4. Search sensitivity, defined as the percent of study cases correctly identified by the third stage of the LEXIS search, is 78.6%; that is, slightly more than 20% of the final study population was missed by the computer search. Since one of these cases was a Supreme Court case,[54] which did not include the name of OSHA or an appropriate synonym anywhere in the file title, it is mandatory that knowledgeable professionals continue to supervise the design and use of computerized legal searches. The positive predictive accuracy of 70.2% for third-stage screening indicates that somewhat less than a third of cases screened were not suitable for the final population. Though these evaluative indices compare favorably with others reported in the literature,[55] selecting a search strategy involving only the first two levels for future OSHA searches would likely increase sensitivity (to 90% in the present example) without unduly burdening study personnel.

RESULTS

The nine cases involving the Occupational Safety and Health Act which have been fully analyzed and tabulated to date contain 82 disputes—10 legal policy, 45 legal, and 27 legislative fact questions. From this group, disputes which involve some aspect of health risk determination[56] or decisions of whether to initiate a regulatory program when presented with an asserted actual or potential occupational health risk have been collected and form the basis of this report.

Substantive Results: Scope of Statutory Coverage of Health Risks

Table 5 lists the statutory terms which determine whether a health risk is within the act's coverage and whether the agency need undertake to control the problem. The statutory terms are also cross-referenced to the scientific contexts which precipitated the legal disputes.

In *IUD v. API*,[57] a plurality of four invalidated[58] OSHA's decision to lower the permissible exposure limit of benzene on the grounds that the agency had failed to make the findings required by the statute. The plurality held that "before [OSHA] can promulgate any permanent health or safety standard, [OSHA] is required to make a threshold finding that a place of employment is unsafe—in the sense that significant risks are present and can be eliminated or lessened by a change in practices."[59] The Court carefully pointed out that "safe" is not the equivalent of "risk-free"[60] and that the agency's precise burden is "to show, on the basis of substantial evidence, that it is at least more likely than not that . . . exposure . . . presents a significant risk of material health impairment."[61]

Even though the significant risk requirement was actually rejected in *IUD v. API*[62] by a five-person majority on the Court,[63] the Court appears to have affirmed its continuing vitality in its subsequent cases involving OSHA.[64] Moreover, various Circuits have also treated the significant risk requirement as controlling.[65]

The important issues from the science policy maker's perspective are the Court's perceptions of the meanings to be given the terms, *significant risk, unsafe,* and *material impairment.* Both the plurality and dissent clearly indicated that the "judgment of whether that risk is tolerable"[66] is for the agency "in the first instance."[67] Though the plurality did not define the term, it did provide some insight into its perceptions of significant risk by several illustrations. At the high risk end of the risk spectrum, the plurality labeled the diseases cited in the congressional hearings, as many as 30% of workers in certain textile operations suffering from a disabling lung disease and the estimated 20–50,000 workers who have or would develop asbestos-related diseases, as unquestionably significant.[68] In still another example, the plurality (less J. Powell) indicated that a hypothetical mortality risk of 2% from occupational exposure to benzene in gasoline vapors would be one that a

Table 5. Is the Health Risk within the Statutory Mandate: Substantive and Structural Analysis of Questions of Law—Selected Court Holdings in OSHA Cases (Supreme Court and Court of Appeals, District of Columbia)

Legal questions[a]	Related scientific questions	Holding[b,c]	Structural analysis types of statutory construction techniques[d]	
			Statute-bound	Non-statute-bound
I. Statutory authority to control health risk				
A. Defining the scope of risk management:				
I. Reasonably necessary threshold (nonemergencies)				
1. Defining the threshold of risk required to regulate significant risks	Health risk:			
i. 652(8) and 655(b)(5)	Clinical and subclinical effects	Expansive[h1] (2/3)	16(1)	0
ii. 652(8) and 655(b)5	Clinical effects	Restrictive[e1] (4/9)	3,4,6,8	0
iii. 655(b)(5)	Clinical and subclinical effects	Expansive[e2] (4/9)	3,4(2),6,7	13(1)
B. Defining the scope of risk management:	Health risk:			
II. Meaning of material Impairment				
i. 655(b)5	Biochemical changes	Expansive[h1] (2/3)	6	16(2)
ii. 651(b) and 655(b)(5)	Acute disease	Expansive[i] (3/3)	6	10

(*continued*)

Table 5. (continued)

Legal questions[a]	Related scientific questions	Holding[b,c]	Structural analysis types of statutory construction techniques[d]	
			Statute-bound	Non-statute-bound
C. Proving health risk				
1. Best available evidence				
i. 655(b)(5)	Inconclusive studies	Expansive[h1] (2/3)	0	16(1)
ii. *Id.*	Modeling assumptions	Expansive[h1] (2/3)	0	0
iii. 655(b)(5) and (f)	Modeling assumptions	Expansive[e1] (4/9)	14, 16(2)	0
iv. 655(b)(5)	Expert opinion	Expansive[e1,2] (8/9)	3,6	14, 11(1)
v. *id.*	Predicted value tables	Expansive[i] (3/3)	0	0
2. Permissible inference				
i. 655(b)(5) and (f)	Data relevance	Expansive[h1] (2/3)	0	11
ii. *id.*	Data relevance	Expansive[i] (3/3)	0	11(1)
D. Setting agency priorities				
i. 655(g)	Health risk (carcinogenicity)	Expansive[f] (3/3) Restrictive[f] (3/3)	16(2) 3	0 11(2), 10
ii. 655(b) and (g)	Health risk (field sanitation)	Expansive[g] (3/3)	3	0

[a] Section numbers refer to 29 U.S.C. 651, *et seq.* Most recent cases first in each section.
[b] Numbers in parentheses indicate: (vote/judicial panel).
[c] Expansive-agency action upheld. Restrictive-agency action overturned.
[d] 1. Narrow by construction
2. Residual executive authority
3. Literal interpretation
4. Intrinsic aids
5. Statutory scheme
6. Extrinsic aids
7. Legislative intent
8. Contemporaneous construction
9. Administrative regulation
10. Statutory purpose/policy
11. Reference to related statutes
12. Reasonable interpretation
13. Remedial legislation
14. Judicial notice
15. Extralegal indicia
16. Prior construction
[e] I.U.D. v. A.P.I., 448 U.S. 607 (1980).
1. Plurality opinion, written by J. Stevens.
2. Dissenting opinion, written by J. Marshall.
[f] Auchter v. Public Citizen Health Research Group (PCHRG), 702 F.2d 1150 (DC Cir., 1983).
[g] National Congress of Hispanic American Citizens v. Usery, 554 F.2d 1196 (DC Cir., 1977).
National Congress of Hispanic American Citizens v. Marshall, 626 F. 2d 882 (DC Cir., 1979).
[h] U.S. Steelworkers v. Marshall, 647 F.2d 1189 (DC Cir., 1980), *cert. denied,* Lead Industries Assn., Inc. v. Donovan, 453 U.S. 913 (1981).
1. Majority opinion, written by J. Skelly Wright.
2. Dissenting opinion, written by J. MacKinnon.
[i] A.F.L. v. Marshall, 617 F.2d 636 (DC Cir., 1979), *aff'd,* in substantial part, *sub nom* American Textile Manufacturers Institute v. Donovan, 425 U.S. 490 (1981).

reasonable person might well consider significant and, on the low risk side, a hypothetical mortality risk of cancer of one in a billion from drinking chlorinated water would be clearly insignificant under the OSHA language.[69] Also on the low risk side, the plurality concluded that the risks associated with everyday tasks such as driving a car or breathing city air do not make a work place unsafe and subject to regulaton.[70] Presumably, well-substantiated risks at the higher levels noted would pass judicial scrutiny.[70a]

The plurality requires that "a risk from a toxic substance be quantified sufficiently to enable [OSHA] to characterize it as significant in an understandable way"[71] but the agency retains broad discretion to select the particular analyses to establish the risk. Risk need not be established with "absolute scientific certainty."[72] The agency may employ models involving "conservative assumptions" as long as those assumptions are supported by "reputable scientific thought"[73] and the agency may use animal-to-man and high-to-low dose extrapolations to establish that a risk is significant.[74] Both plurality[75] and dissent[76] opinions permit proof by expert opinion, though the former opinion permits such proof only if the agency establishes that "reasonable quantification cannot be accomplished by any known methods."[77] In a later case, Judge Wright also concluded that the agency need not provide "absolutely conclusive" evidence of risk but that "the [agency's] decision may be fully supportable if it is based . . . on the inconclusive but suggestive results of numerous studies"[78] and that the court would defer to the agency's judgment where both sides had "equally respectable evidence."[79]

In contrast to the significant risk issue, which was thoroughly ventilated, none of the opinions in *IUD v. API*[80] considered the scope of the term *material impairment,* perhaps because of its obvious coverage of leukemia. However, in a footnote in its next OSHA case, *ATMI v. Donovan,*[81] the majority approved the agency's position that the early acute reversible pulmonary function decreases of byssinosis, the lung disorder produced by cotton-dust exposure which is characterized by chronic irreversible lung changes in its advanced stages (a so-called continuum disease[82]), were "significant health effects in themselves. . . ."[83] The Court's separate discussion of risk assessment indicates that the Court had material impairment in mind when it referred to the acute stages of byssinosis by its use of the phrase "significant health effect."[84]

A still more expansive view of the term *material impairment* is provided by Judge Wright's conclusion in *USWA v. Marshall*[85] that OSHA may select a blood-lead level target which prevents clinical disease because it prevents the preceding stage, subclinical effects; that is, effects which are not observable overtly.[86] Judge Wright characterized such subclinical effects as representing "patho[physio]logical change (closely associated with disease but perhaps not disease in itself) . . ."[87] and observed that they precede, but are on a continuum with, morbidity. In his view, substantial evidence for any one of the four observed subclinical effects would support the standards selection of a blood-lead level target.[88]

Two of the subclinical effects—inhibition of heme synthesis and decreased nerve conduction velocity—clearly represent examples of pathophysiological change since no clinical effects on the red blood cell[89] or the nerve cell synthesis[90] had been documented at the blood-lead level target chosen. The absence of any detectable clinical or pathological[91] change thus widens the concept of material impairment beyond that included by the range acute reversible symptoms to malignancy.[92]

At any stage in the collection and assessment of health risk information, OSHA has the option of managing an identified risk in one of two ways through the standard-setting process. If, rather than a significant risk, there is a "grave danger" of material impairment, connoting a more immediate danger, then OSHA must issue an immediately effective emer-

gency temporary standard and must begin work immediately on a permanent standard.[93] If, on the other hand, the agency decides to issue a permanent standard, then the act provides that the agency consider the "urgency of the need for mandatory safety and health standards"[94] in assigning a priority to the problem and allocating agency resources. The agency's failure to choose or complete either alternative presents the courts with a sensitive legal policy question of whether they should preempt the agency's authority and make the required decisions. The District of Columbia Circuit has grappled with these problems of choosing strategies and setting agency priorities in three cases.

In *Auchter v. Public Citizen Health Research Group,*[95] the court concluded that the District Court[96] had impermissibly substituted its evaluation for that of OSHA[97] and reversed the lower court's order directing the issuance of an emergency temporary standard for ethylene oxide. It refused to compel a finding of "grave danger" even though some workers were exposed to dangerous levels because there was an absence of precise exposure information with which to reject the agency's reliance on an average exposure level which was below the levels for which a carcinogenic effect had been reported. Nevertheless, it concluded, on the same evidence, that the unknown number of workers exposed to levels between the average exposure and current PEL faced a "significant risk of grave danger"[98] due to the chemical's mutagenic and carcinogenic properties. It held that the agency had "unreasonably delayed"[99] agency action by its desultory conduct of the matter and ordered expedited rule making. The order required the agency to issue a proposed rule within 30 days of the decision and anticipated the preparation of a final rule within one year's time of the decision.[100] The court did qualify its decision to intervene by noting that it had determined that the three issues identified as having a higher agency priority did not "approach in urgency" the need for an ethylene oxide standard and that no compelling agency explanation for the proposed delay of three years from the Advance Notice of Proposed Rule Making to final rule had been forthcoming.[101]

In the sequence of five cases involving the National Congress of Hispanic-American Citizens,[102] the Circuit explored the conditions under which the judiciary would intervene to assume control of the priority scheme for setting permanent standards. This series of cases involved the eight-year legal effort of the plaintiff association to obtain a permanent OSHA standard requiring lavatory facilities in the field for farm workers. In *Hispanic II,* Justice Clark held for the Court that the statutory time tables governing standards development[103] were modified at many points in the statute,[104] preserving the "traditional agency discretion to alter priorities and defer action due to legitimate statutory considerations . . . so long as (the agency's) discretion is honestly and fairly exercised."[105] In its second consideration of the case, *Hispanic IV,* Judge Leventhal found that the District Court had substituted its judgment for that of the agency[106] and once again reversed.[107] OSHA's good faith was found established by the agency's record of promulgated standards covering many significant hazards.[108] The Court also found that the prioritizing scheme employed by the agency which had given higher priority to 15 health and 18 safety standards was rational.[109] The opinion did impose on OSHA the requirement that it continually provide estimated completion dates for standards already under way, including standards with low priority such as the field sanitation standard.[110]

In addition to the statutory provisions providing for an emergency temporary standard response to a grave danger, the Supreme Court has upheld the agency's authority to promulgate a regulation that permits individual workers to refuse unsafe work under a rather narrow set of circumstances. In *Whirlpool v. Marshall,*[111] a unanimous Court determined that a worker may refuse unsafe work, without fear of reprimand, if two conditions are met:

(1) The employee is ordered by his employer to work under conditions that the employee reasonably believes poses an imminent risk of death or serious bodily injury; and (2) the employee has reason to believe that there is not sufficient time or opportunity either to seek effective redress from his employer or to apprise OSHA of the danger.[112] The facts of the case involved the imminent risk posed by a dangerously weakened safety net which had earlier caused a worker's death and the subsequent refusal to work on such a net. However, the Court's expectation that "few employees" would face such a dilemma[113] renders problematic the application of *Whirlpool's* "self-help" risk management strategy to any but the most imminent of health risks.

Substantive Results: Substantial Evidence for Health Risk Determinations

Table 6 collects the examples of health risk determinations reviewed for substantial evidence in the nine cases of the current report. The examples are considered together in an attempt to identify the common scientific elements which characterize health risk determinations found to have a basis in substantial evidence. The contents of the table provide concrete examples of what the judges are referring to when they require that the agencies rely on "reputable scientific thought,"[114] "inconclusive but suggestive results of numerous studies,"[115] and "respectable evidence."[116] Obviously, in view of the voluminous scientific records[117] involved for the four substances in the table, the data characteristics described can do little more than indicate the nature of the scientific material cited by the courts in their holdings.

Nonetheless, certain observations are possible, especially when table material is supplemented by reference to additional opinion or agency material. In the lead standard case,[118] Judge Wright characterized the evidence underlying the agency findings of significant risks of material impairment as "more than substantial."[119] For each of the four subclinical (adverse) effects upon which OSHA relied to support its choice of a blood-lead level target of 40 μg% (heme synthesis inhibition, prevention of nerve conduction velocity decreases, renal and reproductive damage), the opinion identified no fewer than 3 to 11 scientific studies[120] which Judge Wright concluded, in sum, was more than a substantial basis for the agency's findings. In general, the opinion noted that these studies both documented significant clinical problems at blood-lead levels slightly above the proposed level[121] and indicated a continuing, though reduced, clinical problem at the proposed lower level.[122] The combination of numerous supportive studies and residual health problems at the proposed level were obviously persuasive on the question of substantial evidence, even though some of the study results were controverted.[123] There is no indication in the opinion that Judge Wright views population risk, rather than individual risk, as the more critical factor in deciding whether a significant risk of material impairment exists.

In the ethylene oxide case,[124] however, the court only had individual risk estimates to consider and concluded that the available studies provided "ample" evidence of a "significant risk of grave danger" to "some" workers[125] requiring the agency to undertake expedited rule making. Though the court cited fewer studies, it noted they were undisputed,[126] that the animal and human studies were consistent, dose–response relationships were present,[127] and that the adverse study effects of carcinogenicity and mutagenicity had been observed at current levels of exposure.[128] On the same data, however, the panel refused to compel a finding of "grave danger" because data describing the distribution of actual exposures were unavailable and the court was, therefore, unable to reject the agency's "average exposure" estimate, which was below the level at which toxicity had been reported.[129] The latter holding appears to impose a required finding of population risk on the notion of grave danger.

Table 6. Proving Health Risk Policy Questions: Transforming Scientific into Substantial Evidence or Its Equivalent

Policy-legislative fact questions	Holding	Data characteristics
I. Significant risk-standards		
Benzene		
Current: 10 ppm TWA Proposed: 1 ppm TWA	Plurality[a1]: scientific assumptions are short of findings required for substantial evidence.	Characterized agency's findings as follows: hematologic changes and chromosomal aberrations at the current PEL of 10 ppm. No empirical or opinion evidence that benzene had ever caused leukemia at or below current PEL.
	Dissent[a2]: OSHA could conclude that exposure poses a definite risk.	Agency found blood disorders, chromosomal damage of uncertain impact, inconclusive but consistent evidence of leukemia risk at or below current PEL, expert opinion of no safe level for carcinogens.
Cotton dust (textile) Previous: (1000 $\mu g/m^3$ TWA (total dust) Adopted: 200–750 $\mu g/m^3$ TWA (lint-free dust)	Substantial evidence consisted of risk estimates at present and proposed levels[b].	OSHA relied on dose-response data showing that 25% and 12.7% of workers suffer at least grade 1/2 byssinosis at 500 $\mu g/m^3$ PEL and 200 $\mu g/m^3$ (proposed PEL), respectively.
Lead Previous: 200 $\mu g/m^3$ TWA Adopted: 50 $\mu g/m^3$ TWA	Substantial evidence of risk of "subclinical" effects[c] (any one of which could be sufficient to uphold standard if confirmed).	OSHA relied on studies documenting serious human effects at, or slightly above, the blood lead level the "great majority" of workers would achieve with the proposed PEL: heme synthesis inhibition (exponential increase >40 $\mu g\%$ PbB), nerve conduction damage (>50 $\mu g\%$ PbB), kidney damage (>39 $\mu g\%$ PbB), reproductive damage (>41 $\mu g\%$ PbB, F > 30 $\mu g\%$ PbB).
Ethylene oxide Current: 50 ppm TWA	Ample evidence of significant risk requires expedited rule-making.[d]	"Undisputed evidence": Chromosome aberrations (≥36 ppm), leukemia

(*continued*)

Table 6. (continued)

Policy-legislative fact questions	Holding	Data characteristics
Current: 50 ppm TWA		and stomach cancer (15-fold increase at 20 + 10 ppm), all cancer (<50 ppm); comparable pathology in animals at the same levels.
II. Grave danger–emergency temporary standard		
Ethylene oxide Current: 50 ppm TWA	Finding of no "grave danger" rational.[e]	Use of low "average" exposure of 10 ppm based on some uncontradicted estimates and the absence of clear evidence of risk at this low average exposure do not compel finding of "grave" danger.
III. Material impairment		
Cotton dust (textile/nontextile) Lead	Acute (cotton dust)[f,g] or subclinical (lead)[h] (clinically silent) aspects of disease that involve a continuum of a response leading to chronic illness or death are material impairments.	Unchallenged evidence (cotton dust-textile). Numerous human studies showing increasing morbidity (signs/symptoms) with increasing evidence of exposure (lead). For nontextile industry Court approved PEL based on inference that lowering the prevalence of acute stages of "brown lung" would lower chronic prevalence, though the latter had not been demonstrated in nontextile industry.

[a] Industrial Union Dept. v. American Petroleum Institute, 448 U.S. 607, 634, 707 (1980).
1. plurality opinion, written by J. Stevens.
2. dissenting opinion, written by J. Marshall.
[b] American Textile Manufacturers Institute v. Donovan, 452 U.S. 490, 505–6 n. 25 (1981).
[c] United Steelworkers of America v. Marshall, 647 F.2d 1189, 1249 (DC Cir., 1980), *cert. denied*, Lead Industries Assn., Inc. v. Donovan, 453 U.S. 913 (1981).
[d] Auchter v. Public Citizen Health Research Group, 702 F.2d 1150, 1157 (DC Cir., 1983).
[e] *Id.* at 1157.
[f] *Supra* n.b.
[g] A.F.L. v. Marshall, 617 F. 2d 636, 667, (DC Cir., 1979), aff'd, in substantial part, sub nom, American Textile Manufacturers Institute v. Donovan.
[h] *Supra* n.c. at 1252–8.

In the benzene case, the dissent found substantial evidence of a "definite risk of material impairment."[130] The dissent's conclusion appears to be based, to a lesser extent, on its own findings[131] of somewhat greater adverse effects at current exposures than those found by OSHA and, to a greater extent, the testimony of "numerous experts (who) testified that the existing evidence required an *inference* that an exposure level above 1 ppm was hazardous" (emphasis added).[132] In the cotton-dust case,[133] though substantial evidence for the risk estimates was not an issue, the majority indicated that the prevalence figures noted in the table met the significant risk requirements imposed by the benzene case regarding risk.[134]

The last observation of Table 6 involves the material impairment category. For both the textile[135] and lead industries,[136] the choice of exposure values rested on a strategy of controlling acute or subclinical effects that would, if left to progress, move along the continuum to chronic irreversible disease. The occurrence of all stages on the disease continuum in the same industries was documented. However, in the cotton-dust case,[137] Judge Bazelon permitted OSHA to extrapolate[138] the evidence of chronic lung disease from the textile to nontextile industries, where only the acute reversible stages of the disease were then well documented, to support a judgment that such workers are at risk of material health impairment.[139] The Fifth Circuit has rejected such an inference.[140]

Process Results—Statutory Construction Techniques

Table 5 also identifies the statutory construction techniques employed in the opinions to give meaning to the statutory terms in the Occupational Safety and Health Act which involve health risk issues. Although there are too few cases covered in this report to permit identification of patterns of use by individual judge or courts (the ideal goal), the examples involving the use of non-statute-bound techniques are informative. Non-statute-bound techniques employed include the following types of construction approaches: statutory purpose/policy,[141] reference to related statutes (the *in pari materia* argument),[142] classification as remedial legislation,[143] and "judicial notice" of secondary sources.[144] This latter group of construction techniques is of special interest, in contrast to the group of techniques which rely on the language of the statute[145] or its legislative history, because the former group necessarily requires courts to consider Congress's broad social policy goals. Since these broad social policy goals are often incorporated into more than one statute, the use of any of the non-statute-bound techniques may yield important insights into the courts' or judges' efforts to harmonize risk management efforts. In any event, the present material documents the use of such techniques to interpret statutory language relating to health risk issues.

The courts' use of non-statute-bound construction techniques is illustrated by their references to related statutes. The District of Columbia Circuit referred to precedents involving statutes administered by EPA to indicate its heightened scrutiny of OSHA's refusal to issue an emergency temporary standard for ethylene oxide[146] (this reference also included a Nuclear Regulatory Commission case[147]), to set the level of scientific certainty required of studies establishing health risks,[148] and to justify the use of extrapolations and inferences from the cotton textile industry to prove material impairment in the nontextile cotton industries.[149] The Supreme Court referenced a case involving the Federal Power Commission to establish that highly conjectural expert testimony might, nonetheless, be accepted by itself as proof of some facts.[150] The D.C. Circuit also sanctioned an inference based on experience under the Federal Coal Mine Health and Safety Act.[151]

Table 7. Linkage of Judge's Statement of Findings, Criticisms, and Rebuttal Findings with Party and Agency Statement of the Same Findings[a]

	Wright's statement of agency finding (from opinion)	Statement of finding in government brief	Wright's statement of LIA criticism (from opinion)	Wright's statement of agency rebuttal findings (from opinion)	Statement of finding in Federal Register
Hematologic disorders	". . . OSHA had evidence that heme synthesis inhibition at blood-lead levels as low as 50 μg/100 g caused lowered hemoglobin and the early stages of anemia . . . JA 1518–1525 (Tola); 1883–1884 (Wolfe); SA 506–513 (Cooper)." @1253	"Several studies in the record demonstrated that this lead-induced condition [anemia] occurred at levels as low as 50." @45; JA 1518 (Tola) 1883 (Wolfe); SA 506 (Cooper)	". . . industry offered counterevidence that anemia did not occur below 100 μg/100 g . . . and generally questioned the methods used by OSHA's studies." @1254, JA 1503 (Cooper), 1529 (Cooper), 1537 (Williams) @48 Gov't Brief; Cross-reference: A-8 LIA	"OSHA carefully responded to these criticisms . . . noting problems in the studies cited by LIA, and in particular finding the source of much of the dispute in the different hemoglobin levels at which different experts chose to denote the presence of anemia. OSHA also explained why it preferred studies . . . which measured drops in hemoglobin level over time during continued lead exposure." @1254 JA 1518-1525 (Tola) 52952-57, 52354-62 @50–52 Gov't Brief	"Studies have associated PbB levels as low as 50 μg/100 g with lowered hemoglobin (lHb) levels. (EX. 6137); 146-A; 5(9) . . . Tola's study, which showed a lowering of Hb over time during lead exposure 50 μg/100 g, is considered by OSHA as an example of lead affecting Hb levels at this low PbB range." @52956/1 [Wolfe is also referred to here].
Neurologic effects	"Probably the most significant study in this area was Dr. Seppalainen's on reduced nerve conduction velocity among workers whose blood-lead had	"In a study generally recognized to be 'immaculate' in its methodology, Dr. Anna Seppalainen (SIC), examined 26 workers whose blood levels never exceeded	"LIA criticized the Seppalainen . . . stud[y], stressing that [her] results might really be due to the natural tendancy of duller, less adept workers to gravitate	"OSHA heard evidence to refute this latter argument . . . and carefully demonstrated the flaws in LIA's attack on Dr. Seppalainen's testing methods . . .	". . . the exposed group . . . was comprised of 26 workers (18 men and 8 women) from a storage battery factory [who] had a mean exposure time

never exceeded 70 μg/100 g and generally ranged between 35 and 60 μg/100 g. JA 1492-1495. In tests generally recognized as scientifically flawless, Dr. Seppalainen found serious reductions in the conduction velocity of the median and ulnar arm nerves of exposed workers, as well as excessive irritability and fibrillation of these nerves." @1254	70 and generally ranged between 35 and 60 (JA 1492). Tests of nerve conduction velocity (NCV) showed that the maximal motor conduction velocity (MCV) of the arm nerves (median and ulnar nerves) were significantly slower in exposed workers, or was the conduction velocity of slow fibers of the ulnar nerve. Further tests showed excessive irritability and fibrillation . . . of nerves." @56–7	toward less attractive jobs in lead plants." @1255i 43F.R. @54369/1; @54373–74; @58 Gov't Brief; Cross-reference: A13–14 LIA	finding nothing to rebut Dr. Malcolm's assessment that they were 'immaculate.' " @1255; JA 377 @61 Gov't Brief	of 4.6 (SD 4.7, median 3.7 years, range 13 months to 17 years). The concentration of PbBs had ranged mostly between 35 μg/100 g and 60 μg/100 g and occasionally between 20 μg/100 ml and 70 μg/100 ml . . . The results indicate the MCV's of the arm nerves (median and ulnar nerves) were slower among the exposed workers . . ." [Fibrillations were found in 5 cases] @54371/ "In both Drs. Valcuikas' and Lilis' professional opinions, job stratification was not an issue and given that Dr. Cole did not specify in more detail his concern, especially with respect to any particular test, OSHA has accepted the findings of the neuropsychologist as being valid." @54369/1–2

[a] USWA v. Marshall, 647 F.2d (DC Cir., 1981) *cert. denied*, Lead Industries Assn., Inc. v. Donovan 453 U.S. 913 (1981).

Process Results—Judicial Review Criteria for Agency Science-Based Determinations

To identify the actual criteria employed by judges in reviewing the scientific bases of agency findings, a comparison was made of the statements by judges, agency, and parties of health risk findings and their scientific support.[152]

Table 7 illustrates the comparisons for hematologic disorders and neurologic effects induced by excess lead absorption, taken from the opinion in the lead case.[153] The two illustrations presented appear representative of the opinion's treatment of the remaining health effects. In each case, the opinion and government brief accurately reflect the agency's findings and underlying supporting data and the party positions. There is no indication that the court sought out additional confirmatory or conflicting studies in the joint appendices or that it engaged in an independent critique of the scientific evidence relied on by OSHA. None of the opinions indicate explicitly the criteria utilized by the judges in deciding that the agency findings and underlying evidence meet the substantial evidence test. Only the conclusory statements are provided. Additional analyses are needed to determine whether the analytic approaches to scientific evidence identified in the OSHA cases are representative either of the particular judges involved or of the remaining judges on the circuit.

In contrast, the dissent in the benzene case (*supra*[154]) and the Fifth Circuit appear to undertake their own independent evaluation of the merits of evidence underlying agency findings. In a recent case involving CPSC,[155] employed here simply to highlight a difference between judges in their approach to scientific evidence, the Fifth Circuit strongly criticized and rejected the scientific methodology underlying the findings of human cancer risk relied on to support CPSC's ban on urea formaldehyde foam insulation. The Court rejected, as "not good science,"[156] the agency's "exclusive reliance" on the frequency of squamous cell carcinoma of the nasal turbinates in rats observed at the highest dose level in a single experiment (103/240 rats developed nasal carcinoma after 24 months' exposure to 14.3 ppm formaldehyde for 6 hours a day, 5 days a week[157]) as a basis for calculating human cancer risk in a risk assessment model.[158]

Unfortunately, the credibility of the Court's conclusion is itself diminished since the Court either misstated the evidence that the agency relied on or used inappropriate comparisons to challenge the reliability of the agency's findings regarding cancer risk. First, the agency had incorporated more than the single "empirical datum"[159] that the Court identified in the Globe 79 risk assessment. The agency explicitly noted its use[160] of the much lower incidence of nasal squamous carcinoma in the next lower exposure group (2/240 rats developed the rare carcinoma) at 5.6 ppm exposure in calculating human risk.[161] In addition, the Court explicitly cast doubt on the precision of the estimate of animal cancer frequency by referring to a later study[162] which demonstrated "only" a 10% incidence of carcinomas at 14.6 ppm formaldehyde exposure. However, the Court's comparison was inappropriate because the animal cancer frequencies were compared at two *different* time periods in the studies. A comparison of frequencies of nasal carcinoma at 18 months in the earlier and later studies indicates frequencies of 15.4% (37/240) and 10% (10/100), respectively.[163] These percentages do not differ appreciably, contrary to the Court's conclusion. In light of its flawed analyses, the credibility of the Court's evaluation of the scientific data is substantially diminished.

Once again, it is important not to overinterpret the data provided by the illustration from the Fifth Circuit. Just as with the material from the District of Columbia Circuit, additional analyses are required to establish whether the approach used in the urea formaldehyde case is representative of the Fifth Circuit's approach. Nonetheless, the cases from

the two circuits do indicate that judges vary widely in their approach to determining the sufficiency of the scientific evidence underlying the agency findings and provide strong support for continued analyses to identify potential bases for standardizing judicial analytic processes in this area.

CONCLUSIONS AND IMPLICATIONS

Cross-sectional analysis (cases considered as a group rather than *seriatim*, as they arose) of just this subset of 9 cases from the study population of 46 cases, comprising the controlling law for the issues decided in the District of Columbia Circuit governing OSHA standard-setting cases, provides substantial information on what the agency can do and the strength of the required justification. Though the agency must find a significant risk of material impairment, the Supreme Court has indicated it will defer to the agency's judgment of what risk is tolerable over a wide range. The Circuit has expanded the notion of what defects constitute a material impairment so that pathophysiological change short of disease is now included and its control can serve as the basis for the selection of a blood-level target.

The type of evidence that will survive substantial evidence scrutiny is identified by the opinions and suggests that a phased health standard-setting process, involving as a first phase standards based upon generic health risk decisions, might survive judicial scrutiny in this Circuit. The evidence which the Circuit characterized as more than substantial documented significant clinical problems at current exposures and subclinical effects, in some cases severe, at proposed exposure levels. Thus, OSHA might consider revising its dated air contaminant tables involving some 400–500 substances[164] by issuing first-phase standards based upon generic health risk decisions that various classes of morbidities constitute significant clinical problems requiring control, e.g., pneumoconioses, and that exposure levels will be initially lowered to a level where no more than some set percentage of workers will experience the subclinical effects on the continuum to the clinical problems sought to be controlled, e.g., early x-ray or pulmonary function changes.[165] In this fashion, an immediate reduction in workers' risks could be brought about and the more cumbersome substance-specific standard-setting process would then be reserved as a mechanism for fine-tuning the exposure levels.[166] An additional advantage to the generic first phase suggested is that industry could plan engineering and administrative controls more efficiently and at less cost if exposure levels were set for groups of air contaminants at one time rather than individually on a sequential basis. Specification of exposure values for large numbers of substances at one time would obviously permit industry to select the management strategy which would meet the most stringent engineering controls required in the group of standards. The present alternative, which sets substance-specific standards serially, requires continual reconsideration of the need to retrofit controls to meet newer and more stringent control requirements. While the latter problem would not be eliminated, it could be considerably reduced by the careful development of a generic approach.

Conversely, remaining problems are highlighted by the structural analysis. These problems include identification of the lower limit of risk deemed significant, the directness with which the pathophysiologic change must be tied to subsequent illness, the level at which pathophysiologic change warrants control, and the minimum data set which will support the required finding. While these remaining problems are all difficult and introduce an element of uncertainty regarding the outcome of litigation of these problems, it is important to note that the classification effort has suggested areas of certainty for risk managers. A completed

catalog representing the information from all 46 study cases would provide a comprehensive perspective on risk management, especially for new risk management personnel, that might reduce the chances of subsequent judicial invalidation. Expansion of the catalog to include other agencies' statutes might facilitate sharing of successful risk management strategies.

The effort to analyze judicial analytic process has been less successful. First, content analyses of opinions for process data are substantially more laborious than legal analyses of the material because some disputes with a single outcome may have as many as 15 to 20 analytic processes involved. Second, since one is looking for analytic patterns in judges and circuits, many more cases are required for this part of the analysis than for the risk classification scheme. Adaptation of computerized information retrieval systems to identify process techniques would do much to alleviate the data collection problem.

SUMMARY

The rapid expansion of federal responsibility in the risk management area over the past 10 to 12 years has had a major impact on the federal judiciary's work load. A substantial number of agency risk management decisions involving some aspect of the standard-setting process have now undergone judicial review. Excluding cases presenting purely procedural issues, the present report estimates that the Supreme Court and the Courts of Appeal have issued opinions in 125–375 cases involving decisions of the type specified (the imprecision reflects the use of estimation techniques) from the Occupational Safety and Health Administration (OSHA), the Consumer Product Safety Commission (CPSC), and the Environmental Protection Agency (EPA) in the period 1971–1983.

The present study was undertaken to develop a catalog of the courts' substantive risk management decisions and the types of data found adequate to support an agency's findings that would be useful to agency risk management personnel. In addition, the study explores the potential for empirical studies of the judicial analytic process. The present report describes a computer search strategy used to identify 46 study cases from a prototypic risk management agency, OSHA, and presents results from an analysis of disputed health risk determinations in the nine cases from the Supreme Court and Court of Appeals for the District of Columbia.

OSHA's act confers broad health risk management authority on the agency. Though the agency must find a significant risk of material impairment before it issues any standard, the cases in the District of Columbia Circuit indicate that this requirement is not likely to restrict significantly the agency's ability to deal with important occupational health problems. The Supreme Court has suggested that it will defer to the agency's view of what constitutes a tolerable risk over a wide range while the appeals court has gradually expanded the notion of material impairment to include pathophysiological changes preceding disease. Since pathophysiological change is on the continuum from normal to the disease state, the precise point at which regulation is warranted remains unclear. The Circuit has, however, significantly limited a petitioner's right to compel the agency to issue an emergency temporary standard.

Nonetheless, the requirement of a finding of significant risk requires new levels of precision in the agency's case. Analysis of this limited set of cases does suggest that the agency's findings will be sustained in this Circuit when several investigators confirm a substance's toxicity throughout an exposure interval that includes the proposed limit. This observation suggests that a generic standard-setting approach which sought to identify a uniform method for reducing, but not eliminating, morbidity might be successful where

morbidity has been documented, not estimated, at both current and proposed exposures. A minimum acceptable data set to support the required finding was not clearly identified in the present case series.

Judicial review criteria for science-based findings were determined by comparing the opinions' statements of the findings and underlying evidence with the agency's findings and party criticisms. Tabulation of all the health risk findings in two cases from the Circuit Court, a sample of which is provided, indicated that the judges accurately represented the agency's findings and the evidence relied on by the agency, the party criticisms, and agency rebuttals. There was no evidence that either of the judges in the District of Columbia substituted their judgment for that of the agency as a result of an independent critique of the underlying methodology nor do the opinions contain any indication of the evaluative criteria applied by the judges in concluding that the findings and evidence, as stated by the court, pass the substantial evidence test. Examples from other courts reaching conclusions on data different from the agency are noted for comparison.

Expansion of the catalog to include comparable material from the remaining cases would provide agency risk management personnel with a comprehensive view of the health risk management structure and data quality mandated by the courts. Wide availability of a completed catalog may be especially valuable to new risk management personnel as a type of training manual.

The methodology employed in the present report is quite labor-intensive for each case. It now appears likely that the catalog of substantive holdings can be completed by normal abstracting methods and that reliable insights into the treatment of scientific evidence by judges can be obtained by a sampling procedure. However, computerized legal information systems will need to be adapted to identify judicial analytic processes if the potential for empirical studies of judicial decision making in the risk management area is to be fully realized.

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REFERENCES

1. The list of federal health and safety risk management agencies is illustrative, not exhaustive, and represents the current focus of the principal author (A.O.) at the School of Public Health.
2. An effort has been made to identify the extent of under- and overestimation in the table. Underestimation of agency cases due to a failure to identify the agency in the case name is probably rare (25 consecutive Court of Appeals cases from the Occupational Safety and Health Case series in Volume 6 of the Bureau of National Affairs contained the agency name or an equivalent that would have been identified by the LEXIS search). Overestimation of agency or total Circuit cases due to inclusion of "Not for Publication" opinions in the F.2d series is minimal (4/71 cases with an F.2d cite in the same BNA volume were "Not for Publication").
3. In general, the Courts of Appeal are designated to hear challenges to standards from the three agencies noted in the table.
4. The following appellate docket sizes are illustrative:

	USWA	AFL-CIO	Society of plastics
	infra n. 43	*infra* n. 26	*infra* n. 25
Docket	(lead)	(cotton dust)	(vinyl chloride)
Brief	1300	532	300
Appendices	2570	4166	3750
	3870	4699	4050

5. Under the Occupational Safety and Health Act, which is the focus of the present report, the agency has rule-making authority regarding health and safety risks under the following sections:

> The Secretary may by rule promulgate, modify, or revoke any occupational safety or health standard in the following manner.
>
> U.S.C. Sect. 655(b) (1982).
>
> The Secretary, in promulgating standards dealing with toxic material or harmful physical agents under this subsection, shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life.
>
> 27 U.S.C. Sect. 655(b) (5) (1982).
>
> . . . an emergency temporary standard to take immediate effect upon publication in the Federal Register if he determines (A) that employees are exposed to grave danger from exposure to substances or agents determined to be toxic or physically harmful or from new hazards, and (B) that such emergency standard is necessary to protect employees from such danger.
>
> 29 U.S.C. Sect. 655(c) (1982).
>
> . . . prescribe such rules and regulations as he may deem necessary to carry out their responsibilities under this Act, including rules and regulations dealing with the inspection of an employer's establishment.
>
> 29 U.S.C. Sect. 657(g)(2)(1982).

6. Though the decision-making process regarding the initial, or continued, registration of a pesticide under the Federal Insecticide, Fungicide and Rodentcide Act (FIFRA) involves a formal hearing on the record (7 U.S.C. Sect. 136d(d)), the decision clearly represents a risk management decision analogous to those made by OSHA or CPSC.
7. The question is not whether the law is systematic (it is) but whether the product of the legal system in the form of opinions is also systematic from a scientific perspective, i.e., whether opinions from different courts impose consistent requirements on science policy makers.
8. Schotland, *Scope of Review of Administrative Action,* 34 Fed. BJ 54 (1975). The category of legal policy has been added by the present investigators.
9. *See, e.g.,* United Steelworkers' of America, 647 F.2d 1189, 1240 (D.C. Cir., 1980) (whether OSHA's proposed access to employee medical records violates right of privacy).
10. *See, e.g.,* Auchter v. Public Citizen Health Research Group, 702 F.2d 1150, 1157 (D.C. Cir., 1983) (court ordered expedited preparation of permanent standard).
11. *See, e.g.,* Industrial Union Dep't. v. American Petroleum Inst., 448 U.S. 607, 639 (1980) (interpreting term *reasonably necessary*).
12. *See, e.g., Id.* at 655 n.62 (determination of whether a risk is significant enough to warrant regulation is a policy question).
13. Procedural questions were not considered further by the project since they do not deal directly with risk management.
14. K. Llewellyn, *The Common Law Traditions,* 56 Little, Brown and Company (1960).
15. *Stare decisis et non quieta movere* (to stand by decisions and not to disturb what is settled).
16. D. Sands, *Statutes and Statutory Construction* (4th ed. 1972).

17. General definition for the judicial standard of review of agency standard setting authority,

> The reviewing court shall . . . (2) hold unlawful and set aside agency action, findings, and conclusions found to be . . . (A) arbitrary and capricious, an abuse of discretion, or otherwise not in accordance with the law, . . . (E) unsupported by substantial evidence.

APA, 5 U.S.C. Sect. 706 (1982).
The specific provision governing OSHA, which is the focus of the present report, states that "the determinations of the Secretary shall be conclusive if supported by substantial evidence in the record considered as a whole." 29 U.S.C. Sect. 655(f) (1982).

18. For example, this has been true in the Office of the Associate Solicitor of Occupational Safety and Health until recently, and may still be the case. A surprisingly high number of lawyers in that office had served almost from the inception of the agency.
19. White, *From Sociological Jurisprudence to Realism: Jurisprudence and Social Change in Early Twentieth-Centruy America,* 58 Virginia Law Review 999 (1972).
20. White, *The Evolution of Reasoned Elaboration: Jurisprudential Criticism and Social Change,* 59 Virginia Law Review 279 (1973).
21. Haar, Sawyer, and Cummings, *Computer Power and Legal Reasoning: A Case Study of Judicial Decision Prediction in Zoning Amendment Cases,* 1977 Am. B. Foundation Res. J. 651, 655 (1977).
22. Though, as indicated in the following text, the standard of review for agency science-based findings has occasioned substantial discussion by judges in opinions and articles, there is no indication that the courts perceive the statutory interpretation problems posed by such risk management statutes as the Occupational Safety and Health Act (OSHA), 29 U.S.C. 651 (1982), as unique and requiring a special approach.
23. Industrial Union Dep't., AFL-CIO v. Hodgson, 499 F.2d 467, 474 (D.C. Cir., 1974).
24. McGarity, *Substantive and Procedural Discretion in Administrative Resolution of Science Policy Questions: Regulating Carcinogens in EPA and OSHA,* 67 Georgetown LJ 729, 733–47 (1979).
25. Society of Plastics Indus., Inc. v. OSHA, 509 F.2d 1301, 1308 (2nd Cir., 1975) (Clark, Justice, sitting by designation).
26. *Id.;* American Federation of Labor v. Marshall, 617 F.2d 636, 651 (D.C. Cir., 1979).
27. I.U.D., 449 F.2d 467, 474 (D.C. Cir., 1974); United Steelworkers of America v. Marshall, 647 F.2d 1189, 1206 (D.C. Cir., 1980).
28. Associated Industries of N.Y.S. v. United States Dep't of Labor, 487 F.2d 342, 347–50 (2nd Cir., 1973).
29. A.F.L., 617 F.2d 636, 650 (D.C. Cir., 1979); U.S.W.A., 647 F.2d 1189, 1206 (D.C. Cir., 1980); I.U.D., 499 F.2d 467, 473 (D.C. Cir., 1974); Assoc'd Indus., 487 F.2d 342, 347–50 (2nd Cir., 1973); S.O.P., 509 F.2d 1301, 1304 (2nd Cir., 1975); Texas Independent Ginners Ass'n. v. Marshall, 630 F.2d 398, 404 (5th Cir., 1980).
30. P.C.H.R.G., 702 F.2d 1150 (D.C. Cir., 1983).
31. Assoc'd Indus., 487 F.2d 342, 354 (2nd Cir., 1973); A.F.L., 617 F.2d 636, 649 n.49 (D.C. Cir., 1979).
32. A.P.I., 448 U.S. 607, 705 (1980) (Marshall, J., dissenting).
33. Universal Camera Corp. v. N.L.R.B., 340 U.S. 474 (1951).
34. *Id.* at 488.
35. *Id.* at 490.
36. *Id.* at 488.
37. Citizens to Preserve Overton Park v. Volpe, 401 U.S. 402 (1971).
38. *Id.* at 415.
39. *Id.* at 416.
40. Bowman Transportation, Inc. v. Arkansas-Best Freight System, 419 U.S. 281, 290 (1974) (rational basis exists where Commission refused to infer performance of an applicant carrier in a market to which it sought admission from its performance in other markets where precisely similar conditions had not been demonstrated).
41. *See, e.g.,* Baltimore Gas & Electric Co. v. Natural Resources Defense Council, Inc., 462 U.S. 87(1983) (O'Connor, J.) (in a case subject to arbitrary/capricious review, cited I.U.D. v. A.P.I., 448 U.S. 607 (1980) (plurality opinion) a case governed by substantial evidence review, for the principle that a reviewing court must be deferential in reviewing science-based determinations); I.U.D. v. A.P.I., 448 U.S. 607, 705 (1980) (Marshall, J., dissenting) (substantial evidence review requires "more careful performance of (the searching inquiry into the facts) . . . " mandated by the "arbitrary/capricious" standard); Ethyl Corp. v. Environmental Protection Agency, 541 F.2d 1, 36 n.75 (D.C. Cir., 1976) (notes three Clean Air Act cases, governed by arbitrary/capricious review standard, which adapted scope of reviewing court's inquiry into evidence from substantial evidence case); Texas Independent Ginners v. Marshall, 630 F.2d 398, 405 (5th Cir., 1980)

(indicating that the reasonableness requirement under substantial evidence stems from the arbitrary/capricious requirement).

42. I.U.D., 499 F.2d 467, 475–76 (D.C. Cir., 1974). *Accord,* Synthetic Organic Chemical Mfrs. Ass'n. v. Brennan, 503 F.2d 1155, 1157 (3rd Cir., 1974); Assoc'd Indus., 487 F.2d 342, 354 (2nd Cir., 1973); Ginners, 630 F.2d 398, 405 n.26 (5th Cir., 1980).
43. U.S.W.A., 647 F.2d 1189, 1207 (D.C. Cir., 1980).
44. Bazelon, *Coping with Technology Through the Legal Process,* 18 Jurimetrics J 241, 246 n.19 (1978).
45. Bazelon, *The Judiciary: What Role in Health Improvement?* 211 Science 792 (1981).

> In enforcing these requirements [of fully articulating the basis for agency decision], the court does not reach out to resolve controversies over technical data . . . it seeks to assure public accountability . . . opening the process to public scrutiny and criticism. . . .

A.F.L.-C.I.O. v. Marshall, 617 F.2d 636, 651 (D.C. Cir., 1979), *aff'd sub nom* A.T.M.I. v. Marshall, 452 U.S. 490 (1981).

> [W]here administrative decisions on scientific issues are concerned, it makes no sense to rely upon the courts to evaluate the agency's scientific and technological determinations.

Coping with Technology through the Legal Process, 62 Cornell LR 817, 822 (1977).

> I cannot believe that Congress intended this court to delve into the substance of the mechanical, statistical, and technological disputes in this case.

Int'l Harvester Co. v. Ruckelshaus, 478 F.2d 615, 651 (D.C. Cir., 1973) (Judge Bazelon would remand the standard because of a failure to provide cross-examination, the process defect which he identified. In Vermont Yankee, 435 U.S. 519 (1978), the Supreme Court unanimously rejected the court imposition of procedural requirements beyond those imposed by the agencies' statutes).

See also., Science and Uncertainty: A Jurist's View, 5 Harv. Envtl. LR 209 (1981).

46. Ethyl, 541 F.2d 1, 68 (D.C. Cir., 1976) (Leventhal, J., concurring).

> We have identified a number of matters that require consideration and clarification on remand. While we remain diffident in approaching problems of this technical complexity, the necessity to review agency decisions, if it is to be more than a meaningless exercise, requires enough steeping in technical matters to determine whether the agency "has exercised a reasoned discretion" . . . (citation omitted).

Portland Cement Association v. Ruckelshaus, 486 F.2d 375, 402 (D.C. Cir., 1973) (Leventhal, J.) (standard for performance for portland cement plants remanded to agency for consideration and clarification for, *inter alia,* failure to provide reliability estimates for compliance capability tests, claimed faulty measurement techniques and failure to provide for variability of emissions associated with industrial malfunctions).

See also Leventhal, *Environmental Decision Making and the Role of the Courts,* 122 U Pa Law Review 509 (1974).

47. Ethyl, 541 F.2d 1, 36 (D.C. Cir., 1980). *Accord,* Lead Industries Ass'n v. EPA, 647 F.2d 1130, 1145 (D.C. Cir., 1980) (Judge Wright engaged in a close scrutiny of the evidence by a detailed exposition of the Agency position on several scientific issues and their rebuttal to criticism. The issues included: Maximum Safe Individual Blood Lead Level; Margin of Safety; Correlations between Air Lead and Blood Lead Levels).
48. McGarity, *supra* n.24, at 798 n.362.
49. The traditional legal research method identifies subsequent citations of the case of interest (SHEPARDIZE) as a means of determining the subsequent history of the principle represented by the precedent.
50. I.U.D. v. A.P.I., 448 U.S. 607 (1980), 4 unreported District Court decisions found in the Bureau of National Affairs' Occupational Safety and Health Cases report series, and 2 later decided cases.
51. The search strategy was modified and used to generate the data in Table 3.
52. Feinstein, *Clinical Biostatistics XXXI. On the Sensitivity, Specificity, and Discrimination of Diagnostic Tests,* 17 Clinical Pharmacology and Therapeutics 104 (1975); Bing and Harvold, *Legal Decisions and Information Systems* (1977).
53. Oleinick and Disney, *Development and Evaluation of a LEXIS Search Strategy Whose Goal is the Identification of Health Risk Management Disputes Arising in the Context of Rule-Making* (in preparation).
54. A.P.I., 448 U.S. 607 (1980).
55. Bing and Harvold, *supra* note 52, at 209–22.

56. Material regarding the other components required of a legally acceptable risk management strategy—control strategies and the technical or economic "feasibility" of such a control strategy—will be considered in subsequent papers.
57. A.P.I., 448 U.S. 607, 642 (1980) (benzene standard). The following opinions were given: Plurality: Stevens, J., Burger, C.J., Stewart, J., Powell, J. (J. Powell concurred in all parts of the opinion except IIID and IV). Concurrence: Burger, C.J. Concurring in part and in the judgment: Powell, J. Concurring in the judgment: Rehnquist, J. Dissent: Marshall, J., Brennan, J., White, J., Blackmun, J. Subsequent references to the portions of the plurality not joined by J. Powell are identified as plurality (IIID).
58. *Id.* at 671–88. J. Rehnquist, who concurred in the decision, but not in the opinion, was the fifth vote in the decision to overturn the standard.
59. *Id.* at 642.
60. *Id.*
61. *Id.* at 653 (plurality, IIID).
62. A.P.I., 448 U.S. 607 (1980).
63. U.S.W.A., 647 F.2d 1189, 1245 n. 84 (1980).
64. American Textile Mfr's. Inst. v. Donovan, 452 U.S. 490 (1981); Cottonwarehouse Ass'n. v. Marshall, 449 U.S. 809 (1981).
65. U.S.W.A., 647 F.2d 1189, (D.C. Cir., 1980); Ginners, 630 F.2d 398 (5th Cir., 1980); Asarco v. OSHA, 647 F.2d 1 (9th Cir., 1981).
66. A.P.I., 448 U.S. 607, 655 n. 62, 706 (1980) (dissent).
67. *Id.* at 655 (IIID).
68. *Id.* at 646.
69. *Id.* at 655. The numbers do not indicate whether the opinion was referring to annual or working life risks. Depending on which was meant there is a 1600-fold difference in the risk level that the court indicated might be considered significant.
70. *Id.* at 642.

70a. The agency findings required by I.U.D. v. A.P.I., 448 U.S. 607 (1980) necessarily specify a range of risk, though not precisely defined at this time, within which risk management by standard setting is appropriate. This range appears to subsume the "zone of reasonableness" principle relied on by the District of Columbia Circuit to validate particular control levels selected by the agency. See e.g., U.S.W.A., 647 F.2d 1189, 1253, 1263 (D.C. Cir., 1980) citing Hercules, Inc. v. EPA, 598 F.2d 91, 107 (D.C. Cir., 1978).

71. *Id.* at 646.
72. *Id.* at 655 (IIID).
73. *Id.* at 656 (IIID).
74. *Id.* at 657 n. 64 (IIID).
75. *Id.* at 667.
76. *Id.* at 707.
77. *Id.* at 666.
78. U.S.W.A., 647 F.2d 1189, 1253 (D.C. Cir., 1980) (quoting Ethyl Corp. v. EPA, 541 F.2d 1, 37–8 (D.C. Cir., 1976) (*en banc*), *cert. denied,* 426 U.S. 941 (1976)).
79. U.S.W.A., 647 F.2d 1189, 1263 (D.C. Cir., 1980).
80. A.P.I., 448 U.S. 607 (1980).
81. American Textile Mfr's. Inst. v. Donovan, 452 U.S. 490, 505–6 n.25 (1981).
82. *Id.* at 496 n.8 (continuum refers to the progressive nature of the disease moving from pathophysiological change to acute reversible clinical disease to chronic irreversible cinical disease).
83. *Id.* at 505–6 n. 25.
84. *Id.*
85. U.S.W.A., 647 F.2d 1189 (D.C. Cir., 1980).
86. *Id.* at 1252.
87. *Id.* at 1258.
88. *Id.* at 1253.
89. *Id.*
90. *Id.* at 1254.
91. The other two effects, renal disease and reproductive damage, though placed in the subclinical class are distinguishable because they involve clear pathological changes in end organs.
92. Ginners, 630 F.2d 398, 407 (5th Cir., 1980) (the Court appeared to reject acute changes as a material impairment).
93. *Supra* n.5, 29 U.S.C. Sect. 655(c) (1982).

94. In determining the priority for establishing standards under this section, the Secretary shall give due regard to the urgency of the need for mandatory safety and health standards for particular industries, trades, crafts, occupations, businesses, workplaces, or work environments. The Secretary shall also give due regard to the recommendations of the Secretary of Health, Education, and Welfare regarding the need for mandatory standards in determining the priority for establishing such standards.

    29 U.S.C. Sect. 655(g) (1982).

95. P.C.H.R.G., 702 F.2d 1150 (D.C. Cir., 1983).
96. Public Health Citizen Research Group v. Auchter, 11 OSHC 1049 (D.C., D.C., 1983).
97. P.C.H.R.G., 702 F.2d 1150, 1153 (D.C. Cir., 1983).
98. *Id.* at 1157.
99. "The reviewing court shall . . . (1) compel agency action unlawfully withheld or unreasonably delayed. . . . ." 5 U.S.C. Sect. 706 (1) (1982).
100. P.C.H.R.G., 702 F.2d 1150, 1158 (D.C. Cir., 1983). The final rule, 29 C.F.R. 1910.1047, was issued June 22, 1984, 14 months later.
101. *Id.* at 1157.
102. I. Nat'l Congress of Hispanic American Citizens v. Dunlop, 425 F. Supp 900 (D.C., D.C., 1975).
    II. Nat'l Cong. of Hispanic Am. Cit. v. Usery, 554 F.2d 1196 (D.C., Cir., 1977).
    III. Nat'l Cong. of Hispanic Am. Cit. v. Marshall, 6 OSHC 2157 (D.C., D.C., 1978).
    IV. Nat'l Cong. of Hispanic Am. Cit. v. Marshall, 626 F.2d 882 (D.C., Cir., 1979).
    V. Nat'l Cong. of Hispanic Am. Cit. v. Donovan, 10 OSHC 1105 (D.C., D.C., 1981).
103. 29 U.S.C. Sect. 652(b)(1)–(4) (1982).
104. Hispanic II at 1199.
105. *Id.* 1200.
106. Hispanic IV at 891.
107. *Id.*
108. *Id.* at 890. OSHA has declined to issue a standard pending state actions (15 OSHR 324, 1985).
109. *Id.* at 886, 889.
110. *Id.* at 891.
111. Whirlpool v. Marshall, 445 U.S. 1 (1980).
112. *Id.* at 10–11.
113. *Id.*
114. *Supra* note 73.
115. *Supra* note 78.
116. *Supra* note 79.
117. The comments and exhibits received before the hearings, the written and oral testimony of the hearing participants, and post-hearing comments and briefs comprise the informal rulemaking record for the final cotton dust standard promulgated by the agency. This record exceeds 105,000 pages in length; it includes comments from 263 parties and testimony form 109 participants at the hearing. The Final Standard and its accompanying statement of reasons fill 68 pages of the Federal Register [footnote omitted].

    A.F.L., 617 F.2d 636, 647 (D.C. Cir., 1979).
118. U.S.W.A., 647 F.2d 1189 (D.C. Cir., 1980).
119. *Id.* at 1249.
120. *Id.* at 1252–58. Named studies only were counted. Federal Register citations were not reviewed to distinguish between studies and expert opinion.
121. At blood levels of 50–70 μg%: *e.g.*, heme synthesis inhibition—more than 70% of population show 70% inhibition of heme synthesis at 50 μg%, behavioral disturbances and decreases in hemoglobin concentration, *Id.* at 1253; neurological effects—encephalopathy and decreased nerve conduction velocity, *Id.* at 1254–55; renal disease—30 to 50% loss of kidney function in 15 workers with blood levels below 60 μg% at the time of renal evaluation, *Id.* at 1255–6; reproductive effects—hypospermia and asthenospermia at blood-lead levels averaging 52.8 μg%, *Id.* at 1257.
122. The studies cited in n. 121 also contained examples of renal disease and sperm defects at approximately 40 μg%, the proposed blood-lead level target, *Id.* at 1255, 1257.
123. ". . . the ordinary situation of controverted evidence, in which we must defer to the reasonable and conscientious interpretations of the agency." *Id.* at 1258.
124. P.C.H.R.G., 702 F.2d 1150 (D.C. Cir., 1983).
125. *Id.* at 1157.
126. *Id.* at 1154.

127. *Id.*.
128. *Id.*.
129. *Id.* at 1156.
130. A.P.I., 448 U.S. 607, 705, 707 (1980).
131. *Id.* Support for this statement is provided by a comparison of the plurality's and dissent's characterizations of OSHA's findings with the actual finding itself in the Federal Register (43 Fed. Reg. 5918, 2/10/78):

Benzene effect ≤10 ppm	Plurality	Dissent	OSHA
Blood	"Slight changes" @631	"Disorders" @698	"Alterations" @5925
Chromosome	"Aberrations" Uncertain health effect @633	"Damage chromosomes" Uncertain health effect @697	"Chromosome aberrations" Uncertain health effect @5933
Leukemia	"No finding . . . benzene at or below 10 ppm had ever in fact caused leukemia" @634	Same as OSHA @699	"[Finding at low exposure] consistent . . . excess leukemia risk . . ." @5928

132. *Id.* at 707.
133. A.T.M.I., 452 U.S. 490 (1981).
134. *Id.* at 505–6 n. 25.
135. *Id.* at 496.
136. U.S.W.A., 647 F.2d 1189, 1258 (D.C. Cir., 1980).
137. A.F.L., 617 F.2d 636 (D.C. Cir., 1979).
138. *Id.* at 667 n. 185.
139. Cottonwarehouse Ass'n., 449 U.S. 809 (1981) (the decision was vacated and remanded for reconsideration in light of I.U.D. v. A.P.I., 448 U.S. 607 (1980). It is not clear that the remand would require reconsideration of the material impairment finding).
140. The agency arguably has adduced substantial evidence of acute respiratory effects on American gin workers from cotton dust exposure; it assumes from cotton industry studies that these acute effects develop into byssinosis and other chronic respiratory disease. OSHA has not provided substantial evidence that byssinosis and other chronic disease arise from the exposure level to cotton dust in the ginning industry with its significantly different conditions and its significantly different exposure level.

    Ginners, 630 F.2d 398, 409 (5th Cir., 1980).
141. It is ancient wisdom that statutes should be interpreted so as to effectuate their manifested purpose or object. With reference to this principle, a statute is liberally construed when its letter is extended to include matters within the spirit or purpose of the statute, . . . The modern course of liberal interpretation, therefore, is to make greater use of legislative manifestations of prevailing social policy and the technique of projecting manifested principle by analogy in order to integrate separate and independent statutory provisions, often inspired by episodic and superficially unrelated events or circumstances, into a consistent and currently relevant body of jurisprudence. [Citations omitted]

    D. Sands, *Statutes and Statutory Construction*, Sect. 58.06 (1973).

    Even though "purpose" statements are now a routine part of statutes enacted, they are often stated so broadly as not to interfere with the judicial discretion implied by the preceding text.

    The Congress declares it to be its purpose and policy, through the exercise of its powers to regulate commerce among the several States and with foreign nations and to provide for the general welfare, to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources . . . (7) by providing medical criteria which will

assure insofar as practicable that no employee will suffer diminished health, functional capacity, or life expectancy as a result of his work experience;

E.g., 29 U.S.C. 651(b) (1982).

142. Statutes are considered to be *in pari materia* . . . to pertain to the same subject matter . . . when they relate to the same person or thing, or to the same class of persons or things, or have the same purpose or object. As between characterization of the subject matter with which a statute deals and characterization of its object or purpose, the latter appears to be the more important factor in determining whether different statutes are closely enough related to justify interpreting one in the light of the other.

D. Sands, *Statutes and Statuatory Construction*, Sect. 51.03 (1973).

143. Remedial statutes are liberally construed to suppress the evil and advance the remedy. The policy that a remedial statute should be liberally construed in order to effectuate the remedial purpose for which it was enacted is firmly established. Expressions of a rule to that effect appear over and over in judicial opinions on issues of statutory interpretation.

Id. at Sect. 60.01.

144. Sands does not explicitly recognize secondary sources although, as our example indicates, courts clearly give some "weight" to academic articles.

145. "One of the common techniques of statutory construction, besides being always a starting point, is to read and examine the text of the act and draw inferences concerning meaning from its composition and structure." *Id.* at Sect. 47.01.

146. P.C.H.R.G., 702 F.2d 1150, 1156 (D.C. Cir., 1983) citing Welford v. Ruckelshaus, 439 F.2d 598, 601 (D.C. Cir., 1971) (in light of close scrutiny required where personal interests in life and health are involved, court remanded EPA decision not to suspend 2, 4, 5-T use because agency had not considered possible harm to farm workers.)

147. *Id.* citing Nader v. Nuclear Regulatory Commission, 513 F.2d 1045, 1047 (D.C. Cir., 1975) (court noted special responsibility to review agency action with potentially disastrous consequences but upheld agency since its action was based on diverse expert opinion. No data reviewed by Court.)

148. U.S.W.A., 647 F.2d 1189, 1253 (D.C. Cir., 1980) citing Ethyl, 541 F.2d 1, 37-38 (D.C. Cir.) (*en banc*), *cert. denied*, 426 U.S. 941 (1976) (court upheld EPA decision to reduce lead additives in gasoline, finding that the agency had established that population lead levels are elevated, seriously so in some groups, and that automobile exhaust contributes to human lead levels. The findings were based upon a "totality of the evidence" drawn from "inconclusive but suggestive results of numerous studies.")

149. A.F.L., 617 F.2d 636, 667 (D.C. Cir., 1979) citing E.D.F. v. E.P.A., 598 F.2d 62, 83–85 (D.C. Cir., 1978) (court permitted extrapolation of data from highly chlorinated to less chlorinated polychlorinated biphenyls).

150. I.U.D. v. A.P.I., 448 U.S. 607, 707 (1980) citing F.P.C. v. Florida Power & Light Co., 404 U.S. 453, 464–465 (1972) (The Court upheld the FPC's jurisdiction over Florida Power and Light Co. on the theory that FPL electricity "commingled" with electricity bound for out-of-state customers. The commingling analysis rested upon expert testimony which, in turn, was "based on what is known and uncontradicted by empirical evidence.")

151. U.S.W.A., 647 F.2d 1189, 1237 (D.C. Cir., 1980).

152. Tabulations were prepared for J. Bazelon (A.F.L., 617 F.2d 636 (D.C. Cir., 1979)) and J. Wright (U.S.W.A., 647 F.2d 1189 (D.C. Cir., 1980)). Since the approaches seemed similar, two examples from U.S.W.A. are provided.

153. U.S.W.A., 647 F.2d 1189, (D.C. Cir., 1980).

154. *Supra* note 131.

155. Gulf South Insulation v. CPSC, 701 F.2d 1137 (5th Cir., 1983).

156. *Id.* at 1146.

157. Though neither noted by the agency in its statement of basis and purpose supporting its decision in the Federal Register nor by the Court in its opinion, this incidence is extraordinarily high. No cases of this tumor type have been reported in observations of 9484 rats of the same strain used in the formaldehyde studies, the Fischer 344 strain. NIOSH, *Current Intelligence Bulletin 34: Formaldehyde,* April 15, 1981.

158. Gulf South Insulation, 701 F.2d 1137, 1146 (5th Cir., 1983).

159. *Id.*

160. 47 FR 14372 (4/2/82).

161. Gulf South Insulation, 701 F.2d 1137, n. 18 at 1146 (5th Cir., 1983). The Court apparently disregarded the experience at 5.6 ppm because the incidence, by itself, was not statistically significant. However, this approach

ignores completely the confirmation of formaldehyde's carcinogenic potential provided by dose–response data at two exposure levels.

162. *Id.* n. 19 at 1146.
163. 47 FR 14369, 14371 (4/2/82).
164. 29 C.F.R. 1910.1000, Table Z-1 to Z-3. These exposure values were adopted under 29 U.S.C. 655(a) (1982) which permitted OSHA, for a period of two years from the effective data of the act, to adopt national consensus standards without complying with the usual standard-setting process. These standards have not been revised subsequently with the exception of those substances in the air contaminants tables which are also included in the list of 24 substances for which OSHA issued standards by the full rule-making process during the period 1971–1982.

    During the time period since the promulgation of the consensus standards (to 1983) the limits permitted by OSHA and those recommended by a major industrial hygiene association, the American Conference of Governmental Industrial Hygienists (ACGIH), have increasingly diverged. An analysis of a 10% sample of substances in Table Z-1 and a 20% sample of substances in the remaining tables (a total of 41 chemicals) indicates that, for 39% of substances (16/41), the ACGIH recommendation is more than 25% below the level permitted by OSHA while for only 5% of substances (2/41), the ACGIH level is greater than 25% above the OSHA level.

    Quite clearly, there is a need to identify a new approach to standard setting which will permit revision of OSHA's dated exposure levels.
165. See, e.g., NIOSH. *Occupational Hazard Assessment Criteria for Controlling Occupational Exposure to Cobalt.* DHHS (NIOSH) Publication N. 82-107 (1981). The document describes fibrotic lung disease occurring at the current exposure limit of 0.1 mg/m^3 and also at substantially lower exposures.
166. The proposed phased standard-setting process differs from that contained in the current OSHA cancer policy, 29 C.F.R. 1990 (1982), in that the first phase proposes a generic decision on what constitutes a significant risk of material impairment.

17

The Political and Institutional Setting for Risk Analysis

Michael E. Kraft

INTRODUCTION

Public concern for a wide array of risks to health, safety, and environmental quality has increased significantly in the last 15 years as have governmental efforts to deal with those risks. More recently, scientific analysis of such technological risks, from nuclear power plant operation to toxic and hazardous materials in the environment, has become a growth industry, the result of which is a substantial literature on risk analysis. Most of this literature, however, focuses on technical and methodological issues of risk assessment; there has been a comparative neglect of processes of risk evaluation and more generally political variables affecting implementation of risk reduction policies. If methods of risk assessment are to be employed more effectively in governmental settings and if they are to help bring greater rationality to policy decisions, improved understanding of political as well as technical aspects of risk analysis is essential. In particular, greater knowledge of how political and institutional forces affect the conduct, use, and impact of risk analysis is necessary to speak confidently of effective strategies of change.

This chapter examines that need from several different angles. First, a review of the major issues and the extant literature on political and administrative dimensions of risk analysis in regulatory policy will highlight the questions and concerns driving current inquiry into these subjects. Second, the particular project supported by the National Science Foundation will be summarized as one example of empirical research on risk analysis in regulatory decision making; it will focus heavily on my own contribution to that collaborative research endeavor, in part because other project work is presented in Chapter 13 of this volume. Finally, the chapter will address future research needs.

Because there is considerable variation in the use of terminology in this area, some definitions should be offered at the outset. Risk analysis is used here to refer to the com-

Michael E. Kraft • Department of Public and Environmental Administration, University of Wisconsin, Green Bay, Wisconsin 54301.

bination of two activities: risk assessment and risk evaluation. Risk assessment includes both the identification of risks and estimation of the probability and severity of harm associated with them. Estimation involves determining the probability of occurrence of certain events and the severity of negative consequences of those events (Lowrance, 1976); the negative consequences may be economic or property loss, injury, disease, premature death, or damage to environmental quality. Risk evaluation refers to the process of determining the acceptability of risks. In this usage, risk assessment may be considered to be chiefly a technical activity whereas risk evaluation is largely a political decision. The distinction is an important one that gives greater emphasis to the politics of risk analysis than is often found in the existing literature. One should add that in practice the separation of risk assessment and risk evaluation is quite difficult. Agencies charged with regulation of technological risks must perform the technical assessments and make some judgments about the acceptability of risk. In enacting the statutes governing those decisions, Congress has delegated broad authority for defining the level of risk considered to be in the public interest, and has set some boundaries within which agencies must make those evaluative judgments. In some respects, then, risk evaluation by Congress has preceded risk assessments conducted within agencies, reversing the order normally assumed for these decisions.

CONTEMPORARY POLITICAL ISSUES IN RISK ANALYSIS

Risk Policy Development and Regulatory Reform

Risk analysis may be an appropriate tool in decisions concerning a rather large number of federal policies. Statutory requirements for those policies differ substantially, not only because the problems addressed are different, but because the policies reflect changing circumstances at the time of enactment and the perspectives and influence of different clusters of policy actors in each problem area. Thus, some policies require consideration of only the technical feasibility of regulating a particular risk (e.g., some provisions of the Clean Air Act); others mandate consideration of only the nature or extent of the risks involved (e.g., the Delaney clause of the Federal Food, Drug, and Cosmetic Act); and a third group requires a more explicit balancing of risks, costs, and benefits (e.g., the Toxic Substances Control Act). All but a few of these policies call for some kind of balancing and give considerable discretion to agency administrators to determine acceptable levels of risk. But different guidelines are provided for carrying out such balancing, and major differences exist in assignment of the burden of proof and of costs associated with providing risk assessment information.

In general, the period of the 1960s and 1970s was fertile ground for the growth of these kinds of regulatory policies for reasons that need not be reviewed here (but see, for example, Anderson, 1978; Nadel, 1971; Wilson, ed., 1980; Marcus, 1981; Rosenbaum, 1977). What is important in comparison to the 1980s is that public concern for newly discovered risks and optimism over governmental capabilities and sustained economic growth was sufficient to support strengthening existing regulatory policies (e.g., the Clean Air Act Amendments of 1970) and expanding federal regulation into new areas such as toxic substances control. In short, economic, social, and political conditions during this period facilitated the development of ambitious policies that critics asserted were often enacted with little understanding of the technical difficulties of implementation, the capability of governmental agencies at the federal, state, and local level to meet statutory mandates, and the

costs that would be imposed on regulated parties. By the late 1970s these conditions had changed, and regulatory reform had become the new fashion in Washington.

Critics of governmental regulation in the late 1970s and early 1980s could be found in many quarters, but the strongest and most visible criticism came from political conservatives, economists, and industry officials. New concerns were expressed over the cost of compliance with federal regulations and their overall economic impact, the complexity and inflexibility of regulations, the capability of agencies to implement policies effectively, the inconsistency of statutory guidelines, and the adequacy of scientific knowledge to establish regulatory standards. Policy goals themselves were often questioned in light of competing social and economic values in the contemporary setting, although most policies survived legislative scrutiny relatively unscathed. By the early 1980s a new agenda for regulatory reform had been shaped by academic critics, industry officials, and sympathetic policy officials from the president on down. As a result, a new and impressively large literature on regulation and its reform had been generated (Bardach and Kagan, 1982; Poole, ed., 1981; Graymer and Thompson, eds., 1982; Ferguson, ed., 1981; Breyer, 1982; Lave, 1981; Bardach and Kagan, eds., 1982; Ferguson and LeVeen, 1981; Litan and Nordhaus, 1983; Anderson Gitelson, and Dubnick, 1985). Along with cost–benefit analysis, risk analysis emerged as a major methodological tool that supporters hoped could be used to streamline governmental regulation and set policy priorities in a new era of limited expectations and scarce economic resources.

By the early 1980s there was a consensus of sorts for regulatory reform, but also considerable disagreement over what particular kinds of reform were desirable. From one perspective, which David Welborn (1977) has termed a "restrictivist" approach, governmental regulation is seen as often unnecessary or unduly burdensome; reforms favored tend to be deregulation (greater reliance on the free market), decentralization of responsibility to states and localities, substitution of economic incentives and disincentives for regulation, and greater use of economic analysis—including risk analysis—to make decision making more efficient. This perspective is found in the Reagan administration's regulatory reform efforts, most notably in the work of the Task Force on Regulatory Relief and in the expanded role of the Office of Management and Budget (OMB) in regulatory review. It is also characteristic of the views of many academic economists. In contrast, others seek reforms to strengthen governmental regulation and make it more accountable to the public. Reform proposals favored often aim to increase agency authority and clarify sanctions that might be used against regulated parties, to increase agency capabilities through larger budgets and recruitment of additional professional staff, and to enlarge the public's role in agency decision making. Efficiency is also a concern here, although generally given less emphasis. This perspective is typical of consumer, labor, and environmental groups, but is also found among some academic policy specialists.

Risk Analysis in Theory and Practice: Issues in the Reagan Administration

Disagreements about regulatory reform extend to the use of risk analysis in regulation. Proponents of risk analysis argue that it is a valuable tool that can be used to make regulatory decision making more scientific and rational (Lowrance, 1976; Wilson and Crouch, 1982; Fischhoff et al., 1981; Lave, 1983). They believe that reliable scientific data on risks can be compiled and that the costs of risk reduction can be calculated, thereby allowing comparative risk analysis and priority setting for allocation of scarce resources. In addition to

some elements of the scientific community, proponents include many industry officials, economists, and conservatives who believe such analysis will support their arguments for regulatory reform. The critics, including many environmental and consumer groups and labor unions, argue that risk analysis is still an inexact science burdened by too many methodological limitations to be of much value in these kinds of decisions. They are skeptical that risks can be estimated accurately, that benefits can be identified and measured as thoroughly as the costs, and that risks, benefits, and costs can be fairly evaluated in all agencies (Baram, 1980, 1982; Bogen, 1980; U.S. Congress, 1980a,b,c; Swartzman, Liroff, and Croke, eds., 1982). Politicization of the Reagan administration's efforts at regulatory reform adds to the skepticism critics express about the way risk assessment is applied in practice whatever its merits may be in the abstract.

President Reagan's Executive Order 12291, issued in February 1981, illustrates the controversy. The purpose of the order in the president's words was to "reduce the burdens of existing and future regulations, increase agency accountability for regulatory actions, provide for presidential oversight of the regulatory process, minimize duplication and conflict of regulations, and insure well-reasoned regulations" (Reagan, 1981). The order required executive agency heads to adhere to the following standards when promulgating new regulations, reviewing existing regulations, and developing legislative proposals concerning regulation: (1) Administrative decisions shall be based on adequate information concerning the need for, and consequences of, proposed governmental action; (2) regulatory action shall not be undertaken unless the potential benefits to society from the regulation outweigh the potential costs to society; (3) regulatory objectives shall be chosen to maximize the net benefits to society; (4) among alternative approaches to any given regulatory objective, the alternative involving the least net cost to society shall be chosen; and (5) agencies shall set regulatory priorities with the aim of maximizing the aggregate net benefits to society, taking into account the condition of the particular industries affected by regulation, the condition of the national economy, and other regulatory actions contemplated for the future.

One effect of the order is to require expanded use of risk assessment methods in regulation because the required benefit and cost analyses cannot be conducted without data on the benefits and costs of risk reduction. Given the president's presumption that much federal regulation could not be justified on this basis, the execution of his order attracted considerable attention. It was a bold attempt to deal with the problem of overregulation that the president had made a major concern of his administration, and it would be a testing ground for the utility and impact of risk analysis and cost–benefit analysis. Indeed, the director of the new Office of Information and Regulatory Affairs (OIRA) in OMB responsible for implementing the order, Christopher DeMuth, observed that making "economic analysis a line function in the regulatory agencies and in the Office of Management and Budget was a qualitative departure from all that had come before, and a decision that was, and remains, controversial" (DeMuth, 1982).

It was controversial in part because of the conservative policy agenda the Reagan administration brought to office and the aggressiveness with which it was put into effect (see, e.g., Nathan, 1983; Tolchin and Tolchin, 1983; Vig and Kraft, 1984). Whatever the merits of the president's policy agenda, the administrative strategy used to achieve policy change, including the role of DeMuth's OIRA, increased public and congressional concern that health, safety, and environmental policies of the last decade were being significantly weakened without sufficient analysis of the consequences (Kraft and Vig, 1984). Thus, when the Task Force on Regulatory Relief issued a final report on its deregulation program citing some $150 billion that business and consumers would save over the next decade as a result of White House initiatives, it was greeted with skepticism by consumer advocates; they

challenged the alleged monetary savings and criticized the contention that elimination of regulations had been accomplished "without compromising important environmental, health, or safety objectives" (Wines, 1983a). There were also allegations that OMB overstepped its legal authority on some environmental decisions; congressional testimony by former Environmental Protection Agency (EPA) officials included charges that OMB tried to dictate regulations to EPA, urged that cost factors be considered in setting health rules where the Clean Air Act prohibited them, threatened reprisals against the agency, and showed proposed rule changes to industry officials before they were made public (*New York Times,* 1983).

In general, critics charged that the administration had seized the regulatory bureaucracy but failed to reform it, and that it had politicized regulation rather than making regulatory decision making a more dispassionate process based on professional analysis of risks, benefits, and costs (see, e.g., Wines, 1982, 1983b; Eads and Fix, 1984). There continued to be consensus on the need for regulatory reform and on the desirability of using cost–benefit and risk analysis where feasible and appropriate (e.g., Swartzman, Liroff, and Croke, eds., 1982), but many were not persuaded that the Reagan administration would adhere to such professional standards. Enough of a backlash against the administration's efforts at deregulation had developed by late 1982 that the much touted regulatory reform bill in Congress went down to defeat when House Democratic leaders refused to back the proposal. That measure would have required the use of cost–benefit analysis as part of a mandated "regulatory analysis" that would be conducted on major proposed rules (those generating $100 million or more a year in compliance or enforcement costs). The requirement would have applied to both independent and executive agencies, whereas the president's executive order did not cover independent agencies such as the Nuclear Regulatory Commission (NRC). The act also would have made court challenges to agency rules easier by placing a greater burden on the agency to support its decisions.

By mid-1983 there was an effort within the administration to encourage more systematic use of risk assessment, particularly within the EPA. In an address to the National Academy of Sciences shortly after replacing Anne Burford as administrator, William Ruckelshaus called for a uniform federal policy to assess and deal with risks to public health, safety, and environmental quality. He indicated that there was broad support within the administration for developing a policy that would include a common "formula" for risk assessment, established by law (Shabecoff, 1983; Mosher, 1983). Consistent with those intentions, by late 1983 the EPA issued several preliminary rules dealing with radiation from active uranium mills, arsenic emitted into air, and industrial emissions of benzene, and announced a new national plan to address the problem of dioxin in the environment. However, Ruckelshaus's inability to formulate an acid rain policy acceptable to the OMB and the White House indicated the continuing difficulty of performing risk assessments in areas where scientific knowledge is too limited or applying risk assessments in policy decisions where economic and political pressures constrain their use. The decisions on uranium, arsenic, and benzene also suggested that the Reagan administration would set higher risk levels than allowed in previous administrations, reflecting its different policy priorities.

Political Science and Risk Analysis

Partly because of the increased prominence of regulatory reform issues and heightened public concern for technological risks like nuclear power and toxic and hazardous materials, political scientists and public policy scholars have recently developed an interest in risk analysis. Aside from the substantial amount of work on regulation and regulatory reform cited above, the literature on risk analysis to date that incorporates the perspectives of these

disciplines is modest in size and scope. However, to judge from recent journal symposia, professional papers, and books and articles on the subject, there is reason to expect sizable growth in the number of future contributions and increasing importance and policy relevance of the work produced.

Both political science and public policy studies in general are characterized by a diversity of approaches, as is work on risk analysis. Even with such diversity, however, there is a distinctive perspective that political scientists bring to the study of risk analysis. The discipline is concerned chiefly with the systematic study of political behavior, political processes, governmental institutions, and public policy; and a major interest is description and explanation of decision making within governmental institutions, particularly the formulation, adoption, and implementation of public policies. Thus, political scientists and policy scholars are especially well equipped to address some of the most important questions about what happens to risk assessments after the technical work is completed. What conditions influence the use and impact of risk analysis in different institutional settings (e.g., executive agencies, congressional committees, federal and state courts)? In what way do political incentive systems, institutional characteristics, legal constraints, and public preferences shape regulatory decision making involving risk analysis? What is the probable impact on such decision making of the various suggestions for regulatory reform? What particular political or organizational arrangements are likely to enhance the use of risk analysis and promote technically sound and accountable decision making? The developing literature within these disciplines offers useful if tentative answers to such questions (e.g., Sabatier, 1977; Nelkin and Pollack, 1980; Mann, ed., 1982; Tobin, 1979; Bartlett, 1980; Vig, 1979, 1984). Some scholars with a more normative bent cast a wider net to describe the social, cultural, and philosophical context of risks and to critique present policies and priorities (e.g., Douglas and Wildavsky, 1982). Others make a strong case for the importance of democratic mechanisms for accountable decision making on issues related to technological risks (e.g., Nelkin, 1981).

A recent symposium on public policy toward risk illustrates the diversity of concerns and suggests the utility of such work. Contributors describe the use of risk analysis in federal agency decision making, technical disputes among experts and the effect on risk policy, organizational responses to issues involving risk (e.g., risk assessment in the courts), and new institutional arrangements that might facilitate risk management (Hadden, 1982). A parallel volume on institutions and risk control describes current risk control strategies in executive agencies, Congress, and the courts; problems of accountability and credibility in managing complex technological risks; and the feasibility of alternative institutional structures and processes such as science courts and regulatory mediation (Hadden, 1984). Work now in press or in progress indicates that scholars are turning increasingly to empirical studies of risk assessment in regulatory processes. Environmental decision making in the EPA, hazardous waste management, and risk assessment in policies regulating carcinogens are receiving special attention (Mogee, 1985; Thomas, 1985; Lester and Bowman, 1983). Another line of inquiry concentrates on comparative state policy making involving risk assessment of toxic and hazardous materials (Matheny and Williams, 1981; Lester, Franke, and Bowman, 1983).

These initial research efforts represent only a small part of the contributions that political scientists and policy analysts might make. Several comprehensive reviews of the field of policy analysis that have appeared in the last few years and recent compilations of work in this discipline as well as in political science suggest a wide variety of research that might be applied to problems of risk analysis (Hansen, 1983; Nagel, 1983; Eyestone, 1985; Edwards, 1985; Anderson, Gitelson, and Dubnick, 1985). Some areas of particular interest will be suggested in the conclusion of this chapter.

RISK ANALYSIS IN REGULATORY DECISION MAKING: PERSPECTIVES FROM EXECUTIVE AGENCIES AND CAPITOL HILL

As the brief review of current literature in political science and policy studies makes clear, one of the central concerns motivating current inquiry into risk analysis is the way in which political and institutional variables affect the conduct, use, and impact of risk analysis in federal regulatory policy. In 1979–1980, the National Science Foundation awarded a major grant to the J. H. Wiggins Company of Redondo Beach, California, to initiate a comprehensive, interdisciplinary study of risk assessment methodologies and their employment in governmental risk management decision making. The purposes of that research were to identify the range of federal activities in which risk management decision making is of particular importance, to sample the decision analysis and policy analysis processes associated with those activities, and to investigate the extent to which formal risk assessment methodologies are or could be utilized in these processes.

Part of the project involved an extensive review of the technical literature on risk assessment to determine the limitations and uncertainties associated with its methodologies, to determine means for improvement in those methodologies, and to recommend means for more effective use of these methodologies in decision making. The results of that technical work are reported in Chapter 13. Another part of the project involved a wide-ranging review of federal policy activities concerning risk analysis and a series of case studies of particular risk assessments and their use in selected policy areas. That work has also been described elsewhere (Atkisson, Kraft, and Philipson, 1985). Finally, one part of the project involved an empirical study of agency and congressional perspectives on the value and use of risk analysis, based on interviews with policy actors in selected regulatory agencies and on Capitol Hill. This section of the chapter reports the major findings and conclusions of that research.

A brief statement on the methodology and orientation of the study is necessary. The documentary record provides abundant information on agency and congressional activities concerning risk analysis. To understand the conditions affecting the use of risk analysis, however, that documentary record must be supplemented with data on informal administrative behavior and attitudes of key policy actors in the agencies and on Capitol Hill. To gather such information, semistructured interviews were conducted in January and in July 1981 with regulatory agency personnel and congressional staffs.* Not all agencies could be covered, but those selected represent a diversity of policy areas and statutory requirements involving risk analysis. This report summarizes the aggregate findings from these interviews, discusses how the use of risk analysis and perceptions of its limitations vary across agencies and across policy areas, and examines the present and potential role of risk analysis both

* The agencies covered in the study included the following: the Nuclear Regulatory Commission, the Occupational Safety and Health Administration, the Food and Drug Administration, the Consumer Product Safety Commission, the Environmental Protection Agency, the Materials Transportation Bureau of the Department of Transportation, and the Office of Minerals and Energy of the Department of the Interior. Interviews were also conducted with professional staffs in the Regulatory Council, the Office of Management and Budget, the Council on Environmental Quality, and selected congressional committees and policy advisory bodies. The most important in the last category were the General Accounting Office, the Office of Technology Assessment, and the Congressional Research Service. Within each agency, office, committee or advisory body, individuals were selected for interviews based on several criteria: formal positions held in offices responsible for risk assessment or regulatory analysis, membership on the National Academy of Sciences–National Science Foundation Risk Analysis Liaison committee, and/or reputation for extensive involvement with risk analysis. This is a group familiar with the methodologies of risk assessment and knowledgeable about agency and congressional procedures regarding its use. Most interviews were recorded, allowing excerpts from the transcripts to be used here.

in the agencies and on the Hill. Particular attention is given to the problems of using risk analysis and various needs for improvement cited by the policy actors interviewed. Given the exploratory nature of the research, only qualitative analysis of the interview data is warranted.

Overview of the Findings

Interviews with policy makers and staff professionals in 1981 indicated recent pressure to make greater use of risk analysis. Thus, while formal risk assessment techniques had not been used very extensively in the past, their use has increased significantly in recent years and is very likely to increase further in the future. Most of those interviewed supported their continued employment, especially when accompanied by further methodological refinements and greater appreciation of their limitations as tools of policy analysis. But attitudes of individual staff and decision makers toward risk assessment ran the full range from highly positive to strongly negative. The range of perspectives and actions can best be demonstrated with a few illustrations.

The Materials Transportation Bureau (MTB) in the Department of Transportation, for example, has made extensive use of risk assessment, and has contracted for several outside studies in the last few years. But one of its top officials nevertheless expressed some modest doubts about this analytic tool: "[We have spent] what I would say is a considerable sum on risk analysis studies. . . . Almost every function that we perform here has some sort of risk analysis associated with it. [But] I don't know how to characterize my attitude toward it. Risk analysis is rather a black art in some ways."

Supportive statements of this type, even with the reservation noted, were made by the majority of staff and officials interviewed. But some were notably less enthusiastic. A commissioner on the Consumer Product Safety Commission (CPSC), for example, recognized the utility of measuring risk, but was skeptical that it could be done very precisely: "I personally find risk assessment useful, but not as a major element of a decision. I don't have a lot of faith in it. There's too much uncertainty about the exposure, about mathematical models that are used to make the extrapolations down at the low-dose range. . . ."

In all agencies surveyed there was some awareness of the technical limitations of risk analysis, a matter of no little concern to the critics of this methodology (e.g., Baram, 1980; Bogen, 1980). The problems most often mentioned included an inadequate data base (e.g., insufficient epidemiological data), the difficulty of estimating the impact of low-probability but high-consequence hazards, the challenge of analyzing phenomena at the limits of scientific understanding, the measurement of the benefits of risk reduction, and uncertainties in establishing acceptable levels of risk. These problems seem to have been recognized and taken into account by technical staff and by most decision makers interviewed. As one biostatistician put it "I would say people are realistic here. You do the best you can. We're dealing with the best available evidence."

Yet there was also considerable concern expressed about the potential for misuse of risk analysis by those unfamiliar with such technical limitations. Statutory requirements may force risk–benefit calculations on officials who would otherwise hesitate to make them. And political pressures from Congress and the administration to use risk analysis or cost–benefit analysis in what some officials consider to be an "invalid" manner have been increasing.

Intraagency Variation in Attitudes toward Risk Analysis

There is, not surprisingly, a good deal of variation within agencies in knowledge of risk assessment methodologies and in perception of their utility and their limitations. Agency

personnel have different roles, values, interests, and perspectives, reflecting their professional training and experience. The major differences noted in the interviews were among the technical, legal, administrative, and political staffs.

A conflict mentioned by several officials was that between natural scientists and other staff, particularly in dealing with "imperfect information," or uncertainty. One Occupational Safety and Health Administration (OSHA) administrator suggested that the "hard scientists" were a real problem in that they acted as if the agency had unlimited resources and no time constraints on action: "They refuse to recognize the need to set priorities." A member of the scientific staff, in turn, made repeated references to the pressures on scientists to "move away from good science" to accommodate the "legislative mandate" imposed on OSHA (especially after the Supreme Court's benzene decision calling for quantitative risk assessment).

Another common theme was conflict between the scientific and policy staffs and the legal staff. For example, an official in the Food and Drug Administration (FDA) commented: "Our scientific people have a lot of policy history in their heads, the senior or older ones. Our senior regulatory people have a lot of science. . . . Where you don't have that kind of kindredship is with the lawyers, because the lawyers tend to turn over very, very rapidly."

Differences such as these can and do result in significant internal conflicts, misunderstandings, and communication difficulties. In some agencies the conflict seems to limit the use of risk assessment (the EPA appears to be one example), and in others, perhaps because of greater adaptation over time, it appears to be of less consequence (e.g., the FDA). The existence of intraagency variation and conflict is not unexpected, but does need to be considered in explaining agency decisions and in devising administrative procedures involving interaction of diverse professional staffs.

Interagency Variation in the Use of Risk Analysis

The extent and type of use of risk analysis varies significantly from agency to agency. This is to be expected given differences in the kinds of policy problems dealt with, statutory mandates, organizational characteristics, and attitudes of decision makers toward risk analysis. Differences in the problems facing each agency are perhaps the most obvious. Some problems are simply more amenable to risk assessment than others. Variables can be more easily identified and controlled, data are available, and the findings can be applied relatively easily. An example is the FDA's assessment of food additives. But consider, in contrast, the task facing the MTB in controlling transportation of hazardous materials:

> You can take isolated pieces of our business and apply risk analysis—specific commodity, specific containment system, specific pathway—and the minute you change any one of those three things, that risk analysis is gone. So what I am dealing with here is not billions, but trillions of permutations. And nobody has shown me the methodology to be applied generally.

Statutory differences are also fairly straightforward. Agencies and policies were created at different times and with varied expectations (Field, 1981). Independent agencies operate in a more flexible political environment than those directly accountable to the White House and OMB, a point noted by several officials. And legal constraints on the use of risk assessment (is it required or not, who has the burden of proof, etc.) directly affect decision making. An official at the MTB noted explicitly the legal environment and its impact.

> [Suppose] a guy wants to build a liquefied natural gas trailer having a 100 hours hold time, and I say "no, too risky, based on my model; I want 200 hours hold time," and I raise the cost of the trailer by $28,000. Could I make something like this hold up? My decision-making process is intertwined with legalistic-type circumstances that I must do business with every day. I deny ex-

> emptions and give reasons. I've never denied an exemption because [a risk assessment] says it's too risky. I've denied it on technical grounds or policy grounds.

Among the agency characteristics that seem to influence the use of analysis are internal capability for performing the technical assessments (primarily having the scientific or technical staff on board), the existence of well-established procedures for risk estimation and evaluation, extent of experience with these techniques, and financial resources to support the work. The attitudes of top policy makers toward the use of risk assessment also seem to be significant. Funding levels understandably affect the degree of activity. A senior official at the MTB said, for example, "I don't see that it will ever be funded at a level where we would call it a major working tool of this office." Equally clear is the influence of top political appointees. An OSHA official admitted (in July, 1981): "We have not engaged in new standards development since the change in administration, and therefore, I'm not sure exactly what the mechanics are going to be. We've been concerned with reviewing some standards that were already out or proposed. It may be different than it was."

The effect of some of the other variables is less demonstrable, but the interview data point to their significance. More detailed study of the conditions influencing the extent or type of use of risk assessment should include examination of the comprehensive set of variables found to be important in regulatory agencies and policy implementation more generally (see, e.g., Sabatier, 1977; Mazmanian and Sabatier, 1983).

Agency Procedures and the Methodology of Risk Assessment

Given the increasing use of risk assessment in regulatory decision making, it is not surprising that a consensus is developing on the most appropriate methodologies. A number of interagency coordination groups have arisen over the past few years and have worked to establish guidelines for the conduct of risk assessments. This type of development is especially evident in the area of carcinogens (Bogen, 1981; IRLG, 1979). Thus, a technical staff person in OSHA reported: "We use EPA methodology in a lot of our work. The work has undergone critical review and represents a reasonable state-of-the-art approach, we feel, to some of these problems. I think there's . . . a consensus on approaches to doing risk assessment."

There is no equivalent consensus for administrative procedures in developing standards and regulations. Some agencies have well-defined, formal procedures; others are just beginning to develop them. What is done seems to depend greatly on the particular case because, as an FDA official put it, "each case presents you with new problems and new opportunities." Typically, however, the risk assessment is performed by a technical or scientific staff, is sent to an office of regulatory analysis where some form of economic analysis is done, and then is sent to the policy makers for a final decision on standards. Unlike the apparently routine work of technical staffs, the regulatory analysis staff is faced with the numerous uncertainties involved in risk evaluation, especially in the calculation of costs and benefits of regulation. As noted above, President Reagan's 1981 executive order on cost–benefit analysis in the agencies represented a major effort to bring some consistency to these procedures. At this writing, however, there is still considerable variation in agency methods of risk evaluation and in the procedures followed after the technical job of risk estimation.

To judge from the interviews, most agencies have adapted to the inherent limitations of risk analysis and to the political context in which regulatory policy operates by developing informal procedures. In OSHA, for example, the regulatory analysis office reports are "not

a one shot deal, [but result from] an iterative process," involving repeated discussions with the political officials and multiple studies and draft reports. In the FDA, there is usually "a collaborative effort between the scientists, on the one hand, and the consumer safety officers on the other. They work it out in a collaborative, cooperative way." When the reports reach the commissioner's office, the dialogue continues, with sharp questioning of the science, the legal implications, and the consistency of judgments made.

> The reason you need all of this interaction between science and policy . . . to come to a regulatory decision is that because of the softness, because of the uncertainty, we cannot, should not, be capricious. And if you just left the technical people to their own devices, they can, unwittingly, be quite capricious. Because they are not the guardians of the overall process, that assures some degree of consistency.

These kinds of procedural adaptations seem particularly significant in light of extensive criticisms of the methodological inadequacies of risk analysis. They help to minimize the use of poor analysis or poor data by subjecting the risk estimation and economic analyses to scrutiny by a diverse set of participants. Maintenance of such a pluralistic decision-making process seems to be an important characteristic of several of the more "successful" agencies.

Methodological Improvements

Despite the constraints noted above, improvements in methodologies will likely produce greater use of risk assessment across a broad range of policy problems. The interviews elicited several noteworthy suggestions for such improvements, including ways of dealing with uncertainty and ways to present it, expansion of data bases, the level of specificity of the assessments, the format in which studies are presented, and consistency in risk evaluation methods. Space here allows only a few brief comments, but additional suggestions emanating from the congressional interviews are presented below.

Most of those who work with risk assessment would endorse the need for expanded data bases, but a special effort needs to be made to develop them. As an OSHA administrator noted, there is a need to create incentives for doing so: "Most people in high levels of public service have a fairly short-term horizon . . . and many of them object to developing long-term kinds of data bases . . . which may not be of much benefit to the current generation of decisionmakers."

The specificity or concreteness of a risk assessment is also important. Excessively general risk analyses were dismissed by one official in the MTB as essentially worthless, whereas one that "really worked" addressed specific questions the office had to face and presented the material in readable and direct English rather than in technical jargon. Similarly, a technical official at the NRC noted a case in which the commission "used [the] risk assessment in a decision, clearly and explicitly." It was one that the commission requested the staff to prepare in "just a few weeks" on a particular plant. It was done quickly and was geared to answer the specific questions posed. The lesson seems to be that to facilitate direct utilization of risk assessment, there is a need to understand, as an Interior Department official put it, "what it is that people who are making policy need to have in order to feel comfortable in decisions." While these examples do not imply that a single approach or style is appropriate for all risk analyses, they do suggest a need to improve institutional capabilities for performing specific risk analyses quickly and cheaply. They also suggest the importance of using a language, style, and format suitable for a policy-making audience of nonspecialists.

Consistency in risk evaluation methods was not mentioned as frequently as other prob-

lems, but is clearly an area in need of improvement. Consider the following statement by an official at the NRC:

> Most regulators make decisions in a fashion that's quite similar. Information is put on the table, technical information, and the regulator looks at it, circles the table three times, and casts a judgment column on the table. And that's a regulatory decision. And then the regulator tries to defend that decision through a hearing process or a public comment process or whatever the regulator has to do. The real issue is what's the information you put on the table and how do you sort it out? Because in the last analysis it does boil down to judgment. In any complex regulatory field no simple formula will suffice.

This perspective is an important reminder that most of the professional commentary on risk analysis concerns technical issues of risk identification and risk estimation. Much less attention has been given to the manner in which judgments are made about the acceptability of risk. This omission is particularly striking because it is the supposed arbitrary or biased process of determining the public interest in these matters that provokes so much dissent about governmental regulation in the 1980s. An examination of congressional involvement with risk analysis should be especially instructive on these critical and largely ignored processes of risk evaluation.

RISK ANALYSIS IN CONGRESS

Most discussions of risk analysis in regulation focus on administrative agencies. Although this focus in understandable, federal agencies are implementing policies enacted by the Congress exercizing its constitutional lawmaking powers. Congress has been quite active in legislating regulatory policies, and most of these policies, of necessity, give wide discretion to agencies to determine appropriate standards and regulations. As a consequence of the controversies that have arisen over agency decision making and the use of risk assessment, Congress in recent years has taken a serious interest in the subject. That interest can best be described as part of a more general concern with regulatory reform. But legislation has also been introduced to improve the methodologies and applications of risk assessment through research and demonstration projects; and numerous oversight hearings have been held in the last several years in response to decisions of the Reagan administration. Because Congress has the legal authority to alter public policies governing agency activities and can influence agency actions through oversight hearings and budgetary decisions, it is obviously an important institution shaping the future of risk analysis.

For present purposes, one might add that Congress is especially important because it is the most representative branch of government. It is also a strong and independent institution capable of challenging the executive branch, and often more friendly to interests ignored by the administration. In the early 1980s, for example, consumer and environmental groups found Congress much more receptive to their arguments than was the Reagan administration. If technical expertise lies in the agencies and legal expertise in the courts, Congress can lay claim to political expertise in the best sense of that term. A major challenge of modern government is to make policy choices that are responsive to public demands or needs as well as "correct" technically; and Congress is the institution best suited for keeping government accountable to the public, if not necessarily for ensuring that public policy is always coherent or economically efficient. The use of risk analysis in the legislative process should be assessed with those needs in mind.

The Major Issues

In contrast to the fairly well-defined role of risk analysis in the agencies, there is no agreement on the way in which risk analysis is used or ought to be used in the legislative process. The lack of consensus was evident in a major set of hearings held in July, 1979 (U.S. Congress 1980a, 1980b). Many of the problems with risk analysis identified there parallel those noted in the agency interviews. Among other significant problems or issues raised were the poor understanding of risk on the part of the general public; the inadequate coverage of risk-related events, probabilistic concepts, and conflicting scientific claims by the media; and the most appropriate role for Congress in risk–benefit analysis. Regarding the last, there were two sharply contrasting views: (1) that Congress should not be involved in the day-to-day or routine decisions of risk management, but should limit its actions to setting policies and criteria for evaluating the acceptability of risk (that is, the more political decisions), and (2) that risk–benefit analysis is too subjective to leave solely to agencies and reputed "experts," and therefore that members of Congress should play a much expanded role as the legitimate representatives of the American public.

The present study, of course, was designed in part to provide reliable, if tentative, information about the present degree of interest in risk analysis on the Hill, the prevailing perspectives toward its employment in regulation, and problems and needs in congressional use of risk analyses. The role that Congress ought to play is a matter of political preference or judgment about relative institutional capacities. But some of the information presented below may bear on those preferences and judgments.

Congressional Interest in Risk Analysis

In a review of risk analysis in the U.S. Congress, Moss and Lubin (1981) report that "risk analysis is part of the legislative process and is being used all the time, in a great variety of ways." Certainly, one can find corroborative evidence for the assertion in the range of committees with formal legislative or oversight responsibility involving risk analysis, and in the number and variety of congressional hearings and studies in the past few years (Kraft, 1982a; U.S. Congress 1980c). Yet productive legislative activity in the committee rooms does not necessarily indicate widespread interest among the general membership of Congress, or appreciable understanding of the technical difficulties in conducting risk assessments. Interviews with House and Senate committee staff as well as with staff of the Office of Technology Assessment (OTA) and the Congressional Research Service (CRS) confirm those suspicions.

For example, according to a senior staff member of the Science Policy Division in CRS, the basis of current interest in risk analysis is largely the politicization of the regulatory reform movement; members and their staffs believe they need to cover themselves by keeping abreast of any new developments in the area, but they have little interest in probing deeply. Consequently, he said, they have little understanding of the complex methods of generating risk assessments, the uncertainties involved, and scientific disagreements.

The conclusions lead to a somewhat complex answer to the question of congressional interest and involvement in risk analysis. To judge from the activities of key committees and the more technically sophisticated members, risk analysis is solidly on the congressional agenda; Congress is deeply involved and likely to play a major role in the future. At the same time, the majority of members remain only marginally interested; their role in any future risk policy activities is more difficult to predict. There are some important implications for what Congress needs to know about technological risks and risk assessment methods.

Problems Identified by Congressional Staff and Suggested Improvements

Interviews with congressional staff substantially reinforced the general picture presented in the joint hearings. Some of the technical limitations were underscored and additional problems of a political and institutional nature were mentioned. Some of the more significant comments merit review here. They will be presented under three categories: methodology, available resources, and institutional capacity.

Methodology. Nearly all individuals interviewed on the Hill noted the general difficulty in performing risk analyses, mentioning one or more of the technical limitations discussed earlier. As one division director of the OTA put it, the problems addressed are often complex and too difficult to analyze, and scientists are not always equipped to answer the kind of questions posed by members of Congress. Congressmen often say "give me a number"; they have relatively less interest in the methods used to reach conclusions than in the "bottom line" of the study. A staff member in the CRS noted, similarly, that scientific capabilities are "not high," and that this was not understood by most members of Congress. Thus, there is often a conflict between politicians eager to identify, measure, and mitigate risks—in order to respond to public demands to "do something" about the risks—and the scientists who must perform the assessments.

The complex nature of risk analysis, limited scientific capability, and the production of varying estimates of risk lead congressional staff and the technical advisors in OTA and CRS to one of two distinct positions: (1) that present methodology is inadequate and must be improved before risk assessments can be of much use to Congress or (2) that scientists must learn how to work with the present limited capabilities and should not wait for improved methodologies. The first position is characteristic of "scientific purists" who are more removed from the day-to-day decision making on the Hill. They tend to invoke professional standards and to speak critically of "premature" application of risk assessment methodologies. The second position was more common in the group interviewed. It reflects the position of those staffers more sympathetic to the need of members of Congress to act in the short term than to the protestations of scientific staff that more research and methodological improvements are necessary before any advice can be rendered. Thus, what members need most, said one division director at OTA, is a kind of "macro-risk analysis" to allow them to "rationalize policy decisions" in order to explain to their constituents the basis for their actions.

Resources. In a recent review of environmental risk analysis, Moss noted that the nation lacks the resources necessary to gather and analyze comprehensive data on a wide range of environmental problems. If legislatures insist on "airtight arguments" to make decisions, he said, scientific resources will be severely strained; the cost of data gathering and analysis "may be staggering" (Moss, 1980). His observations were echoed by many of the professional staff interviewed. For example, according to a program director at OTA, the amount of money available to conduct the studies is simply not sufficient to answer the questions put to OTA by members of Congress. He added, "there is not likely to be any significant improvement in that picture anytime soon."

What is needed for the future? There is no easy answer. Some call for substantially greater investment in research and training programs to improve scientific capabilities for performing detailed risk assessments. They believe that only such scientifically valid studies will suffice given the sharp political conflict surrounding the major regulatory issues. But others suggest that limited budgetary resources can be invested with a greater return if the

scientific community gives more emphasis to economical ways of performing risk assesments. Members of Congress and interested parties would have to settle for less definitive answers to technical questions, but might make more progress in setting policy if they reach agreement on what methodologies would be acceptable for such purposes.

Institutional Capacity. Congress is often criticized for its institutional weaknesses. Overlapping committee jurisdictions, limited capacity for highly technical policy analysis, vulnerability to pressure from a range of narrow interest groups, and a tendency toward short term and palliative solutions to policy problems are commonly noted. Similar arguments were made in the interviews. Two other major constraints on producing and using risk analyses deserve mention. Several high-level staffers in OTA and CRS emphasized the lack of an institutional mechanism for bringing together the scientific community and the decision makers. As one director in CRS explained, there is much ignorance and uncertainty in Congress on risk assessment, but scientists are not well equipped by themselves to improve the situation. The two sides reflect different professional training and perspectives, respond to different concerns, and often speak different languages. While he is "not quite sure why," he believes CRS and OTA cannot resolve this problem by themselves.

A second limitation is that congressional oversight of agency activities tends to be unsystematic and uncoordinated, and occurs irregularly. Investigations and oversight depend heavily on the motivation of senior committee members, available staff resources, and the expected visibility and political appeal of the proceedings (Aberbach, 1980; Ogul, 1976). Moreover, Congress is strongly supportive of much bureaucratic activity; committees or subcommittees which might otherwise be expected to provide oversight and criticism are instead closely tied to the particular "subgovernment" involved.

What might be done to improve institutional capacity? There has never been a shortage of recommendations for reforming Congress, and a number of the standard prescriptions are relevant for improving use of risk analysis. These include clarification of committee jurisdictions, provision of greater incentives and resources for oversight of administrative agencies, and enhancement of capacity for technical policy analysis. Perhaps the greatest need is for a mechanism or process for improving congressional understanding of the scientific issues in risk analysis. Much depends on the scientific community itself and on its willingness and ability to inform members of Congress and the public on technological risks. Those interviewed emphasized development of new ways of communicating with the public and with Congress, particularly for sorting out conflicting scientific claims and for presenting probabilistic concepts.

Comparing Congress and the Agencies

How does the use of risk analysis in Congress compare with its use in the agencies? And how might that change if Congress assumes one or another of the two roles identified earlier: more direct involvement in agency decisions of risk management through extensive use of its oversight functions, or more limited involvement, with emphasis on clarifying policies and criteria for evaluating risks? The first question can be answered through use of the interview data, but the second calls for some speculation on the institutional and political implications of the two roles?

For the most part, the use of risk analysis in these two quite different institutional settings is what one would expect given the characteristics and functions of the agencies on the one hand and Congress on the other. The former are highly specialized bureaucratic organizations staffed with technical and policy experts. They deal with a relatively narrow

constituency of knowledgeable individuals who demand well-developed and articulated rationales for agency decisions. Risk assessment is seen as a technical, if imperfect, methodology for providing information necessary for such decisions. Although the highest-level policy staffs are concerned with the more political processes of risk evaluation (particularly when subject to central review by the OMB), the agencies follow a well-defined procedure for developing and using technical information, and seek to defend agency decisions chiefly on those grounds. This is not to say that economic and political forces have no influence on regulatory decision making; obviously they are extremely important (Wilson, 1980). But agency decisions are also subject to judicial review and thus must be based on defensible interpretations of statutes and acceptable evidence and methods of analysis (Vig and Bruer, 1982). Lave (1983) puts it well: "A careful review of scientific evidence and a quantitative risk assessment should be the basis of regulatory decisions. Regulation without these elements is uninformed, arbitrary, and unlikely to withstand litigation, induce cooperation from those being regulated, or produce the results desired."

In contrast, Congress is an independent, intensely political, and highly fragmented institution. Decision-making authority on risk policies is dispersed among dozens of committees and subcommittees, making coordination of policies and consistency in evaluative criteria unlikely. Most members of Congress, including many on those committees, have little background in science and technology and pay little attention to the issues in risk policy. The general public they represent tends to misperceive and overreact to technological risks, but is ambivalent about safety and the cost of government regulation to that end (Harris, 1980). Congress mirrors both the poor understanding of risks and the ambivalence over regulation. Members expect risk analysis to clarify the political choices they face and to provide a partial rationale for their decisions. But there are no well-defined procedures for developing and using risk analyses—even in the relevant committees and subcommittees; nor do members defend their decisions mainly on technical grounds. Given the adversarial nature of the political process and their lack of scientific training, members often discount the scientific basis of regulatory decisions and stress legalistic standards of evidence, ideological values, the economic interests of particular industries or groups affected by regulatory decisions, or general public fears over health and safety.

In short, the use of risk analysis in the legislative process is affected not only by technical weaknesses in methodologies, but by the very nature of decision making in Congress. Members of Congress believe that "good public policy" emerges from a process of extended debate and deliberation that allows for a full airing of public and interest group concerns. They are not willing to rely solely on the analyses performed by scientific and professional experts in the agencies. In effect, Congress adds a strong measure of political rationality to the bureaucratic standard of technical rationality.

Can Congress play a more active role in the regulation of technological risks? Is public policy on risk likely to be improved if it does so? In terms of institutional capacity there are few major impediments to a more active congressional role in risk analysis. If the problems and needs identified above are attended to, Congress is probably capable of a good deal more involvement with regulatory actions in the agencies. There is more disagreement about whether assumption of such a role is desirable. Political scientists frequently have advocated a much greater oversight role for Congress in the belief that the oversight function is a particularly suitable one for representative legislatures (Huntington, 1973; Aberbach, 1980). As noted above, greater congressional supervision of agency use of risk analysis might bring a more democratic perspective to what tends otherwise to be technocratic decision making. Certainly public fears about risks would be more likely to be given consideration, and significant biases or procedural irregularities in the agencies would be less likely to

occur if a strong, independent congressional presence were assured. But other scholars and many scientists have argued that risk assessment belongs in the agencies and not in Congress. They believe public policy would not be improved through increased congressional oversight, partly because the direction and impact of that oversight may be affected by political pressure from well-organized interest groups and because members are too poorly informed to understand the scientific basis for agency actions. Instead they would have Congress limit its actions to reducing inconsistency in statutory mandates for risk assessments and clarifying evaluative criteria to guide agency decision making.

No one really knows, of course, precisely how use of risk analysis would change if Congress assumed a more active role. But regardless of preference for one kind of institutional decision making or another, it seems clear that Congress will necessarily be involved when agencies consider or adopt health, safety, and environmental regulations having a significant impact on the American public. Moss and Lubin (1981) explain why:

> We can't turn back the clock of political mood. We can't tell legislative bodies that they will have to wait for better science, or better risk assessment methodology, or better risk-balancing institutions (mechanisms) to develop from the better science.

Rather than debate the merits of variable congressional or agency roles, one might better assume that Congress has certain political needs that must be met and proceed to develop the institutional capacity that will allow Congress to participate in regulation of technological risks. To do otherwise is to invite continuous controversy and regulatory stalemate.

Development of such an institutional capacity is no easy trick. The internal dynamics and organization of Congress militate against efficient or coordinated approaches to risk policy, and in general there are too many policy issues, too many competing demands for scarce resources, and too little time for members to make risk policy a high priority item on the congressional agenda. But the kind of risk analysis that Congress needs should be clear enough from the interview data and discussion above. It is not going to use risk analysis the way the agencies do and does not need to have the expansive research base that scientific "purists" typically advocate. Members do need to understand the basis of agency decisions, however, and be able to separate the factual elements in risk analysis from the judgmental. To provide such information to Congress, the scientific community and agency decision makers need to develop more flexible methods of risk analysis and to learn to communicate methods and findings to members more clearly. Experimenting with a diversity of approaches should provide some evidence on what kind of information and what kind of procedural arrangements are likely to be most effective toward these ends.

CONCLUSION AND FUTURE RESEARCH NEEDS

Risk analysis is not now and will not ever be a panacea for dealing with the multiple hazards of modern industrial societies. Even if methods of risk estimation are further refined and other limitations on their use are overcome, there will remain the subjective element inherent in evaluating risks and devising appropriate public policies or regulations. But risk assessment methodologies can be useful tools in this process if employed carefully and with proper regard for the uncertainty of scientific knowledge.

Beyond the particular study reported here, a larger research agenda for political science and policy studies can be constructed that might lead to greater knowledge about successful performance of risk assessments and risk evaluations within regulatory decision making. No

order of priority is implied in this exercise, although some research is likely to be viewed as more valuable or useful from one perspective or another. The focus here is on political science, but interdisciplinary research is obviously appropriate for some lines of inquiry. Among the topics of special interest from a political science perspective are case studies of decision making, institutional characteristics and capabilities, risk evaluation processes, attitudes of political decision makers toward problems of risk and risk analysis, and comparative analysis of state and local decision making on risk policy. Each will be discussed briefly.

Case studies of policy decisions are often considered to be of less scientific value than analysis of aggregate data of some kind. Certainly generalization beyond a case study is hazardous, but detailed study of decisions involving risk analysis is more likely to reveal the range of factors that affect the way in which risk decisions are made. Case studies can be performed within any institutional setting (e.g., Congress, executive agencies, the courts, state governments, local government) and can make good use of documentary records as well as interviews with participants in the decisions. Comparative case studies might reveal why risk analysis works well in some areas and less well in others, or why decision makers in some institutions are better equipped or more inclined to use such information than those in other settings. A full case study that traces action from the discovery of a particular problem to policy formulation and adoption and through to the development of an appropriate risk assessment and its use might be especially instructive.

There is a similar range of studies that might be made of institutional characteristics and capabilities. The research report included in this chapter indicates some possible paths of study, but much more might be done. Here also any institutional setting can be the object of study, with Congress, executive branch agencies, and the courts obvious candidates. Studies of congressional support agencies and congressional committees might focus on capabilities for performing or providing risk assessments and ways that information might be presented in a more effective manner. Agency decision making should be a prime target of inquiry; studies of each of the major regulatory agencies would be useful, and might focus on resources available, capabilities, procedures used for performing risk assessments, processes of risk evaluation within the agencies, and the impacts of such decisions on policy objectives. The OMB now plays such a critical role in regulatory review that study of its procedures for review, capabilities, decisions reached, and impact on agency rule making would be extremely interesting; data collection, however, might be a problem inasmuch as the new regulatory review process is not accompanied by a documentary record open to the public. Because the courts are increasingly involved in review of regulatory decisions concerning technological risks, studies of judicial capabilities, decisions, and policy impact would also be valuable. Finally, because there has been much discussion and proposal of alternative institutional arrangements for facilitating risk analysis, empirical studies of how such arrangements have worked when tried on an experimental basis would be of value. Comparative analysis of state and local arrangements of this kind (e.g., environmental mediation) might be especially appropriate.

Because risk evaluation is largely a political decision, it is especially suitable for study by political scientists. Where, how, and by whom should risk evaluations be performed? What methods of risk evaluation are used, and how well do they measure up to standards of political legitimation as well as to standards of technical rationality? To what extent are public perceptions of risk accurately communicated to decision makers, and to what extent is there an opportunity for public participation in such decisions? What are the respective and legitimate roles for professional staffs in the agencies and on the Hill, the scientific community, appointed officials, and elected policy makers? Risk evaluation might be studied

in any institutional setting and at any level of government, but scholars might well focus on decisions made in Congress, in the regulatory agencies, in OMB, and in the courts.

Studies of attitudes of political decision makers toward risks and risk analysis might help to clarify their understanding of both, the sources of information to which they turn, problems in using such information in the decisions faced, and the needs they have for different information or information presented in a different way. Such studies might tell us something useful about the perceived utility and feasibility of the alternative institutions most often suggested for providing information or resolving scientific disputes more constructively (e.g., science courts). Because those performing risk assessments often have little understanding of the perspectives and needs of policy officials, learning more about their attitudes and perceived capabilities to use technical information might result in more extensive or productive use of risk assessments in the future.

Finally, comparative studies of state and local decision making seem valuable in part because of the limited attention given to the subject to date and the increasing importance of decisions reached at these levels. From the location of hazardous power-generating facilities to the disposal of toxic wastes, local and state governments will be expected to assume greater responsibility in the future for protection of public health, safety, and environmental quality. To what extent do these governments have the resources and capabilities to make such decisions in a rational and responsive manner? How might resources and capabilities be increased? How well have they been doing so far in managing risks, and what factors explain variation among states and localities in risk management decision making? What changes seem desirable for the future if risk management is to be improved?

This is a long list of questions and suggestions, but it is meant only to be indicative of the kinds of research political scientists and policy scholars might conduct over the next several years. The chapter began with the observation that greater knowledge of political and institutional forces that affect the use of risk analysis is a prerequisite to the development of more effective means of dealing with technological risks. Studies of the kind noted here offer some promise of contributing toward that goal.

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REFERENCES

Aberbach, Joel D., 1980, "Changes in Congressional Oversight." *Making Bureaucracies Work*. Edited by Carol H. Weiss and Allen H. Barton. Beverly Hills, California: Sage Publications.

Anderson, James E., 1978. "Economic Regulatory and Consumer Protection Policies." *Nationalizing Government: Public Policies in American*. Edited by T.J. Lowi and A. Stone. Beverly Hills, California: Sage Publications.

Anderson, James, Alan R. Gitelson, and Mel Dubnick, eds., 1985. *Public Policy and Economic Institutions*. New York: JAI Press.

Atkisson, Arthur A., Michael E. Kraft, and Lloyd L. Philipson, 1985. "Risk Analysis Methods and Their Employment in Governmental Risk Management." Technical Report No. 83-1398-1, J.H. Wiggins Co., Redondo Beach, California, February.

Baram, Michael S., "Cost–Benefit Analysis: An Inadequate Basis for Health, Safety, and Environmental Regulatory Decisionmaking." *Ecology Law Quarterly* 8 (1980): 473–531.

Baram, Michael S., 1982. *Alternatives to Regulation: Managing Risks to Health, Safety, and the Environment.* Lexington, Massachusetts: Lexington Books.

Bardach, Eugene, and Robert A. Kagan, eds., 1982. *Social Regulation.* Rutgers, New Jersey: Transactions Books.

Bardach, Eugene, and Robert A. Kagan, 1982. *Going by the Book: The Problem of Regulatory Unreasonableness.* Philadelphia: Temple University Press.

Bartlett, Robert V., 1980. *The Reserve Mining Controversy: Science, Technology, and Environmental Quality.* Bloomington, Indiana: Indiana University Press.

Bogen, Kenneth T., "Public Policy and Technological Risk." *Idea: The Journal of Law and Technology* 21 (1980): 37–74.

Bogen, Kenneth T., 1981. "Coordination of Regulatory Risk Analysis: Current Framework and Legislative Proposals." Washington, D.C.: Congressional Research Service, June 19.

Breyer, Stephen, 1982. *Regulation and Its Reform.* Cambridge, Massachusetts: Harvard University Press.

DeMuth, Christopher, 1982. "A Strong Beginning on Reform." *Regulation* (January/February), pp. 15–18.

Douglas, Mary, and Aaron Wildavsky, 1981. *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers.* Berkeley: University of California Press.

Eads, George C., and Michael Fix, 1984. *Relief or Reform? Reagan's Regulatory Dilemma.* Washington, D.C.: The Urban Institute Press.

Edwards, George C., III, ed., 1985. *Public Policy Formation and Implementation, Part II: Policy Implementation.* New York: JAI Press.

Eyestone, Robert, ed., 1985. *Public Policy Formation and Implementation, Part I: Policy Formation.* New York: JAI Press.

Ferguson, Allen R., ed., 1981. *Attacking Regulatory Problems: An Agenda for Research in the 1980s.* Cambridge, Massachusetts: Ballinger.

Ferguson, Allen R., and E. Phillip LeVeen, 1981. *The Benefits of Health and Safety Regulation.* Cambridge, Massachusetts: Ballinger.

Field, Robert, 1981. "Statutory Language and Risk Management." Prepared for the Committee on Risk and Decisionmaking of the National Academy of Sciences, Washington, D.C.

Fischhoff, Baruch, Sarah Lichtenstein, Paul Slovic, Steven L. Derby, and Ralph L. Keeney, 1981. *Acceptable Risk.* New York: Cambridge University Press.

Graymer, LeRoy, and Frederick Thompson, eds., 1982. *Reforming Social Regulation: Alternative Public Policy Strategies.* Beverly Hills, California: Sage Publications.

Hadden, Susan G., ed., "Symposium on Public Policy Toward Risk." *Policy Studies Review* 1 (May 1982): 651–747.

Hadden, Susan G., ed., 1984. *Risk Analysis, Institutions, and Public Policy.* Port Washington, New York: Associated Faculty Press.

Hansen, Susan B., 1983. "Public Policy Analysis: Some Recent Developments and Current Problems." *Political Science: The State of the Discipline.* Edited by Ada W. Finifter. Washington, D.C.: The American Political Science Association.

Harris, Louis and Associates, 1980. "Risk in a Complex Society: A Marsh and McLennan Public Opinion Survey." New York: Marsh and McLennan.

Huntington, Samuel P., 1973. "Congressional Responses to the Twentieth Century." *The Congress and America's Future,* 2nd ed. Edited by David B. Truman. Englewood Cliffs, New Jersey: Prentice-Hall.

Interagency Regulatory Liaison Group, 1979. *Scientific Basis for Identifying Potential Carcinogens and Estimating Their Risks.* Washington, D.C.: Work Group on Risk Assessment, February.

Kraft, Michael E., 1982a. "Risk Analysis in the Legislative Process: Congress and Risk Management Decisionmaking." Technical Report No. 82-1398-2, J.H. Wiggins Company, Redondo Beach, California, April.

Kraft, Michael E., 1982b. "The Use of Risk Analysis in Federal Regulatory Agencies: Problems and Prospects." Technical Report No. 82-1398-3, J.H. Wiggins Company, Redondo Beach, California, June.

Kraft, Michael E., and Norman J. Vig, 1984. "Environmental Policy in the Reagan Presidency." *Political Science Quarterly* 99 (Fall): 415–439.

Lave, Lester B., 1981. *The Strategy of Social Regulation: Decision Frameworks for Policy.* Washington, D.C.: Brookings.

Lave, Lester B., 1983. *Quantitative Risk Assessment in Regulation.* Washington, D.C.: The Brookings Institution.

Lester, James P., and Ann O'M. Bowman, eds., 1983. *The Politics of Hazardous Waste Management*. Durham, North Carolina: Duke University Press.

Lester, James P., James L. Franke, and Ann O'M. Bowman, 1983. "A Comparative Perspective on State Hazardous Waste Regulation." *The Politics of Hazardous Waste Management*. Edited by J.P. Lester and Ann O'M. Bowman. Durham, North Carolina: Duke University Press.

Litan, Robert E., and William D. Nordhaus, 1983. *Reforming Federal Regulation*. New Haven, Connecticut: Yale University Press.

Lowrance, William, 1976. *Of Acceptable Risk: Science and the Determination of Safety*. Los Altos, California: William Kaufman.

Mann, Dean E., ed., 1982. *Environmental Policy Implementation*. Lexington, Massachusetts: Lexington Books.

Marcus, Alfred, 1981. "Measuring and Analyzing the Growth of Regulation." Paper presented at the 1981 Annual Meeting of the American Political Science Association.

Matheny, Albert R., and Bruce A. Williams, 1981. "Risk Assessment in the American States: Assessing the Assessors." Paper presented at the 1981 Annual Meeting of the Midwest Political Science Association.

Mazmanian, Daniel A., and Paul A. Sabatier, 1983. *Implementation and Public Policy*. Glenview, Illinois: Scott, Foresman.

Mogee, Mary, 1985. "Risk Assessment in the Regulatory Process: Rule Making in EPA." *Public Policy and the Physical Environment*. Edited by Helen Ingram and Kenneth Godwin. New York: JAI Press.

Mosher, Lawrence, 1983. "'Acceptable' Risk—Can the Government Decide Whether to Be Safe or Sorry?" *National Journal*, December 3, pp. 2529–2532.

Moss, Thomas H., 1980. "Environmental versus Emission Control Costs—A Legislative Perspective." *Atmospheric Sulfur Deposition: Environmental Impact and Health Effects*. Edited by D.S. Shriner, C.R. Richmond, and S.E. Lindberg. Ann Arbor: Ann Arbor Science Publishers.

Moss, Thomas and Barry Lubin, 1981. "Risk Analysis: A Legislative Perspective." *Health Risk Analysis: Proceedings of the Third Life Sciences Symposium*. Edited by C.R. Richmond, P.J. Walsh, and E.D. Copenhauer. Philadelphia: The Franklin Institute Press.

Nadel, Mark V., 1971. *The Politics of Consumer Protection*. Indianapolis: Bobbs-Merrill.

Nagel, Stuart S., ed., 1983. *Encyclopedia of Policy Studies*. New York: Marcel Dekker.

Nathan, Richard P., 1983. *The Administrative Presidency*. New York: John Wiley.

Nelkin, Dorothy. "Some Social and Political Dimensions of Nuclear Power: Examples from Three Mile Island." *American Political Science Review* 75 (March 1981): 132–145.

Nelkin, Dorothy, and Michael Pollack, 1980. "Problems and Procedures in the Regulation of Technological Risk." *Making Bureaucracies Work*. Edited by Carol H. Weiss and Allen H. Barton. Beverly Hills, California: Sage Publications.

New York Times, 1983. "Ex-E.P.A. Aide Says Budget Office Put Case for Industry." *The New York Times*, September 28, pp. 1, 11.

Ogul, Morris S., 1976. *Congress Oversees the Bureaucracy: Studies in Legislative Supervision*. Pittsburgh: University of Pittsburgh Press.

Poole, Robert W., Jr., ed., 1981. *Instead of Regulation: Alternatives to Federal Regulatory Agencies*. Lexington, Massachusetts: Lexington Books.

Reagan, Ronald. "Executive Order 12291." *Weekly Compilation of Presidential Documents* (February 17, 1981): 124.

Rosenbaum, Walter A., 1977. *The Politics of Environmental Concern*, 2nd ed. New York: Praeger.

Sabatier, Paul, "Regulatory Policy-Making: Toward a Framework of Analysis." *Natural Resources Journal* 17 (July 1977): 415–460.

Shabecoff, Philip, 1983. "E.P.A. Chief Urges Uniform Pollution Assessment." *The New York Times*, June 23.

Swartzman, Daniel, Richard A. Liroff, and Kevin G. Croke, eds., 1982. *Cost–Benefit Analysis and Environmental Regulation: Politics, Ethics, and Methods*. Washington, D.C.: Conservation Foundation.

Thomas, Stephen, 1985. "Risk Assessment in Cancer Treatment." *Public Policy and the Physical Environment*. Edited by Helen Ingram and Kenneth Godwin. New York: JAI Press.

Tobin, Richard, 1979. *The Social Gamble: Determining Acceptable Levels of Air Quality*. Lexington, Massachusetts: Lexington Books.

Tolchin, Martin, and Susan J. Tolchin, 1983. *Dismantling America—The Rush to Deregulate*. Boston: Houghton Mifflin.

U.S. Congress, 1980a. *Risk/Benefit Analysis in the Legislative Process*. Summary of a Congress/Science Joint Forum, prepared by the Congressional Research Service for the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, U.S. House of Representatives, and the Subcom-

mittee on Science, Technology and Space of the Committee on Commerce, Science, and Transportation, United States Senate, 96th Congress, 2nd session. Washington, D.C.: Government Printing Office.

U.S. Congress, 1980b. *Risk/Benefit Analysis in the Legislative Process*. Joint hearings before the Subcommittee on Science, Research, and Technology of the Committee on Science and Technology, U.S. House of Representatives, and the Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science and Transportation, United States Senate and Congress/Science Forum with the American Association for the Advancement of Science, 96th Congress, 1st session. Washington, D.C.: Government Printing Office.

U.S. Congress, 1980c. *Comparative Risk Assessment*. Hearings before the Subcommittee on Science, Research and Technology of the Committee on Science and Technology, 96th Congress, 1st session. Washington, D.C.: Government Printing Office.

Vig, Norman J., 1979. "Environmental Decisionmaking in the Lower Courts: The Reserve Mining Case." *Energy and Environmental Issues*. Edited by Michael Steinman. Lexington Massachusetts: Lexington Books.

Vig, Norman J., "The Courts: Judicial Review and Risk Assessment." *Risk Analysis, Institutions, and Public Policy*. Edited by Susan G. Hadden. Port Washington, New York: Associated Faculty Press.

Vig, Norman J., and Patrick J. Bruer, "The Courts and Risk Assessment." *Policy Studies Review* 1 (May 1982): 716–727.

Vig, Norman J., and Michael E. Kraft, eds., 1984. *Environmental Policy in the 1980s: Reagan's New Agenda*. Washington, D.C.: Congressional Quarterly Press.

Welborn, David M., 1977. "Taking Stock of Regulatory Reform." Paper presented at the Annual Meeting of the American Political Science Association, September.

Wilson, James Q., ed., 1980. *The Politics of Regulation*. New York: Basic Books.

Wilson, Richard, and Edmund Crouch, 1982. *Risk/Benefit Analysis*. Cambridge, Massachusetts: Ballinger.

Wines, Michael, 1982. "Reagan's Reforms Are Full of Sound And Fury, But What Do They Signify." *National Journal,* January 16, pp. 92–98

Wines, Michael, 1983a. "Mission Accomplished, Bush Says of His Rules Task Force." *National Journal,* August 20, p. 1749.

Wines, Michael, 1983b. "Auchter's Record at OSHA Leaves Labor Outraged, Business Satisfied." *National Journal,* October 1, pp. 2008–2013.

18

The Management of Risk

Rae Zimmerman

INTRODUCTION

There has been a steady rise in awareness of and interest in risk, particularly environmental risk, on the part of the general public and the professional community over the past few decades (see for instance, Regens, Dietz, and Rycroft, 1983; Wildavsky, 1979; Wilson, 1979; Marsh & McLennan, 1980). A recent analysis of citations in scientific journals showed a dramatic increase in the use of the word *risk* in that literature since 1960 (Inhaber and Norman, 1982). Bills have been introduced into Congress to promote the use of risk assessments in the management of environmental risk (H.R. 6159, the "Ritter" bill) by a wide range of agencies. These legislative actions have emphasized the lack of a systematic use of risk analyses in agency decision making in establishing just how susceptible the public is to environmental risks (H.R. 6159, Section 2 (g)). A recent National Academy of Sciences study of several federal agencies came to the same conclusions (NAS, 1983). These attempts at quantifying risk in environmental health contexts are similar to attempts to value a life, first popular during World War II in a military context, then in the context of nuclear power, and now as a basis for evaluating the costs and benefits of governmental regulatory programs and funding decisions for consumer safety and environmental protection (see for instance, Acton, 1976; Zeckhauser, 1975). What distinguishes the recent interest in risk from earlier concerns is the emphasis upon risks whose consequences are delayed rather than immediate, and whose causes are primarily man-induced rather than the result of natural phenomena.

After more than a decade, the field of risk analysis has emphasized three major interrelated areas: (1) the quantification of the risk consequence levels and the probability of risk occurrences (Rowe's concept of risk determination, 1977); (2) the estimation of human reactions toward or judgments about risk (that is, the concepts of risk acceptability, aversion, and reduction developed by Rowe, 1977; Slovic et al., 1981; Kates, Hohenemser, and Kasperson, 1981); and (3) the methodologies to integrate judgmental aspects with empirical

Rae Zimmerman • Graduate School of Public Administration, New York University, New York, New York 10003.

and probabilistic approaches to evaluate trade-offs among risk alternatives (Lave, 1982; Sage and White, 1980).

Efforts in these three areas are necessary to provide a common analytic framework for decision making regarding events involving risk. The final step in this scheme is the integration of the three areas of risk analysis into the decision-making process itself—a process called risk management. Risk management is defined here as the process by which decisions about risk are made linking analytical procedures with the administrative, legal, political, organizational, and human dimensions of the decision-making process. Except in a few instances (Otway and Pahner, 1976, 1977; Greer-Wootten, 1980; NAS, 1983), this stage has rarely been singled out in the overall schemes for risk assessment. The risk management process as conceptualized here and its relationship to risk assessment is portrayed in Figure 1.

The risk management process plays an important role in resolving controversy and uncertainty in the policy arena. A number of significant problems have emerged in society's attempts to deal with risk that point to the insufficient attention given to the decision-making or management component. First, questions have arisen concerning the ability of agency manpower and information- processing resources to cope with the technical advances and demands of risk assessment techniques. Second, the conditions under which organizations should modify their organizational arrangements or decision-making structure in response to risk are often not known, hence impairing the agency's ability to deal effectively with high-risk situations.

The introduction of increasingly complex technologies into society will continue to fragment the management of the risks that ensue from these technologies. This underscores the need to understand the nature of a management system so as to be able to design systems to address problems of risk decisions, manage information and knowledge for effective utilization in decision making, and integrate perceptions and attitudes of managers and the affected populations into decisions about risk. While risk management is potentially applicable to a wide range of technologies, the focus of attention has been on toxic and hazardous materials.

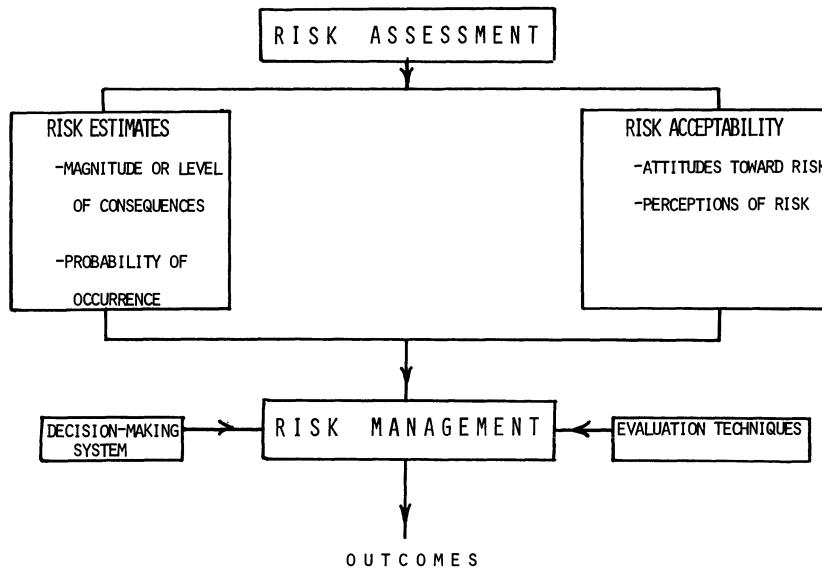

Figure 1. The risk management process and its relationship to risk assessment.

IMPORTANT PREVIOUS WORK

Risk management has its roots in a broad range of disciplines, yet within each field the number of directly relevant studies has been quite limited. The major foundations of risk management include environmental law, organizational decision making, knowledge utilization, and risk perception.

Legal Basis for Risk Management

The literature in environmental law pertaining to decisions involving risk includes (1) studies of the relationship between law and administrative process and (2) typologies of environmental, health, and consumer protection laws based on the use of the risk concept in statutes, risk characteristics, and the nature of risk–benefit analysis implied or mandated by administrative decision making. The review of the literature contained herein pertains to these two areas. Legislative studies that are detailed interpretations of particular statutes are beyond the scope of this work.

Law and Administrative Process. Many studies of the relationship between the legal and administrative dimensions of risk management focus upon the discretionary authority of administrative agencies making risk determinations and the role of the courts in evaluating and overriding this discretion. Studies of the role of judicial review in decision making tend to concentrate on the degree to which the courts second-guess the technical decisions and legal interpretations of agencies that regulate risk and, more specifically, on whether scientific information should be used directly by the courts (Bazelon, 1979). The positions of Judges Leventhal and Bazelon, both of the D.C. Circuit Court of Appeals, represent extremes (Yellin, 1977: 970; Ricci and Molton, 1981: 1096). The stance attributed to Judge Leventhal implies that critiques of the way administrative agencies make decisions are well within the scope of judicial review processes. In contrast, Judge Bazelon maintains that, rather than engaging in technical or substantive reviews, the courts should focus upon administrative procedures, and not second guess the technical determinations of agencies directly (Ricci and Molton, 1981: 1096; Bazelon, 1979, 1981).

The position that a judicial review process takes at any given time or on a particular subject has deep ramifications for the nature of administrative decision making for risk. Beyond the mere identification of these two extremes, the linkage between judicial review and administration has not been well established in either the organizational decision-making or legal literature. One exception is the analysis of the role of the judicial review process in the benzene case by Rodgers. Here, the issue was whether the Occupational Safety and Health Administration (OSHA) could regulate benzene without establishing the costs and benefits of alternative regulatory strategies, adhering only to its policy of regulating carcinogens to the lowest possible level, in this case, to 1 part per million (Rodgers, 1981: 304).

The debate hinged upon the extent of proof needed to back the reduction of the standard from 10 to 1 part per million. Rodgers maintained that the role of judicial review depends on one's concept of administrative decision making: rational versus freewheeling ("muddling through") models and the prescriptions these two models imply (Rodgers, 1981: 315). Rodgers maintains that any settlement of the benzene question has to come to terms with some theory of administrative decision making: "the greatest debating point of the benzene decision is the appropriate role of the delegation doctrine, if any, in judicial review of administrative decisions" (Rodgers, 1981: 318--319). He related a loose administrative decision-making model with less judicial scrutiny and a rational decision-making model with a stricter, closer

judicial review process (Rodgers, 1981: 315). Rodgers only makes this broad connection between law and administrative process, and does not delve into the conditions under which certain models are more appropriate than others.

Typologies of Environmental Law along Risk Dimensions. To integrate the approaches to risk management across a wide range of government programs, a number of efforts have been made to construct typologies of environmental, consumer protection, and nuclear power laws as to the way they define risk, their use of risk evaluation techniques such as risk and benefit trade-off analysis, and their identification of characteristics of risk. The sophistication of the typologies ranges from discussions of several laws in a comparative framework (Ricci and Molton, 1981) to the development and application of scales for statutory characteristics (Morris and Duvernoy, 1982). Field (1979) conducted an extensive review of 31 laws dealing with environment, health, and safety, and categorized the major statutes according to the nature of the risk-balancing methodology employed using a five-dimensional categorization for statutes: risk only, technology only, implicit balancing, explicit balancing, and uncertain mandates.

A more extensive categorization of 33 laws along eight dimensions (hazard, causative event, risk measure, risk incidence, data and methods, expression of risk, evaluation standard, and value of information) was developed by Morris and Duvernoy (1982). In both of these studies, statutes were merely compared as to their incorporation of risk dimensions without any normative considerations. Sabatier and Mazmanian (1979) have ranked legislation in general by degree of ambiguity as one element in the development of policy implementation strategies. Such efforts are important first steps in understanding the legal basis for agency interactions and interagency coordination on risk issues.

Organizational Decision Making and Conflict Resolution

A key aspect of managing risks is understanding the influence of organizational contexts and their administrative and political characteristics, including loosely structured, serendipitous experiences, upon decisions about risk. The roots of such an inquiry are the field of crisis management and its more applied form in emergency and disaster preparedness or response, studies of the structure and determinants of organizational decision making for decisions involving risk, models of political decision-making processes (primarily those involving conflict resolution), and studies pertaining to the administrative process of risk regulation.

Crisis Management. The field of crisis management, while originally addressing emergencies and accidents, has developed a number of concepts that are directly applicable to situations involving risks not necessarily associated with accidents. While crisis differs from risk in that risk consequences have already been realized during a crisis, the two concepts have a number of decision-making characteristics in common, namely, the need to reduce, avert, or avoid the consequences usually under conditions of uncertainty. An early approach to the relationship of organizational behavior, including decision making, to sudden or catastrophic events emerged in the context of the general response of organizations to their environments. Thompson and Hawkes (1962) conceptualized community response to disaster in terms of the emergence of a specific "synthetic" organization followed by a restoration of community equilibrium and institutional norms. This was further expanded to general organizational and environmental interactions by Thompson (1967): organizations would differentiate their structures as a means of adapting to crisis. In the mid-1970s,

organizational response to crisis began to coalesce in various organizational decision models primarily to explain responses and, in some cases, to predict or prescribe solutions. For instance, Turner (1976), basing his explanations on actual events, outlined the steps in decision making in organizations following the emergence and resolution of crises and hypothesized a causal sequence of events as the basis for a model of decision making under crisis conditions.

Smart and Vertinsky (1977) built upon this conceptualization and developed a number of preventive strategies and structural adaptations to avoid rigidity and insensitivity preceding a crisis so as not to trigger its realization. Hermann (1972) developed a model of the behavior of organizations in a crisis in an international context. This model is based on the concept of crisis as embodying a threat to goals or policies, a short time frame for decision making, and surprise to decision makers. A series of hypotheses were developed relating the existence of these three characteristics of crisis to five aspects of decision making: the structure of authority (number of decision makers involved), the number of alternative proposals developed to deal with the crisis, the rate of internal communication among a system of agencies, external communication among agencies in one nation with those of another, and frequency with which decision makers take action.

A statistical analysis revealed that threat and time were the key aspects of crisis that were related to the five decision-making characteristics, rather than surprise. Furthermore, when participants in the crisis rated the variables, the significance of threat and time was greater than when outside observers rated it. Kupperman, Wilcox, and Smith (1975), rather than defining crisis explicitly, associate it with certain management problems similar to those identified by Hermann (such as scarce information, communication problems, and the changing character of the role players). The first two problems are emphasized and are used as the basis of a computer-based information system for crisis managers. Billings, Milburn, and Schaalman (1980) developed a model of crisis perception demonstrating that administrators' perception of crisis is related to a difference they perceive between the crisis situation and some expected norm or standard. Thus, the frame of reference of crisis managers, according to this research, appears to be variations from norms that managers expect (perceived disruption) rather than the actual disruption that occurs.

To summarize, the behavior of individual decision makers and organizations in a state of crisis has many similarities to their decision-making behavior about risk: a high degree of uncertainty prevails, information utilization and communication problems are common, decision makers typically use reference points or standards either implicitly or explicitly against which they evaluate risk or crisis outcomes, and alterations in the normal administrative arrangements occur when decisions about risk or crises are being made.

Organizational Decision Making. An extensive literature in organizational decision making exists from the perspectives of formal decision analysis (Raiffa, 1968), the steps in or form of the decision process using a rational, semirational (Simon, 1976), or unstructured (Lindblom, 1959; Cohen, March, and Olsen, 1972) framework (Allison, 1971), and models focusing on behavioral variables from the perspective of the individual, small group, or total organization (Mintzberg, Raisinghani, and Theoret, 1976). While much of this literature rarely deals explicitly with the risk aspects of decision making, the value of organization decision-making studies in understanding risk management is in the transference of these decision processes to the risk situation. For instance, Mintzberg, Raisinghani, and Theoret (1976) have outlined a number of stages common to some 25 decision situations, all of which shared a lack of a predetermined response on the part of the organization as a means to cope with the situation (that is, the initial conditions for the decision-making

process were "unstructured"). Their framework for conceptualizing highly structured decision routines, such as the identification, development, and selection phases for decisions, has been applied directly to the sequence of events in certain stages of risk decision making dealing with hazardous materials (Zimmerman, 1984). In the hazardous materials study, the role of more fluid, unstructured decision processes (such as the introduction of new information, the setting of new standards) in influencing more routine decision processes was explored.

The National Academy of Sciences has recently considered two alternative organizational designs to integrate risk assessment into federal government decision making: the separation within organizations of risk assessment and risk management functions and the creation of a single organization to centralize risk assessment activities for regulation (NAS, 1983: 5). After reviewing risk assessment activities in several federal agencies, the academy committee concluded that information problems rather than organizational changes were the key inhibiting factors in the use of risk assessment for federal decision making.

Conflict Resolution. The literature on conflict provides still another approach to coping with risk. It originates primarily from political science and sociology, but is concerned with questions about the perceptions and beliefs of decision makers, an approach more commonly associated with behavioral psychology and organizational behavior. Much of this literature has in fact been directly applied to risk situations unlike the general organizational decision-making literature. Conflict resolution provides overall conceptual models as a basis for risk decision making and rich case study material amenable to future risk management research. One set of cases on controversy explored attitudes toward risk in health and environmental hazards associated with science and technology (Nelkin, 1979).

The interaction between political and technical decisions is explored focusing upon the identification of disputants and their roles, the nature of the debates, the loci of decision making, and the role of technical expertise in decision making (Nelkin, 1979: 21). More recently, this literature has expanded into decision-making models for the resolution of conflict or the achievement of consensus. For instance, Nelkin and Pollack (1980) develop a two-dimensional typology of consensus procedures based on advisory or information-oriented models, each of which is broken down further into elitist and participatory dimensions. Conflict resolution procedures from some 17 examples are then categorized according to this typology with purpose and participants identified. Gladwin (1981) has developed a typology of 10 decision-making strategies ranging from executive fiat to negotiation for varying degrees of both disputant and third-party control. In addition, conditions were developed for the attractiveness of using certain decision strategies over others. These are the kinds of models that, when merged with risk considerations and organizational decision-making processes, will enrich the development of theories of risk management.

Risk Regulation. A number of studies exist that focus on the nature of the administrative process governing the regulation of risks. As a group they are valuable in shedding light upon the influence of the behavior of individuals and agencies, and the structure and performance of regulatory processes upon the outcomes of risk decisions. Kagan (1978) evaluated the role of discretion in regulation and its effect on agency decision making. Pressman and Wildavsky (1979) attribute the failure of program implementation to the large number of actors and decision points partially as a result of the regulatory process.

The studies of the Food and Drug Administration (FDA; Quirk, 1980), OSHA (Kelman, 1980), and the Environmental Protection Agency (EPA; Marcus, 1980) are particularly noteworthy in providing the details of regulatory processes within specific federal agencies. As a group, these three studies identified a number of failings that influenced agency per-

formance with respect to risk and other aspects of the regulatory problem. These deficiencies included poor information-processing ability, vague laws as a basis for establishing and implementing administrative procedures, and the inappropriateness of manpower for the problems at hand.

Knowledge Utilization

The late 1960s and early 1970s were marked by a tremendous growth in the information and data base upon which decisions about risk were being made. This was especially true in the fields of environmental health and protection where major pieces of legislation passed during the early part of the decade produced tremendous demands for data gathering. A number of studies pointed to the underutilization, misunderstanding, poor design, and high cost of information that was the basis of risk decisions in the environmental field (National Research Council, 1977; U.S. Congress, Office of Technology Assessment, 1982; Weiss, 1977, 1978). As a result of the proliferation and use of incomplete information and the misapplication of information, the latter half of the 1970s was marked by a period of consolidation in which a great deal of attention was paid to organizing knowledge and understanding and designing knowledge utilization processes for decision making.

Risk analysis is experiencing a similar need for information consolidation through the risk management process (see, for instance, Nelkin (1982: 143) for information problems connected with the Three Mile Island case), and much can be learned from the work done in the mid- to late 1970s in this area. The first stage in the utilization or consolidation process is the development of information typologies which can then be related to user groups, levels of risk, etc. Important typologies have been developed by Sabatier (1978) and Lindblom and Cohen (1979), and a synthesis has been developed by Zimmerman (1982b: Appendix to Volume 1) for risk management specifically. Pierce and Lovrich (1981) have compared the relative information bases of major decision-making groups, namely, experts, policy makers, activists, and citizens. Kilmann (1981) has formally linked the knowledge utilization process to certain aspects of organizational structure, namely, designs for overall formal organization (short- and long-term), coordination ("interdependencies") within and between organizational subunits, and structural differentiation of organizational subunits. Kilmann's discussion of coordination provides a linkage between knowledge utilization and the coordination typology developed by Thompson (1967).

Knowledge utilization has often been dealt with in the applied literature as well. The U.S. General Accounting Office recommended a stronger organizational structure and management process to implement improvements in the U.S. EPA's information system (U.S. GAO, 1980). While the issue areas dealt with in many of these studies did not explicitly involve high or catastrophic risk, the transferability of the approach to risk management processes is clear, and is beginning to occur in selected areas of risk decision making (see for instance, Viscusi, 1982; Rushefsky, 1982). Urkowitz and Laessig (1982) developed a specific tool for environmental and health planners to quantitatively evaluate information credibility for decision making. The determinants of information utilization have also been approached by defining legal constraints to information (Kagan, 1978: 18).

Risk Perception

The perspective of the individual with respect to events involving risk is an important underpinning for organizational behavior and society's role in shaping this behavior. This psychological perspective emphasizes risk perception, though the relevance of attitudinal research to human behavior toward risk is equally important (Otway, 1980). The literature

review below focuses only on those aspects of the risk perception literature that interface explicitly with or have implications for the risk management function in an organizational context.

The literature on individual risk perceptions elicits information via individual behavior or expressed beliefs. A recent review of the literature on individual perceptions of risk was conducted to design communication strategies for information about risk (Vertinsky and Vertinsky, 1981). Risk perception studies using interview techniques have been applied to a subgroup of the general public: college student respondents were asked to rank several dozen hazards over 18 risk characteristics (Slovic, Fischhoff, and Lichtenstein, 1981). The perceptions or judgments of a group of experts were elicited for 93 hazard categories over 12 hazard descriptor codes by Kates, Hohenemser, and Kasperson (1981).

The relevance of the risk perception literature to risk management is in gaining insights into the behavior of the risk managers during the decision-making process. Risk managers are the individuals that are involved in decisions about risks primarily within organizational contexts, such as regulators, financial planners, and policy makers. Short of a few surveys of attitudes and perceptions of federal regulators toward risk (Marsh & McLennan, 1980) and some similar studies in the environmental field, it is here that a gap in the literature exists: the perceptions of risk managers about risk and the relationship of these perceptions to individual and role attributes and characteristics of the risk decisions need to be understood. Without such a perspective, one is restricted to understanding risk management processes at the organizational level alone. Comprehensive studies of the risk perceptions of the other categories of individuals or actors mentioned above, that is, policy makers, activists, and citizens, also are needed to round out the group of actors involved in decisions about risk.

CURRENT RESEARCH

Advances in risk assessment techniques have recently been made in the refinements of the measurement of risk and the application of evaluation techniques to risk problems. The importance of risk management as a component in the implementation of these assessments has been recognized. Now, organizational decision making, knowledge utilization, regulation, and risk perception need to be introduced into the management of risk.

A descriptive model that combines these attributes with risk assessment over time is developed here and applied to a dozen case studies dealing with the risks associated with toxic and hazardous materials. Risk assessment has frequently been applied to this substantive area. The cases in the toxic and hazardous materials area and some of their characteristics are listed in Table 1.

The risk management process in these cases can be portrayed in terms of the following sequence of steps, which conceptually parallels some of those developed by Turner (1976) for crisis management: (1) in-place systems to identify or recognize and estimate (assess) risks before they are realized (surveillance); (2) in-place management systems for risk avoidance and aversion in the face of uncertainty, once risks begin to be realized in spite of surveillance; (3) management systems to reduce the immediate impacts of the risks once they have been realized to minimize actual consequences and magnitude; and (4) the readjustment of the risk identification or prerealization risk management system to avoid or reduce the probability of risk realization in the future. The relationship among the four steps over time is shown in Figure 2.

These steps provide an important analytical framework to critique and identify problems in existing decisions involving risk, and can also be organized and applied to the design of

Table 1. List of Cases and Summary of Selected Characteristics

Case	Location	Technology	Source		Pathway/receptor	Toxic effects	Estimated population at risk	Estimated land area directly affected (acres)	Estimated quantity of contaminant (tons)
			Agent	Usage					
Cadmium	Foundry Cove, New York	Industrial/ electrical equipment	Marathon Battery	Manufacture of batteries, subsequent seepage into surface water	Seepage to surface water and into aquatic life	Bioaccumulation and bioconcentration; carcinogenicity	2,000	400	20
Mercury	Berry's Creek, Hackensack Meadowlands, New Jersey	Mercury processing	Ventron Corp.	Miscellaneous industrial usages	Industrial waste discharge into surface water and soil	Bioconcentration and bioaccumulation; neurological disorders	15,000	40	200
PCBs	Hudson River Valley, New York	Electronics	General Electric	Capacitors	Industrial waste discharge into surface water	Bioaccumulation and bioconcentration; carcinogenicity	44,000	360	250
PCBs	College Point, New York	Industrial waste oil disposal	Durante Bros.	Not known	Industrial waste discharge into surface water from waste disposal	Bioaccumulation and bioconcentration; carcinogenicity	19,774	10	600
Aldicarb (Temik)	Suffolk County, Long Island, New York	Agricultural production (pest control)	Union Carbide	Control of Colorado potato beetle and golden nematode	Seepage to potable water supplies	Cholinesterase suppression in humans	3,100	25,000	1,050
Dibromochloro-propane (DBCP)	San Joaquin Valley and Lathrop, California	Agricultural production (pest control)	Amvac Chemical, Occidental, Shell, Dow	Nematode control: citrus fruits, tomatoes	Seepage to potable waters via irrigation wells and percolation	Reduced fertility; suspected carcinogenicity	56,750	335,600	6,800
Kepone	James River—Chesapeake Bay, Virginia	Agricultural production (pest control)	Allied Chemical	Pesticide against banana root borer; ant and roach poison	Industrial spills to surface water affecting aquatic life	Bioaccumulation and biomagnification; carcinogenicity	25,000	5,888	51

(*continued*)

Table 1. (continued)

Case	Location	Technology	Source		Pathway/receptor	Toxic effects	Estimated population at risk	Estimated land area directly affected (acres)	Estimated quantity of contaminant (tons)
			Agent	Usage					
Trichloro-ethylene (TCE)	Southeastern Pennsylvania	Machining	Multiple industries	Chemical degreasing agent	Seepage to surface and groundwater to potable water supplies	Animal carcinogen	20,000	128,000	Not available
Chlorinated organics (Trihalo-methanes)	Dade County, Florida	Water purification	Miami–Dade Water and Sewer Authority	Chlorination of naturally occurring organic material in groundwater	Chlorination of potable water supplies with high natural organic content	Carcinogenicity	1,300,000	1,000,000	Not available
Chlorinated organics	North Miami Beach, Florida	Miscellaneous industrial technologies	North Miami Beach Water and Sewer Authority	Use of well water contaminated with industrial wastes	Seepage of industrial waste into groundwater used as potable water	Suspected carcinogenicity	38,000	3,264	Not available
Chemical Control Corp.	Elizabeth, New Jersey	Miscellaneous industrial operations	Chemical Control Corp.	Industrial waste disposal	Seepage of miscellaneous toxic substances into surface and groundwater; explosion releasing contaminants into the air	Suspected carcinogenicity	104,405	4	8,800
Love Canal	Niagara, New York	Chemical manufacture	Hooker Chemical	Industrial waste disposal	Seepage of miscellaneous toxic substances into surface and groundwater	Suspected carcinogenicity	1,000	300	21,800
Positive chemical	Travis, Staten Island, New York	Miscellaneous industrial operations	Positive Chemical/ Chelsea Terminal	Industrial waste disposal	Seepage of miscellaneous toxic substances into surface and groundwater	Suspected carcinogenicity	130	6	1,200

[a] Source: Zimmerman (1982d).

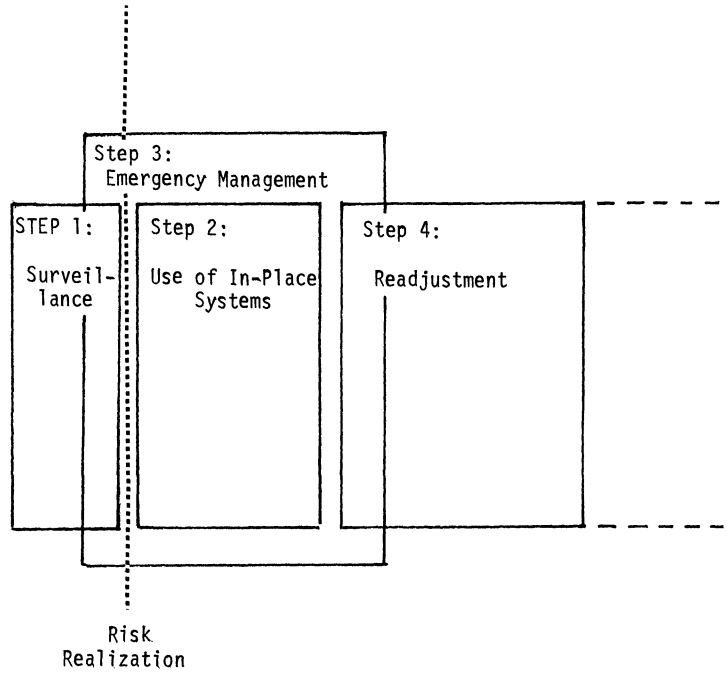

Figure 2. Conceptual scheme for the sequence of steps in risk management.

more effective strategies to improve risk management in the future. Both perspectives, analysis and design, are used in the application of the decision-making process to the cases below (Zimmerman, 1982b).

Risk Identification or Recognition Systems (Surveillance)

By its very definition, risk involves an estimation of the occurrence and magnitude of the impacts of an event that is considered to have adverse consequences to an exposed population. To the extent that the occurrence or realization of a risk and its magnitude (if it does occur) can be anticipated, its uncertainty can be reduced, which is a first step in reducing the impact of risk. While risks associated with a number of events are often initially considered catastrophic or sudden, further investigations into the events leading up to the realization of the risks often show that risks could have been avoided had certain signs been read appropriately and acted upon in time. If this is true, it underscores the importance of surveillance systems to identify risks before they materialize.

In each one of the following cases a sudden or catastrophic event was identifiable that actually resulted in a change in the course of governmental actions. Yet, looking more closely at the course of events, a gradual buildup of events occurred that went unnoticed or was not acted upon.

In the industrial waste discharge cases, major changes in governmental action were precipitated by general nuisance complaints, environmental health, or ecological problems. The cadmium discharges into Foundry Cove came to public attention in the late 1960s as a result of a fish kill and the realization in Japan that cadmium was a known cause of the "Itai-itai" disease. When EPA came into being in 1970, it became one of the agency's first enforcement cases. In spite of the suddenness of these events, the alkalinity problem was

well known to the health department, which had been monitoring the company's wastewater problems for some time. In the Ventron mercury case, samples analyzed by the newly formed EPA in 1970 revealed extraordinarily high concentrations of mercury in waters and sediment around the plant, which touched off regulatory actions during the 1970s under the Clean Water Act and building demolition on the site by OSHA in 1974 to prevent further risk of occupational exposure. While the discovery of mercury occurred suddenly, state officials had, in fact, been monitoring the wastewater discharges from the plant for almost two decades, and had unsuccessfully tried to negotiate settlements with the company during this time. PCBs came to international attention from the "Yusho" incident (rice oil contamination) in Japan in 1968 resulting in widespread skin disorders. But, the relationship between PCBs and chloracne was known as far back as 1943. The Hudson River PCB issue surfaced relatively suddenly as a result of the ban on fishing in the Hudson River by the New York State (NYS) Department of Environmental Conservation (DEC) in 1975. However, the discovery of PCB concentrations in fish in excess of the FDA limit (5 ppm) was made back in 1972, PCB was identified as a blocking agent to the measurement of DDT earlier than that, and the NYS DEC and EPA were monitoring PCB wastewater discharges indirectly as the general category of chlorinated hydrocarbons all during the early half of the 1970s. Early recognition of risk is often inhibited by the scientific uncertainties in establishing cause-and-effect relationships in biological organisms and the inability to establish scientific thresholds as a result of this uncertainty.

In the pesticide contamination cases involving aldicarb (Temik), dibromochloropropane (DBCP), and Kepone, the chemicals were apparently discovered suddenly in the environment. In reality, a gradual buildup in the environment had occurred to a point where adverse consequences began to be feared. Aldicarb was suddenly discovered in potable groundwater supplies on Long Island in August 1979, precipitating an immediate ban on the use of those supplies for drinking water. The potential for groundwater contamination, though, had been emphasized in the wastewater management plan for Long Island two years prior to that. Recognition of the adverse consequences of the chemicals also occurred gradually over time. Workers in a California plant manufacturing DBCP filed a formal complaint on the basis of the appearance of sterility among the workers. Experiments indicating the potential for sterility were published in the scientific literature as far back as the late 1950s and stomach cancer was intimated in studies conducted by the National Cancer Institute in 1972; both were prior to the "sudden" event precipitating formal governmental action. Kepone followed a similar history. In mid-1975 Kepone poisoning among production workers was discovered through an OSHA investigation, ultimately causing the plant to close during the same month. However, considerable evidence had built up during the 1950s and 1960s showing extreme toxicity and carcinogenesis from Kepone exposure, and an NCI study begun in 1971 demonstrated carcinogenesis from Kepone in lab animals. All of this was occurring simultaneously with an escalation in the production of Kepone.

The third category of cases relating to the discovery of organic contamination of drinking water should be viewed against the backdrop of a nationwide sampling program for organic contaminants prompted by the passage of the Safe Drinking Water Act in 1974. Thus, the precipitousness of the discoveries of chlorinated organics in Miami–Dade County's drinking water, the chlorinated organics incident in North Miami Beach, and the contamination of southeastern Pennsylvania water supplies by trichloroethylene (TCE), in part, reflect the sudden emergence of this national priority. The slow buildup of events is reflected in these cases as well: the decades of industrial discharges and relatively lax policies toward spills of TCE leading to the contamination of water supplies in Pennsylvania, the chlorination of a naturally organic water supply for over three decades producing chlorinated organic com-

pounds during that time in Miami–Dade County, and the long recognized contamination of the East Drive well fields that supply the City of North Miami Beach with water.

The fourth category of cases involving the spread of contamination at hazardous waste disposal sites also shares a sudden nationwide consciousness reflected in the passage of major federal legislation. Love Canal suddenly became a nationwide issue when, during a rainy season, chemicals in the canal rose up through homes surrounding it. Yet, dumping in the canal had occurred over an 11-year period, and land transfers and development occurred around the canal. The existence of two other landfills in the Niagara area with many times the weight of contaminants found at Love Canal (F.C. Hart, Assoc., 1978), although never receiving the public attention of Love Canal, is a testimony to the selectivity with which sudden events emerge. The illegal chemical waste disposal at the Chemical Control Corporation site in Elizabeth, New Jersey, was known to law enforcement officials in the State of New Jersey for about five years prior to the explosion and fire that occurred in April of 1980 that thrust the gradual cleanup of the dump into an emergency situation.

Finally, there are other areas involving toxicity, not directly dealt with here, that exemplify the same phenomenon. Nuclear power cases, for instance, also reflect the occurrence of a set of events prior to the apparent suddenness of risk realization. For instance, the Three Mile Island (TMI) shutdown was preceded by several dozen operating failures and knowledge of weaknesses in the plant's general design. A recent analysis of the TMI accident pointed out that warnings were unheeded to such an extent that it was questionable as to whether the incident was even an accident (Ford, 1982: 15).

Thus, events that appear to be sudden or catastrophic in the way they reach the public's attention may be inherently evolutionary or predictable when the events are carefully examined. This pattern has recently been observed in the development of technology in general, where technological advances are much less commonly the result of breakthroughs than of the accumulation of small steps in an evolutionary pattern (Gomory, 1983). The important question is how one gains the benefit of hindsight before an event occurs, without incurring the loss of credibility associated with being wrong. As Lowrance has said, "Wearing the prophet's cape is itself a risky business. Unless it is done with care, not only is the specific prophecy ignored, but the prophet loses his credibility" (Lowrance, 1976: 121).

The experience outlined above in the area of toxic and hazardous materials control has a number of implications for the predictability of risk. One area is the use of environmental standards as a surveillance device. The concern over the use of standards in decision making is as old as the regulatory process itself, but what has typically eluded the standards setting and standards application process is not so much the type or level of the standard but the explicit role the standards should play in decisions. While Turner (1976) has observed the gradual violation of standards that go unnoticed or not enforced as a prelude to the realization of a crisis, the problem when applied to risk runs deeper than that. Many of the cases occurred in the context of shifting standards and uneven application of standards with respect to acceptable risk over time. Levels for standards often dropped as detectability limits were lowered, illustrated by the case of vinyl chloride in the mid-1970s (see Figure 3). Agencies were using coarse screens alone to identify risk to the environment; that is, alkalinity for the presence of toxic metals, total organic carbon for chlorinated hydrocarbons, and so forth. In addition, public agencies during the 1950s and 1960s were not yet oriented toward environmental values, even though many laws were in place to allow adequate enforcement, and agencies were heavily penalized during the judicial review process for not using them (see, for instance, the Ventron Chemical case and the General Electric PCB Settlement Agreement where state environmental agencies had to share the liabilities for not adequately enforcing the environmental laws).

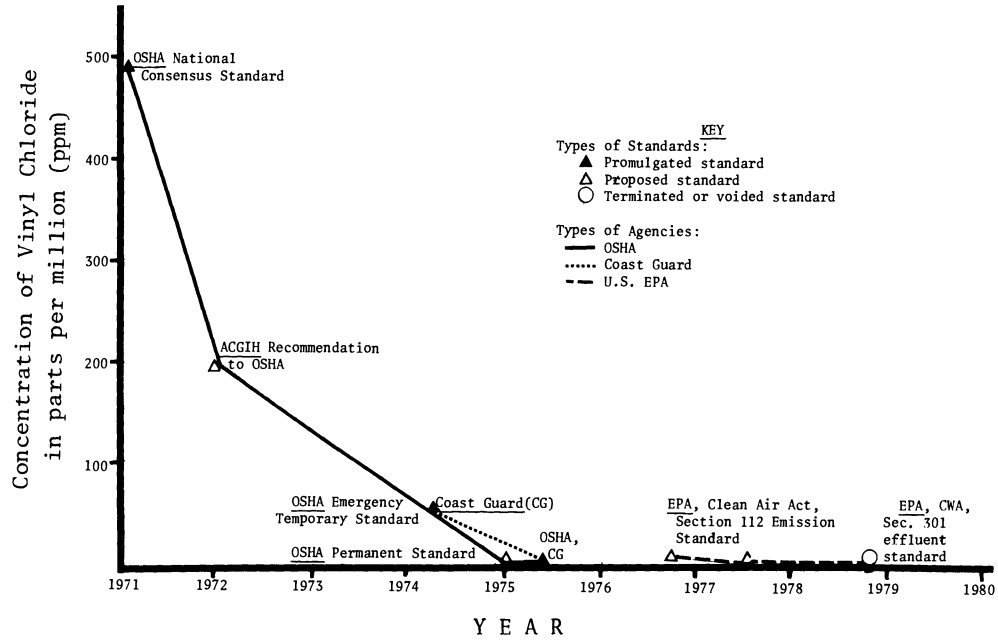

Figure 3. Variations in standards for vinyl chloride by agency and time, 1970–1980.

What is really at issue in the use and design of standards for surveillance for risk identification is the acceptability of standards. This is revealed clearly in nuclear power plant cases where the low probability of the occurrence of a nuclear accident tended to dominate sensitivities toward risk in the absence of a consideration of the magnitude of the risks should an accident occur (Yellin, 1977). This created an environment in which system failures were considered routine, and their gradual contribution to an increase in the probability of accidents went unnoticed. Thus, using standards as a screen for identifying risk will first require a determination of acceptable risk in the form of a range for a particular set of standards and the criteria upon which they are based. It is at this point that standards can then act as a basis for risk determinations. The determination of acceptable ranges for standards has the advantage that the measurement task is made easier (the measurement problem often takes up a substantial amount of time in risk issues), because not all values have to be determined—only those within the acceptable threshold range. An appropriate standard or set of standards is one that is general enough to be flexible (e.g., "toxicity" as a general standard) but can then be made specific enough to be able to distinguish among substances with varying levels of risk. Decision makers always look to standards as a basis for risk decisions, and if their design and role is not explicit, the majority of the time is spent searching for standards as the basis for risk decisions.

A second type of surveillance activity, in addition to standards (but not unrelated to them) is the process of regulation itself. It is apparent from the cases reviewed that the regulatory systems in place during the time period just preceding risk realization were ineffective screens for identifying the nature and severity of the impending risks. This occurred as a result of a common administrative response to highly uncertain situations: the factoring of problems into subproblems that are easily dealt with on a piecemeal basis (Mintzberg, Raisinghani, and Theoret, 1976; Simon, 1962). As applied to the regulation of

risk, this refers to reliance upon existing regulatory systems to solve unique and atypical risk problems or a narrowing of the focus of decision making to a point where decision-making closure has adverse effects for the predictability of risk. Decision-making closure and openness have distinct meanings in organizational decision making: openness or unstructured decision making refers to loosely structured decision making in which information flows and other inputs into the system are unrestricted and decision-making steps are not necessarily sequential; closure or structured decision making is more rigid, and information inputs as well as other entry points are relatively more restricted and decision-making steps are more defined and ordered in some way (Zimmerman, 1984: 15).

While such closure has the effect of making problems more manageable, it also fragments decision making. In many of the cases, laws needed to be changed or decisions had to be opened up entirely to develop a new course of action.

The use of existing regulatory systems to cope with a new risk phenomenon as an initial reaction to these risks is the second step. In the next section, numerous examples are discussed in detail.

Reliance upon Existing Management Systems for Risk Aversion or Reduction

At the time that many of the events occurred, regulatory and other management systems (including the financing of corrective facilities) were available to reduce risks associated with toxic and hazardous materials in one form or another. These were preexisting regulatory processes such as wastewater discharge and waste disposal permits, facility construction permits, environmental impact statements, and funding programs for facilities reducing environmental risk. The way in which these existing programs related to one another and were brought into play in the context of industrial waste, hazardous waste disposal, and pesticide cases is portrayed in Figure 4. Specific programs used in each case are identified in Table 2. The major groupings of program areas include wastewater treatment and disposal, dredging and filling activity, hazardous waste disposal and transport, and toxic substance (including pesticide) registration.

As risks suddenly escalate or change their form as a result of catastrophic events or changing public values, the first reaction of governmental agencies is to rely upon these familiar processes to deal with the risks. They look to existing programs to manage the risks and to reduce or make manageable the uncertainties associated with them. Analogies are made between the uncertainties decision makers now face and those that were confronted earlier and to which various programs were applied. The nature of uncertainty is a major determinant of the managerial response, and has been discussed in depth elsewhere (Zimmerman, 1982b, 1983).

The need to circumscribe or factor problems into discrete subcategories to cover the overall problem has been observed in a number of decision situations (Mintzberg, Raisinghani, and Theoret, 1976; Simon, 1962). The circumscription may be more useful at certain stages of decision making than at others. Assume, for instance, that decision making can be broken down into the following sequence of steps: goal formulation, objective formulation, generation of alternatives, evaluation of alternatives, and selection and implementation of one alternative. Alexander (1979) has pointed out that circumscription or closure may be more relevant between the alternative evaluation and implementation stages than in the alternative formulation stage. While closure has the advantage initially of making a problem more manageable, if not approached properly it may fragment decision making and preclude more effective courses of action.

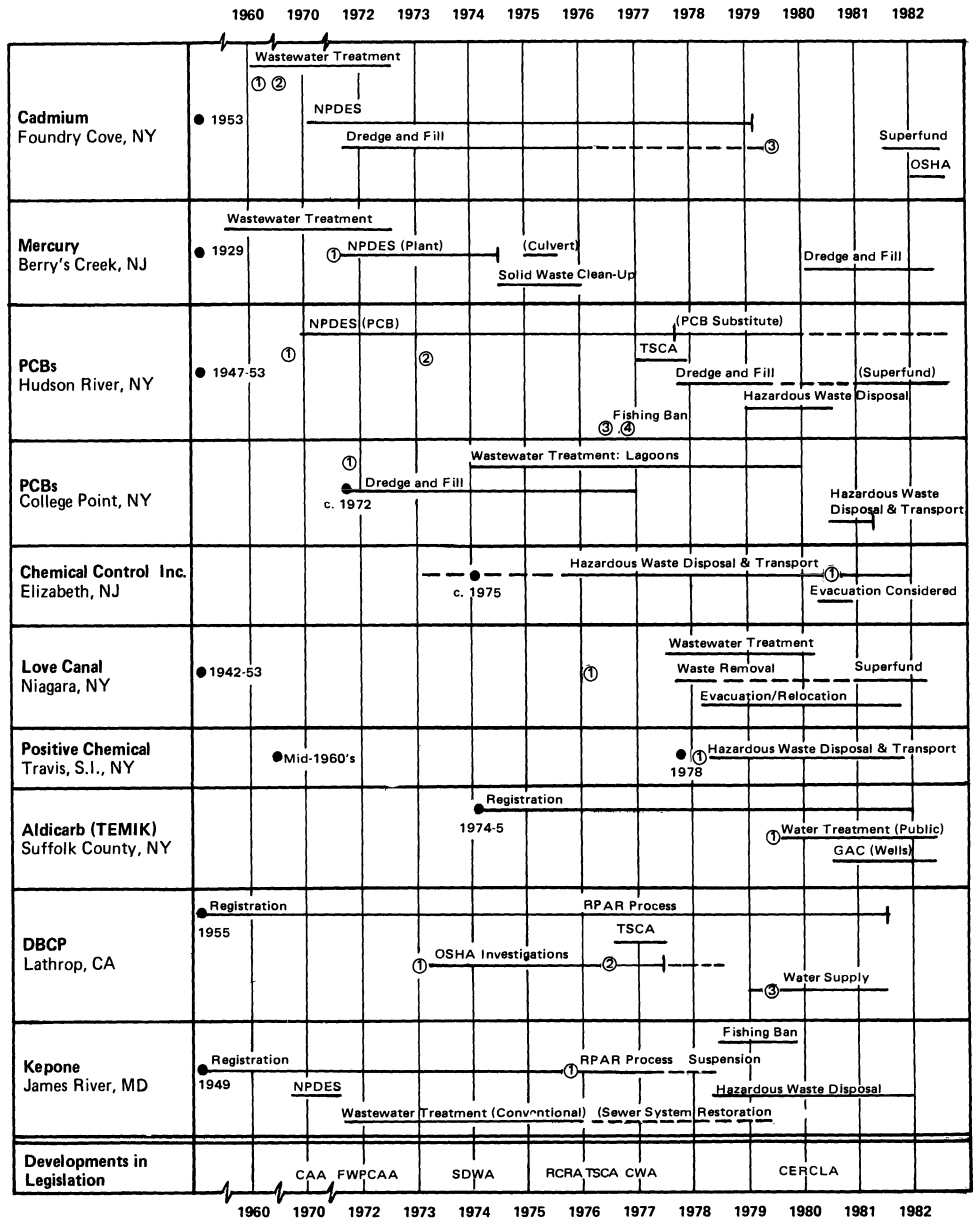

Figure 4. Sequence of events and utilization of regulatory programs in selected toxic substance cases.

When the risk events emerged in the cases shown in Figure 4, agencies initially turned to programs that were already in existence prior to 1976 as a solution to the emergency problem. While these provided some relief by slowing the rate of increase of the risk, they did not address the heart of the problem, or confront the totality of the risk problem. After 1976 existing legislation was strengthened with the passage of regulations or laws (discussed in more detail under the "readjustment" stage below). The older, preexisting program upon which agencies initially relied and the relationship of these programs to the development of the cases is described briefly below.

Abbreviations:

CERCLA Comprehensive Environmental Response Compensation and Liability Act
GAC Granulated Activated Carbon (a system of removing organic contaminants from drinking water)
NPDES National Pollutant Discharge Elimination System (permit for wastewater discharges into navigable waterways) under Section 401 of the Clean Water Act
PCB Polychlorinated Biphenyls
RCRA Resource Conservation and Recovery Act of 1976
RPAR Rebuttable Presumption Against Registration (suspension proceedings for pesticide regisration) under the Federal Insecticide, Fungicide and Rodenticide Act
TSCA The Toxic Substances Control Act of 1976

Symbols:

⊣ Termination of an activity (e.g., plant closing, substitution of one chemical for another), but not necessarily the termination of risk
o Commencement of an activity (e.g., building an industrial plant, siting a toxic waste dump, applying for permission to use pesticides)
● A major critical event; realization or perception of risk that is the basis of future remedial action (see numerical key below)

Key to Major Critical Events (encircled numbers within each case):

CADMIUM, Foundry Cove
1. 1966: Fish kill
2. 1968: Formal announcement in Japan of the linkage between "Itai-itai" disease and cadmium from industrial wastes
3. 1980: Leakage of dredge spoil at disposal site

MERCURY, Berry's Creek
1. 1971: Formation of the U.S. Environmental Protection Agency, and attention to the mercury problem as an early enforcement case by the agency

PCBs, Hudson River
1. 1968: "Yusho" rice contamination incident in Japan
2. 1973: Fort Edwards dam is removed sending PCBs downstream
3. Feb. 1976: Fishing ban is imposed in the Hudson by the New York State Department of Environmental Conservation
4. April 1976: 100-year flood occurs causing PCBs to migrate downstream more

PCBs, College Point
1. 1972: Complaints received about waste illegal dumping at College Point

Chemical Control, Inc., Elizabeth, NJ
1. April 1980: Explosion and fire occurs at the hazardous waste site

Love Canal, Niagara, NY
1. 1976: Heavy rains cause chemicals in Canal to enter residential homes

Positive Chemical, Staten Island, NY
1. August 1979: Discovery of well water contamination by aldicarb (pesticide)

DBCP, California
1. 1973: National Cancer Institute study discovers adverse effects of DBCP on laboratory animals
2. August 1976: Workers at Lathrop, California plant complain of sickness that they associate with DBCP exposure
3. August 1979: DBCP is found in the water supply distribution system of the City of Riverside with a population of 166,000

Kepone, James River
1. 1975: Poisoning symptoms reported at manufacturing plant in Hopewell, Va.

Key to Figure 4. Symbols, abbreviations, and explanation of terms.

Wastewater Discharge Permits. Included are those permits issued under the National Pollutant Discharge Elimination System; earlier federal and state programs were in force to control discharges of cadmium, mercury, and PCBs directly from plants and, in some cases, from drainage ditches. This program approached risk from the perspective of the impact of the discharge on natural water bodies, emphasizing risk reduction by decreasing the rate of contaminant release into the environment. The risks from in-place contaminants, which became the focus of public attention in the late 1970s, were not addressed by these programs. In-place contaminants are those lodged in soil and sediment.

Permits for Dredge and/or Fill of Material in Navigable Waterways. Issued under Section 401 of the Clean Water Act, these permits are designed to deal with risks from releases or disturbances of in-place contaminants from construction activity. This mechanism was used in the case of cadmium contamination of Foundry Cove, ultimately unsuccessfully since it did not retard the later release of cadmium from dredge spoil into the cove. It has been seriously evaluated for mercury decontamination of Berry's Creek,

Table 2. Regulatory Programs and Risk Management: Selected Cases and Programs

Case name and location	P.L. 92-500 (Section 401) NPDES or wastewater treatment connection permit	P.L. 92-500 (Section 404) Dredge and/or fill permits	P.L. 94-580 Solid waste disposal and transport permits	P.L. 93-523 Water supply regulations and permits	P.L. 92-516 Pesticide registration	P.L. 92-516 Rebuttable presumption against registration	P.L. 94-469 Premanufacture notice	P.L. 95-510 Superfund
Industrial waste discharges								
Cadmium Foundry Cove, N.Y.	●	●	●	—	—	—	—	●
Mercury Berry's Creek, N.J.	●	●	●	—	—	—	—	—
PCBs Hudson River, N.Y.	●	●	●	●	—	—	●	●
PCBs College Point, N.Y.	●	●	●	—	—	—	●	—
Pesticides								
Aldicarb (TEMIK) Suffolk County, N.Y.	—	—	—	●	●	●	—	—
DBCP Lathrop, Calif.	●	—	—	●	●	●	—	—
Kepone James River, Md.	●	●	—	—	●	●	—	—
Water supply contaminants								
TCE Southeastern Pa.	●	—	—	●	—	—	—	—
Chlorinated organics Miami–Dade County, Fla.	—	—	—	●	—	—	—	—
Chlorinated organics North Miami Beach, Fla.	—	—	—	●	—	—	—	—
Toxic waste dumps								
Chemical Control, Inc. Elizabeth, N.J.	—	—	●	—	—	—	—	—
Love Canal Niagara, N.Y.	—	—	●	—	—	—	—	●
Positive Chemical Travis, S.I., N.Y.	—	—	●	—	—	—	—	—

New Jersey, the cleanup of Kepone in the James River to prevent its spread into Chesapeake Bay, and the removal of PCBs in the Hudson River, but in each case the permit mechanism was insufficient to guard against the potential for later releases of contaminants. It was used for ancillary cleanup in a waste disposal case (the PCB Oil Lagoon, College Point, Queens, New York).

Hazardous Waste Disposal and Transport Permits. These permits, issued under the Resource Conservation and Recovery Act (RCRA) and comparable state laws, similarly control risks from releases of chemicals from waste disposal sites. Earlier solid waste legislation was not explicitly applicable to hazardous waste, and thus, a gap existed in the regulation of land disposal of hazardous waste for many years. The focus of the 1976 legislation is upon the siting of new facilities and waste transport; however, the issuance of permits for existing facilities is a major function of several state versions of RCRA. It was not until new regulations were passed under RCRA in 1979 and 1984 that the law was strengthened considerably in preventing many of the risks it was designed to prevent.

Pesticide Registration and Registration Revocation (RPAR) Procedures. Under FIFRA, these procedures were both aimed at preventing risks from spreading at the source by regulating the marketing and use of a substance from the start. The RPAR process could have been used to revoke the registration of aldicarb on Long Island after groundwater contamination was discovered (but the manufacturer voluntarily withdrew it on Long Island); RPAR was used to revoke the registration of DBCP in California after a similar discovery was made, and it was used for Kepone in the James River area after it was found to have substantial health effects upon workers. In each case, however, the RPAR process took several years to implement, and was then only applied selectively to a given geographic area.

The Registration of Public Water Supply Systems. Under the Safe Drinking Water Act of 1974, there were requirements for the maintenance of certain levels of water quality (spelled out under the National Interim Drinking Water Standards). This act was critical in initiating a nationwide sampling program for public water supplies that ultimately led to the discovery of widespread contamination of these supplies by complex organic substances. This discovery initiated much of the concern over trichloroethylene in southeastern Pennsylvania water supplies, the use of chlorine for the Miami water supply system, and the finding of organic contaminants in the water supplies of the City of North Miami Beach, Florida.

Thus, the regulatory programs that existed prior to the mid-1970s were unable to adapt to or could not go far enough in coping with the new attitudes toward and discovery of new risks in the area of toxic and hazardous substances. Two responses occurred as a result of these deficiencies. First, in the short term, emergency procedures were invoked where risks were actually realized to control the immediate impacts of the risks. Second, readjustments in regulatory and other management systems occurred to reduce the probability of risks being realized in the future or to reduce the magnitude or consequences of the risk once realized.

Management Systems for Immediate Impacts of Risk

Coincident with, or immediately following the use of preexisting programs to manage risk is the implementation of relatively short-term programs to reduce the impacts of risks

once they are realized. While the implementation of any given program is meant to be temporary, as a whole this type of management—emergency planning and control—begins to weave itself into the fabric of risk management.

Emergency planning and control systems are mechanisms for internalizing and circumscribing risks and uncertainty in the short term, recognizing that long-term decision-making processes have shortcomings and uncertainties, and often cannot respond quickly to a sudden change in the course of events (Zimmerman, 1982b: 45–47). Many emergency management processes often become permanent management systems. The creation of the Federal Emergency Management agency (FEMA) is such an example. While emergency management is relatively commonplace in certain risk management areas, such as nuclear power, and became applicable to accidental spills of oil and hazardous materials under section 311 of the Clean Water Act, it is gradually being applied to hazardous waste disposal and contamination problems in a variety of forms. None of the cases reviewed here were operating under fully developed and tested emergency plans prior to the realization of the risks, though in some cases such plans did emerge in the course of events. In the cases reviewed, the degree of progress in emergency planning was positively correlated with the quantity of contaminant material involved ($r = 0.7740$, $n = 10$) and the currency of the problem ($r = 0.6199$, $n = 15$).

The emergency planning response tends to appear in the following sequence: (1) the provision of resources for quick responses to crisis, such as the passage of P.L. 93-288 to provide emergency funds for Love Canal; (2) early warning or public notification systems to minimize exposure to the risks, such as those outlined by the California Department of Health Services in the DBCP water contamination case and in the North Miami Beach contamination case (while such warning systems have long been used for natural hazards, they are only just beginning to be used for the hazards associated with man-induced events); (3) requirements for changes in resource utilization patterns, such as the substitution of public water supply use with emergency water supply sources, as in the well water closings in the aldicarb and DBCP pesticide contamination cases and the water allocation process implemented by the Water Command Post in the North Miami Beach water contamination episode; (4) provisions for increasing the distance between sources of risk and a potential exposed population, such as the development of evacuation plans in the nuclear power cases of Indian Point and Three Mile Island and hazardous waste disposal sites such as the consideration of evacuation during the explosion at the CPC site in Elizabeth, New Jersey, and the actual evacuation that occurred during the Love Canal episode; and (5) specification of operating procedures for minimizing risks according to some set of standards or guidelines typical of the regulation of power plants and wastewater treatment systems, or the worker protection procedures spelled out in conformance with OSHA requirements to protect workers demolishing mercury-contaminated buildings in Berry's Creek, landfill and dredging operators proposed to clean up Hudson River PCBs, and warehouse workers potentially exposed to cadmium at the Foundry Cove site. (For a more extensive discussion of the relationship of emergency management to chemical risks, see Zimmerman, 1985.)

Readjustment of Risk Management Systems following Risk Realization

Many of the toxic and hazardous substance cases have caused or initiated major readjustments in risk management systems, unlike those mentioned above that have been essentially driven to a conclusion by preexisting programs. In a number of cases, preexisting programs proved to be insufficient to cope with the risks that surfaced. Love Canal is a prime example; it was instrumental in the passage of the Comprehensive Emergency Response

Compensation and Liability Act of 1980 (CERCLA), which provided an industry- and government-financed "Superfund" program for toxic waste cleanups. It is not unusual in the area of environmental regulation for a single case to precipitate new legislation: the Santa Barbara Oil spill, for instance, brought about the passage of NEPA. Other cases effected changes in programs rather than introducing new legislation. Still others simply modified administrative procedures (Zimmerman, 1985).

The major programs that reflect the "readjustment" period in toxic and hazardous substances control are CERCLA, which established an industry-supported fund for the cleanup of toxic waste disposal sites, the Toxic Substances Control Act (TSCA) of 1976, which required premanufacture notifications for potentially toxic chemicals, and new regulations under RCRA, passed in 1979, which detailed the procedures for siting new hazardous waste disposal sites and for transporting and disposing of wastes at existing waste disposal sites (usually embodied in state legislation). The pesticide and water supply laws were not changed significantly to prevent the long delays or reaction time between the discovery of contamination and actions regarding the usage of the causative agents. Readjustments in these two areas were primarily programmatic and administrative. For instance, in the area of water supply, a nationwide groundwater study and numerous statewide studies have been and are being conducted to identify sources of contamination and necessary remedial action strategies. In the area of pesticide management, the registration and RPAR processes are gradually being coordinated with other environmental laws to more accurately gauge potential adverse impacts.

The knowledge generation and utilization process within government and in the private and public interest groups sectors that interact with government potentially play an important role in the readjustment process, that is, in the adaptation of old programs or in the introduction of new ones to manage risk. The complexity, formality, and type of knowledge and information used in the risk management process is very variable. The relationship between these characteristics and the degree of influence the knowledge has in the management process is often unclear. New technologies are especially vulnerable to unpredictable knowledge utilization. For instance, advances or refinements in measurement techniques for inorganic and organic substances that allowed extremely small quantities of material to be detected dramatically transformed the regulation of risks from these substances, moving regulation in extremely conservative directions. As a result of the refinements in detectability limits, standards were established for aldicarb and vinyl chloride. Some new technologies, which require large initial capital investments to implement, take much longer to penetrate the risk management process, if they ever manage to at all. An example from the cases reviewed is the large number of new technologies that have emerged to degrade PCBs, thermally, chemically, and bacterially. These studies and discoveries were unable to influence the remedial action alternatives for the Hudson River Reclamation project. Decision-making processes rarely provide the funds to develop new technologies in the context of specific decisions.

Data collection through monitoring and surveillance activity is a major information generation function in the area of toxic and hazardous substances in addition to the development of new technologies. The data collection efforts in some ongoing or sporadic monitoring efforts were instrumental in discovering or confirming risks from hazardous materials in time to prevent the risks from spreading. This was true of the groundwater, surface water, and soil sampling which detected pesticide contamination in the aldicarb, DBCP, and Kepone cases. In other cases, extensive empirical analyses and monitoring did no more than confuse the integration of scientific information with decision making because of poor design, bad timing, or lack of consensus on methods. This was the case in the multi-million-dollar study con-

ducted to ascertain the extent of contamination in the Love Canal case, the chromosome study of Love Canal residents preceding it, and the nationwide survey of aldicarb contamination.

What is clear in these attempts at knowledge utilization is the need for a "knowledge broker" (Sundquist, 1978) that acts as an interface between empirical research and decision making to design information generation and utilization strategies and establish priorities. As originally conceived by Sundquist, this function usually involves more than one type of role or individual, namely, the "academic intermediary" followed by the "research broker," who interface with one another and with empirical research and policy makers (Sundquist, 1978: 127). Also, the ability of such an intermediary to function depends on the extent to which decision processes are open to such influence. Many of the in-place management systems discussed previously are often only open at discrete points to new information (Zimmerman, 1982b,1984). For example, while the environmental impact assessment process under NEPA is a "full-disclosure" process, in fact, the introduction of new information formally occurs only at the beginning during the "scoping" process, during the public hearings on a draft environmental impact statement toward the end of the process, and, after the final statement is prepared, in the form of a "supplemental" environmental impact statement. Permit review processes tend to channelize information into discrete substantive categories rather than to restrict the timing of inputs, which can impede the flow of information into the decision-making process.

IMPORTANT ISSUES FOR FUTURE RESEARCH

The successes and failures in the decisions made about risks associated with hazardous materials that have occurred for many decades in spite of a constantly increasing legislative and resource base point to the need for more attention to the process of risk management. Such a process integrates technical and decision-making aspects of risk. A number of substantive and methodological gaps currently exist in risk management research.

As outlined earlier, the important components of or foundations for the risk management discipline are organizational decision making, conflict resolution, regulation, knowledge utilization, and risk perception.

A better linkage needs to be made between the organizational decision-making literature, including crisis management and risk management. A beginning in this direction has been made with respect to the federal government's role in a National Academy of Science study dealing with organizational arrangements for risk assessment (NAS, 1983), but the scope of organizational alternatives considered and the rigor with which such arrangements were considered were limited. The influence of various organizational and decision-making contextural factors upon decisions about risk needs to be known more comprehensively at many levels of government in order to understand why most systems fail to avert, avoid, or reduce risk, while a few seem to succeed. The explicit role of serendipitous experience or unstructured decisions must not be overlooked in the total scheme of risk management, and needs to be linked into decision making along with more rational, circumscribed approaches. The delicate interplay between these open and closed decision processes needs to be understood. In order to design more effective surveillance systems to identify risks before they are realized, empirical studies are needed that relate risk identification to organizational characteristics such as size, diversification, staffing, function, and the nature of risk management functions (location in the hierarchy, prestige, resources, etc.). There is almost no research that establishes a precedent in this area. In the area of decision making, the structure of decision processes is critical to an understanding of how risks are identified and weighed

against other priorities, what resources are allocated to risk decision making, what components go into the formulation of decisions, and what interorganizational relationships are successful in terms of the composition and leadership of coordination entities. Models of conflict resolution can be applied specifically to risk problems in order to ascertain successful interaction strategies, leadership styles, organizational members, and interfaces. Organizational decision making should also address the conditions faced by risk managers and suggest the options, in terms of administrative arrangements and decision-making strategies, that are available to cope with risk under alternative conditions. Existing case material should be organized into the kinds of conditions that were faced and the management options available and chosen, as a basis for developing and designing choices for new situations.

The connection between legal and administrative decision making needs to be clarified. There are enough court decisions to allow a more systematic analysis of current cases as to their opinion about and influence upon administrative processes for dealing with risk.

The area that is one of the most critical for risk management research at the present time is that of risk perception—in particular, the way in which decision makers (risk managers) perceive risk in general and the risks they must decide upon. The underpinnings of these perceptions need to be investigated in terms of (1) standard social and economic characteristics: age, marital status, number of children, education, years of professional experience, income, mobility; (2) personal and professional experience with risk: experience with risk decisions, location of residence relative to high-risk incidences, personal experience with risk effects (e.g., sickness, death of relatives or friends), attitudes, preferences and perceptions of societal risk issues; and (3) risk decision making (general functions and specific to cases): degree of discretion allowed in making decisions about risk, amount of time spent on decisions involving risk, general opinions about regulation of risk, risk-related functions and roles performed; knowledge of scientific and regulatory basis of risk.

CONCLUSION

Now that risk assessment techniques are making great strides, more attention needs to be paid to risk management, which is the process by which these techniques are integrated with organizational, decision-making, political, and legal systems. As a start in understanding the risk management process as it succeeds or is integrated with risk assessment, it is useful to look at a sequence of steps in risk management decision making. In this regard, an adaptation to risk management of Turner's typology for crisis management (Turner, 1976) and its extension by others provides an important basis for such a sequence of steps. By categorizing a number of key cases involving risks from toxic and hazardous substances into such a typology, it is evident that the first step, the surveillance or "intelligence" function, failed to identify a gradual buildup of events prior to the realization of risk. Second, in-place management systems, while making important strides in the direction of risk reduction and risk aversion, were not sufficient to cope with the risks entirely. This generated a third and fourth step, the use of emergency planning and control systems in the short run and the readjustment of long-term management systems by passing new legislation, introducing new programs, or implementing administrative changes to better manage risks.

Risk management research needs to turn to an understanding of what organizational and decision-making strategies work or do not work as a basis for designing future strategies. A considerable amount of case material exists (such as the cases cited here) that could be organized within a conceptual framework for condition–option relationships. At another level, knowledge of the characteristics of the risk manager, in terms of personal, professional,

and organizational context in which the manager functions, would lend an important dimension to the risk management process.

REFERENCES

Acton, J.P., "Measuring the Monetary Value of Lifesaving Programs," *Law and Contemporary Problems* (Autumn 1976).

Alexander, E.R., "The Design of Alternatives in Organizational Contexts: A Pilot Study," *ASQ, 24* (September 1979), 382.

Allison, G.T., *Essence of Decision*. Boston, Mass.: Little Brown and Co., 1971.

Bazelon, D.L., "Risk and Responsibility," *Science, 205* (1979), 277–280.

Bazelon, D.L., "The Judiciary: What Role in Health Improvement?" *Science, 211* (February 20, 1981), 792–793.

Billings, R.S., T.W. Milburn, and M.L. Schaalman, "A Model of Crisis Perception: A Theoretical and Empirical Analysis," *ASQ, 25* (June 1980), 300–316.

Cohen, M., J.G. March, and J. Olsen, "A Garbage Can Model of Organizational Choice," *ASQ, 17,* (March 1972), 1–25.

Field, R.I., "Statutory and Institutional Trends in Governmental Risk Management: The Emergence of a New Structure." Prepared for the Committee on Risk and Decisionmaking, Assembly of Behavioral and Social Sciences, National Research Council, National Academy of Sciences. Washington, D.C.: NAS, 1979.

Ford, D., *Three Mile Island*. New York, N.Y.: Penguin, 1982.

Gladwin, T.N., "Environmental Mediation and a Contingency Theory of Preferred Third Party Intervention." New York, N.Y.: New York University, Graduate School of Business Working Paper, March 1981.

Gomory, R.E., "Technology Development," *Science, 220* (May 6, 1983), 576–580.

Greer-Wootten, B., "Context, Concept and Consequence in Risk Assessment Research." In: *Society, Technology, and Risk Assessment,* edited by J. Conrad. New York, N.Y.: Academic Press, 1980, 67–101.

Fred C. Hart Associates, Inc., "Assessment of the Extent of Environmental Problems Posed by Hooker Chemical Dumps in Niagara Falls, NY and Estimated Cleanup Costs." New York, N.Y.: Fred C. Hart Assoc., Inc., December 11, 1978.

Hermann, C.F., "Threat, Time and Surprise: A Simulation of International Crises." In: *International Crises: Insights from Behavioral Research,* edited by C.F. Hermann. New York, N.Y.: The Free Press, 1972, 187–211.

Inhaber, H. and S. Norman, "The Increase in Risk Interest," Letter to the Editor, *J. of Risk Analysis, 2* (1982), 119–120.

Kagan, R.A. *Regulatory Justice*. New York, N.Y.: Russell Sage, 1978.

Kates, R., C. Hohenemser, and R.E. Kasperson, "Causal Taxonomies of Technological Hazards," Draft manuscript. Worcester, Mass.: Clark University, 1981.

Kelman, S., "Occupational Safety and Health Administration." In: *The Politics of Regulation,* edited by J.Q. Wilson. New York, N.Y.: Basic Books, 1980.

Kilmann, R.H., "Organization Design for Knowledge Utilization," *Knowledge, 3* (December 1981), 211–231.

Kupperman, R.H., R.H. Wilcox, and H.A. Smith, "Crisis Management: Some Opportunities," *Science, 187* (February 7, 1975), 404–410.

Lave, L.B., *Quantitative Risk Assessment*. Washington, D.C.: Brookings, 1982.

Lindblom, C.E., "The Science of Muddling Through," *Public Administration Review, 19* (1959), 59–88.

Lindblom, C.E. and D.K. Cohen, *Usable Knowledge*. New Haven, Conn.: Yale University Press, 1979.

Lowrance, W.W., *Of Acceptable Risk*. Los Altos, Calif.: Wm. Kaufmann, Inc., 1976.

Marcus, A., "Environmental Protection Agency." In: *The Politics of Regulation,* edited by J.Q. Wilson. New York, N.Y.: Basic Books, 1980.

Marsh & McLennan, Co., Inc., *Risk in a Complex Society*. New York, N.Y.: Marsh & McLennan, 1980.

Mintzberg, H., D. Raisinghani, and A. Theoret, "The Structure of Unstructured Decision Processes," *ASQ, 21* (June 1976), 246–275.

Morris, F.A. and E. Duvernoy, "The Statutory Basis of Risk Assessment." Seattle, Wash.: Battelle, June 1982.

National Academy of Sciences, *Risk Assessment in the Federal Government: Managing the Process*. Washington, D.C.: NAS, 1983.

National Research Council, National Academy of Sciences, *Decision-Making in the EPA (Vol. II)*. Washington, D.C.: NAS, 1977.

Nelkin, D., *Controversy. Politics of Technical Decisions*. Beverly Hills, Calif.: Sage Publications, 1979.

Nelkin, D., "The Role of the Expert at Three Mile Island." In: *Accident at Three Mile Island,* edited by D.L. Sills, C.P. Wolf, and V.B. Shelanski. Boulder, Colo.: Westview, 1982.

Nelkin, D. and M. Pollack, "Consensus and Conflict Resolution." In: *Technological Risk,* edited by M. Dierkes, S. Edwards, and R. Coppock. Cambridge, Mass.: OG & H, 1980.

Otway, H.J., "The Perception of Technological Risks: A Psychological Perspective." In: *Technological Risk,* edited by M. Dierkes, S. Edwards, and R. Coppock. Cambridge, Mass.: OG & H, 1980.

Otway, H.J. and P.D. Pahner, "Risk Assessment," *Futures, 8* (1976), 122–134.

Otway, H.J. and P.D. Pahner, "Present Status of Risk Assessment." In: *Risk Analysis, Industry, Government and Society (10th Annual T.N.O. Conference).* The Hague, Netherlands: T.N.O. Conference, 1977, 6–28.

Pierce, J.C. and N.P. Lovrich, Jr., "Knowledge and Politics," *Knowledge, 3* (December 1981), 211–231.

Pressman, J.L. and A. Wildavsky, *Implementation.* Berkeley, Calif.: University of California Press, 1979.

Quirk, P.J., "Food and Drug Administration." In: *The Politics of Regulation,* edited by J.Q. Wilson. New York, N.Y.: Basic Books, 1980.

Raiffa, H., *Decision Analysis.* Reading, Mass.: Addison-Wesley, 1968.

Regens, J.L., T.M. Dietz, and R.W. Rycroft, "Risk Assessment in the Policy-Making Process: Environmental Health and Safety Protection," *Public Administration Review, 43,* No. 2 (March/April 1983), 137–145.

Ricci, P.F. and L.S. Molton, "Risk Benefit in Environmental Law," *Science, 214* (December 4, 1981), 1096–1100.

Rodgers, W.H., Jr., "Judicial Review of Risk Assessments: The Role of Decision Theory in Unscrambling the Benzene Decision," *Environmental Law, 11,* (1981), 301–320.

Rowe, W.D., *An Anatomy of Risk.* New York, N.Y.: John Wiley, 1977.

Rushefsky, M., "Technical Disputes: Why Experts Disagree," *Policy Studies Review, 1* (May 1982), 676–685.

Sabatier, P., "The Acquisition and Utilization of Technological Information by Administrative Agencies," *ASQ, 23* (September 1978), 396–417.

Sabatier, P. and D. Mazmanian, "The Conditions of Effective Implementation: A Guide to Accomplishing Policy Objectives," *Policy Analysis* (Fall 1979), 481–504.

Sage, A.P. and E.B. White, "Methodologies for Risk and Hazard Assessment: A Survey and Status Report," *IEEE Transactions on Systems, Man and Cybernetics, 10* (August 1980), 425–446.

Simon, H.A., "The Architecture of Complexity," *Proceedings of the American Philosophical Society, 106* (December 1962), 467–482.

Simon, H.A., *The Sciences of the Artificial.* Cambridge, Mass.: MIT Press, 1969.

Simon, H.A., *Administrative Behavior.* 3rd ed. New York: Free Press, 1976.

Slovic, P., B. Fischhoff, and S. Lichtenstein, "Characterizing Perceived Risk." In: *Technological Hazard Management,* edited by R.W. Kates and C. Hohenemser. Cambridge, Mass.: OG & H, 1981.

Smart, C. and I. Vertinsky, "Designs for Crisis Decision Units," *ASQ, 22* (December 1977), 640–657.

Sundquist, J.L., "Research Brokerage: The Weak Link." In: *Knowledge and Policy: The Uncertain Connection,* edited by L.E. Lynn, Jr. Washington, D.C.: NAS, 1978.

Thompson, J.D., *Organizations in Action.* New York, N.Y.: McGraw-Hill, 1967.

Thompson, J.D. and R.W. Hawkes, "Disaster, Community Organization, and Administrative Process." In: *Man and Society in Disaster,* edited by G.W. Baker and D.W. Chapman. New York, N.Y.: Basic Books, Inc., 1962.

Turner, B.A., "The Organizational and Interorganizational Development of Disasters," *ASQ, 21* (September 1976), 378–397.

Urkowitz, A.G. and R.E. Laessig, "Assessing the Believability of Research Results Reported in the Environmental Health Matrix," *PAR, 42* (September/October 1982), 427–438.

U.S. Congress, Office of Technology Assessment, "Use of Models for Water Resources Management, Planning and Policy." Washington, D.C.: OTA, 1982.

U.S. General Accounting Office, "Stronger Management of EPA's Information Resources Is Critical to Meeting Program Needs." Washington, D.C.: U.S. GPO, March 10, 1980.

Vertinsky, I. and P. Vertinsky, "Communicating Environmental Health Risk Assessment and Other Risk Information: Analysis of Strategies." In: *Risk: A Seminar Series,* edited by H. Kunreuther. Laxenburg, Austria: IIASA, 1981.

Viscusi, W.K., "The Informational Requirements for Effective Regulatory Review: An Analysis of the EPA Lead Standard," *Policy Studies Review, 1* (May 1982), 686–691.

Weiss, C.H., ed., *Using Social Research in Public Policy Making.* Lexington, Mass.: Lexington Books, 1977.

Weiss, C.H., "Improving the Linkage Between Social Research and Public Policy." In: *Knowledge and Policy: The Uncertain Connection,* edited by L.E. Lynn, Jr., Washington, D.C.: National Academy of Sciences, 1978.

Weiss, J.A., "Coping with Complexity: An Experimental Study of Public Policy Decision-Making," *J. of Policy Analysis and Management, 2* (Fall 1982), 66–87.

Wildavsky, A., "No Risk Is the Highest Risk of All," *American Scientist, 67* (January–February 1979), 32–37.

Wilson, R., "Analyzing the Daily Risks of Life," *Technology Review, 81* (February 1979), 41–46.

Yellin, J., "Judicial Review and Nuclear Power: Assessing the Risks of Environmental Catastrophe," *George Washington Law Review, 45* (August 1977), 969–993.

Zeckhauser, R., "Procedures for Valuing Lives," *Public Policy, 23* (Fall 1975), 419–464.

Zimmerman, R., "Formation of New Organizations to Manage Risk." Symposium on Public Policy toward Risk," *Policy Studies Review, 1,*
4 (May 1982a), 736–748.

Zimmerman, R., "Management Systems for Low-Probability/High Consequence Events." In: *Low-Probability/High Consequence Risk Analysis*, edited by R.A. Waller and V.T. Covello, New York: Plenum, 1984. pp. 425–454.

Zimmerman, R., "The Management of Risk. Toxic and Hazardous Substances Control." 2 Volumes. New York, N.Y.: New York University, Graduate School of Public Administration, August 1982b.

Zimmerman, R., "The Management of Risk. Toxic and Hazardous Substances Control." Executive Summary. New York, N.Y.: New York University, Graduate School of Public Administration, December 1982c.

Zimmerman, R., "Synopsis: Integrating Approaches to Risk Management in the Context of Toxic Substance Cases. Uncertainty and Risk Relationships." Paper presented at the 44th Annual Conference of the American Society for Public Administration (ASPA/83), New York Hilton, New York, N.Y. April 18, 1983.

Zimmerman, R., "The Relationship of Emergency Management to Governmental Policies on Man-Made Technological Disasters," *Public Administrative Review,* January 1985.

19

Approaches to Risk Management
A Critique

Lester B. Lave

INTRODUCTION

Many types of hazards confront individuals, families, communities, businesses, and nations. Individuals face immediate danger from accidents and acute disease. They face longer term danger in the form of chronic disease. Financial hazards loom in the form of unemployment, assets becoming worthless, large liabilities emerging, expenses for housing or children's education, and the termination of earned income at retirement.

Should an unfortunate event occur, such as a financial loss or severe injury, the enjoyment of life is diminished. Indeed, happiness can be compromised simply by the prospect that such an unfortunate event may occur. Risk management attempts not only to mitigate the effects of some unfortunate event, but to prevent its occurrence.

More recently, people have developed the ability to lessen both the magnitude of potential hazards and probability of the occurrence. Most efforts have been directed at reducing the probability of occurrence, or of mitigating the loss given some initial untoward event. For example, substituting less hazardous substances and smaller scale projects reduces the potential hazard; double hulls and watertight compartments in tankers reduce the probability of spills and of ships sinking. Until very recently, little thought has been given to actions that would reduce the largest potential hazard.

Although innovations in technology, living patterns, and institutions have changed the nature of hazards and their probabilities of occurrence, most of the types of hazards have prevailed for many decades. The principal new factor is a change in public attitudes about these hazards. During the 1960s, public concerns changed dramatically (Bloomgarden, 1983). Hazards that had been accepted (at least tacitly) were viewed as so alarming as to constitute crises and the previous mechanisms for coping with them were viewed as so deficient that active governmental intervention was required.

Lester B. Lave • Graduate School of of Industrial Administration, Carnegie-Mellon University, Pittsburgh, Pennsylvania 15213.

Whether judged by legislation, public hearings, or media reports, there has been a vast increase in public concern for the management of risks associated with nuclear power, air pollution, disposal of toxic wastes, occupational safety and health, consumer products, and many other areas (Lave, 1981a). One possible explanation is that risk reduction is a "superior good," that is, people will give more attention to risk reduction as their incomes rise. People living at a subsistence level have no resources to look beyond day-to-day problems. Those with higher incomes can plan and seek to protect their future happiness by managing risks.

Probably a more important explanation than a gradual change in climate created by higher incomes is the perception that risks are important and that something can be done to manage them. These perceptions are affected by social interactions. When a few individuals find fertile ground (due to gradual increases in income that trigger rejection of some heretofore accepted hazard combined with the perception that steps can be taken to reduce the risk), they can start a process that reinforces itself (see also Wildavsky, 1979; Douglas and Wildavsky, 1982).

As new individuals are informed of the possibilities of risk management and new phenomena are added to the list of risks to be managed, public demands for change increase exponentially. Such social feedback seems to have been triggered for the environmental area by Rachel Carson's *Silent Spring* and for auto safety by Ralph Nader's *Unsafe at Any Speed.* Both books and subsequent speeches and popular articles uncovered areas of general ignorance but potential concern. If the ground had not been made fertile by the increases in income and satisfaction of some of the most intense desires for private consumption, the campaigns would never have gotten started. Furthermore, if the social movements had not raised consciousness levels and the notion that the current situation was intolerable, rapid action would never have occurred.

From the initial concerns about the effects of DDT on the environment, people's perceptions about and concerns for environmental, occupational, consumer product, and other risks expanded rapidly. The public stirring was interpreted to be demanding a qualitatively different approach to lowering risks. The result was a host of federal statutes that created new regulatory agencies with the authority to manage risks.

The results of the activism of the 1960s and 1970s have not been entirely satisfactory. The sense of alarm seems to have grown in response to the discovery of problems. Some of the regulations raised rather than lowered the expected loss from a particular hazard. In general, institutions for managing risks have gotten in each other's way and tripped over their own feet.

A major theme in Ronald Reagan's 1980 presidential campaign was that these regulatory agencies were burdensome. Scholarly works showed that the agencies had not achieved their legislative objectives, and often had made little progress toward reducing risk (Zeckhauser and Nichols, 1978; Lave and Omenn, 1981; Ackerman and Hassler, 1981; Ruff, 1978). Surveys showed the public had not abandoned the desire for risk reduction but felt that the regulatory agencies had not been doing a good job and were imposing larger costs than necessary.

Many plausible proposals have been suggested for changing the ways society manages risk. (See American Bar Association, 1979; American Enterprise Institute, 1979; U.S. Congress, 1976.) However, before embarking on regulatory reform that might lead to as much disruption and expense as the first round of attempts, it might be well to examine the nature of the problem of managing risks. Furthermore, the success of previous management methods must be examined to determine which have proven effective.

Some risk management should be done by individuals, some by private institutions

(such as businesses, industry organizations, and consumer organizations), some by passive—in the sense of having the problems brought to them—government institutions (such as the courts), and some by active governmental institutions (such as regulatory agencies) (Baram, 1982; Lave, 1981b). Clearly, not all individuals and institutions are equally adept at coping with each hazard. Along with a theory to decide which hazards to attack, we need a theory to decide which institutions should be given each type of hazard.

DEFINITIONS

The terms *risk, hazard,* etc., are used loosely in common speech. In common usage, risk is used to refer to hazard, probability, or expected loss. To be clear in what follows, it is important to define these concepts more precisely (Okrent, 1980).

Hazard refers to some undesirable event that might occur. For example, one hazard might consist of an oil tanker spilling 1000 gallons of crude oil and another of spilling 300,000 tons of crude oil. Another type of hazard might be a mishap resulting in a slight bruise and still another would be a fatal mishap.

The probability of occurrence of a hazard refers to how frequently a particular hazard would be expected to occur. For example, the probability of my dying this year in a mishap is roughly 10^{-3}, or 1 chance in 1000. Thus, if my circumstances don't change, I would have 1 chance in 100 of being killed in a mishap over the next decade, assuming I do not die from other causes. This calculation also illustrates the notion that the probability will change with the time period and circumstances, such as ceasing to travel. Of 1000 people exposed to the same level of risk as I, 1 would be expected to die in a mishap each year.

The expected loss or risk is the sum of the products of each possible hazard and its probability of occurrence. To simplify, suppose that the probability of a tanker spilling 1000 gallons of oil this year is 10^{-2}, and the probability of spilling 1,000,000 gallons of oil this year is 10^{-6} (and these are the only two hazards). Then the expected loss of the first hazard would be 10 gallons per year, and of the second hazard, 1 gallon per year. The expected loss from oil spills from this tanker would then be 11 gallons per year.

Many people do not regard the expected value of the potential oil spills as being a meaningful indicator. The probability for zero spill is 0.989999. For a spill of 1000 gallons, the probability is 0.01 and for a 1,000,000 gallon spill the probability is 0.000001. There is a high probability that no spill will take place, a small probability that a large spill will occur, and a tiny probability that a catastrophic spill will occur. Over many centuries oil spills would average 11 gallons per year, but the average would be computed from many years of no spills, a few dozen years of large spills, and a handful of years of catastrophic spills. Some people prefer to see the range of the distribution of spills, from 0 to 1,000,000 gallons, feeling that it is more enlightening, at least for situations like this with a high probability of no untoward event and tiny probability of a catastrophe.

For such situations, another measure is likely to be more informative than the risk. The expected utility is similar to the expected loss, except that the hazards are treated in utility terms, rather than in physical units or dollars. Suppose that the utility loss associated with no spill is zero, the utility loss associated with a 1000-gallon spill is -1000 (in arbitrary units), and the utility loss associated with a 1,000,000-gallon spill is $-1{,}000{,}000{,}000$. In this case, the person specifying these utility losses is saying that a very large spill is proportionally worse than a small spill, perhaps because of the widespread destruction of plants and animals and the saturation of the area with oil. For this case, the expected utility

loss for zero spills is $0 \times 0.98999 = 0$. The expected utility loss for the large spill is $-1000 \times 0.01 = 10$. Finally, the expected utility loss for the catastrophic spill is $1{,}000{,}000{,}000 \times 0.000001 = 1000$. Thus, the expected utility loss from all spills each year would be $0 + 10 + 1000 = 1010$. In terms of the expected number of gallons spilled, the small spill is 10 times as important as the large spill, but in terms of the expected utility loss, the large spill is 100 times as important as the small spill.

This phenomenon of increasing utility loss with the size of the hazard might be due to a large oil spill doing much more extensive damage than an equal amount of oil spilled in small amounts. A more important example is public concern given for a tiny probability of wiping out the human race in a nuclear war.

RESEARCH ON RISK MANAGEMENT

The risk management process is represented schematically in Figure 1 (Lave, 1983). The first step is the identification of some untoward outcome or hazard. This hazard and associated risk must be characterized, at least in general terms. What is the possible magnitude of loss? What are the causes of the possible problem?

The second step is risk assessment. The quantitative magnitudes of each hazard (at least for the important hazards) must be characterized, along with the probabilities of occurrence. The result of this second step is at least a rough estimate of the expected loss. For most cases, this expected loss, in either physical units or utility terms, will be so small that no further attention is warranted.

Where further action is contemplated, alternatives for managing the risk must be identified. These might be grouped under the two headings of "regulatory" alternatives and "nonregulatory" alternatives. The former refer to alternative government actions such as standard setting. The latter refer to actions such as legal remedies or voluntary standards.

To resolve which of these approaches to risk management should be used, a decision analysis is required. The nature of the problem, characteristic of each management alternative, and of the expected outcomes from each must be considered. Almost always, the problem will be dominated by uncertainty. The precise hazards and their probabilities of occurrence will be unknown. The efficiency of each risk management alternative can be estimated only crudely. Therefore, the decision analysis must consider the uncertainties explicitly.

A wide gulf separates deciding which risk management alternative and goal is most desirable and what can be achieved in practice (Wilson 1974, 1980). For example, political forces might make a regulatory approach with a particular goal impossible to achieve (e.g., regulatory standard setting designed to reduce risks only slightly). Thus, the next step is to decide on a management approach and goal, given the political and other constraints.

Whatever approach and goal are decided upon, many people will believe that the wrong decision was taken. Some of these are likely to mount legal and political challenges or refuse to obey the decision. The legal and political challenges must be resolved, and the level of acceptance of the decision assessed before a specific risk management strategy can be put into place.

The next step is the actual implementation of the risk management strategy. During this step, the nature of the hazards and probabilities of occurrence will be determined with greater certainty and new hazards are likely to be discovered. The management strategy might be shown to be hopelessly inefficient or inefficacious. This stage could lead to a

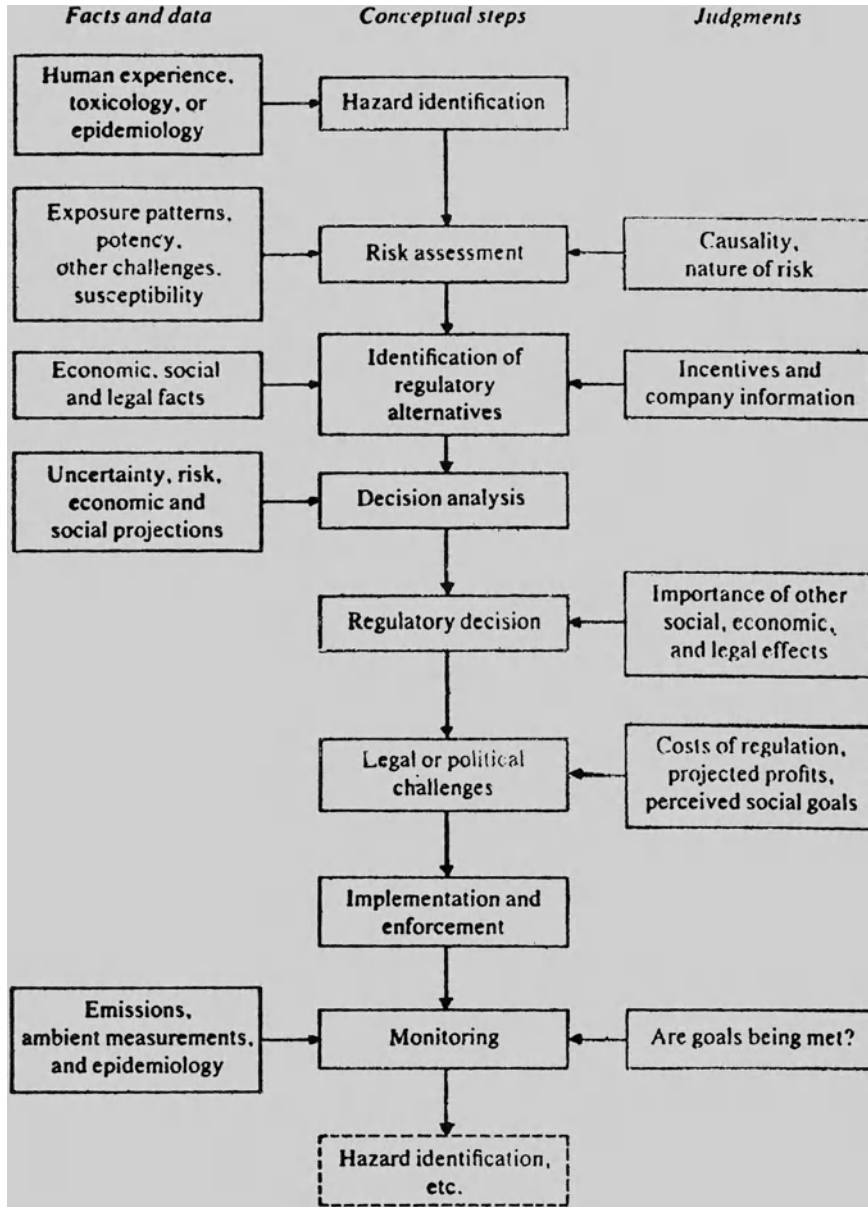

Figure 1. The risk management process.

reconsideration of the problem and the retracing of various stages, possibly all the way back to hazard identification.

The final stage consists of monitoring the management strategy to determine how well it is working and how costly it has proven to be. This monitoring is likely to turn up new hazards, new estimates of the probabilities of occurrence, and related problems. Thus, it will result in a revision of the hazard identification process, and lead to a recycling through the entire set of steps.

Risk Identification

At least until recently, health risks have been identified predominantly by unsystematic means (Lave, 1982). For example, the occurrence of some unusual disease or an unusual concentration of cases of some common disease or condition causes an alert health practitioner or officer to investigate further. In a few cases, epidemiological studies have turned up an unexpected effect that then requires further exploration. Perhaps the most common means of identifying possible risk from toxic substances, particularly carcinogens, is laboratory testing with cell cultures, or animals such as fruit flies or rodents. A method that has been used, although not with much confidence, is classification on the basis of chemical structure (structural toxicology). Unusual patterns of observed diseases and conditions, observed unsystematically, turn up a small number of risks. But even a small number may be beyond the power of scientists to identify and investigate thoroughly (see Crandall and Lave, 1981).

However, it is laboratory experiments that have identified the greatest number of potential carcinogens, many more than can be investigated in detail. Some of the laboratory tools are relatively inexpensive and quick, such as the Ames test (Salmonella plate assay). Using such short-term tests, chemicals can be screened in two days at a cost in the hundreds of dollars (Lave, Omenn, Heffernan, and Dranoff, 1983). It would be possible, and not exorbitantly expensive, to test all 60,000 chemicals in common use. Some thousands of chemicals would be expected to turn up positive on the test.

Other laboratory tools, such as the long-term bioassay, require three years and cost about $1 million per chemical. It would not be possible to test all 60,000 commonly used chemicals or even the thousands found positive on a short-term screening test. This is an example of a more general problem. Namely, many more chemicals (and other circumstances) are identifiable as possibly toxic than can possibly be explored in detail.

Risk Assessment

However, at least some rough characterization is required. The next step makes this characterization more formal by requiring at least a rough estimate of the magnitude of the hazard, the possibility of its occurrence, and the number of people at risk. At least a crude estimate of the quantitative risk (expected loss) is required to set priorities. Current processes of risk identification turn up many more possible concerns than can be managed, or even considered in depth. If risk management is to be systematic rather than capricious, each of the possible problems must be characterized with sufficient information to allow making a judgment about which should be considered first.

Estimating the expected loss requires a number of controversial steps, collectively known as quantitative risk assessment (Crump, 1979; Hoel, 1974; ILRG, 1980). These are most highly developed for exploring the carcinogenicity of chemicals, although they are also used for other hazards. The first step is deciding what inferences can be drawn about human carcinogenicity from the results of laboratory tests. For example, should a chemical found to be mutagenic in an Ames assay be considered a human carcinogen (U.S. Office of Technology Assessment, 1977; Marcus, 1983; Food Safety Council, 1978)? Should a chemical found to increase the number of benign tumors in rats during a long-term bioassay? Should a chemical found to induce malignant tumors in rats' zymbal glands (note that humans don't have zymbal glands)?

The second step is estimating the dose–response relationship. The classical curve from pharmacology traces out the relationship between the proportion of people manifesting a response to the drug and the amount of the drug they ingest. Some people are extraordinarily

sensitive to the drug and manifest a response at very low doses. Some people are extremely resistant and do not manifest a response until very high doses. Most people, however, manifest a response at moderate doses. For example, the amount of aspirin required to get individuals to say that a common pain, such as a toothache, has gone away would be expected to display a classical dose–response relationship.

The same sort of relationship appears to hold for chronic diseases, such as the proportion of the population that would develop cancer as a result of exposure to a carcinogen. Lung cancer caused by cigarette smoking appears to display a classical dose–response relationship, where an increase in the number of cigarettes smoked raises the likelihood of getting lung cancer. In practice, there are rarely sufficient data available on human exposures and the resulting mobility rate to allow reliable estimation of a dose–response relationship.

More commonly, the dose–response relationship is estimated from animal tests and long-term bioassays. However, long-term bioassays rarely provide data on more than zero, low, and high doses (Lave, 1982). Almost all of the functional forms for a dose–response relationship can be fit to these three points (with additional assumptions required in some cases) and all are likely to fit about equally well. In extrapolating from rodents to humans, two steps are required: extrapolation from a small rodent to a large human and from a high dose to a low dose. Extrapolation from a small rodent to a large human can be done on the basis of dose per unit of body weight, per unit of area, by holding constant the concentration in air, food, or water, or by other means. Extrapolation from high to low dose is determined by the dose–response relationship. However, since many alternative relationships fit the data equally well, some sort of assumption (such as choosing the most conservative relationship) is required.

The most comprehensive examination of dose–response relationships in a long-term bioassay, ED-01, found that virtually all of the suggested mathematical forms for dose–response relationships fit the data about equally well. Thus, all of them closely predicted the prevalence of cancer among the rodents at the measured doses. However, they gave predictions that differed by more than a factor of 1000 for the cancer rate that would be expected at very low doses. When scientists understand the underlying physiological factors, they can deduce the proper basis for extrapolating from small to large mammals and from high to low doses. However, this understanding is obtained for only a small number of cases and so assumptions are required. The result is a vast amount of uncertainty concerning the quantitative risk to humans. However, even with this uncertainty, the quantitative estimates are better than no data.

Management Options

Before selecting a management option, the goals to be accomplished must be made clear. For example, the goal of eradicating all cancer would lead to focusing on very different management options than one of lowering the cancer death rate by 10%.

It should not be surprising that society espouses contradictory goals, depending on the precise circumstances (Schelling, 1968). For a child who has fallen into a mine shaft or an astronaut on a space mission, no expenditure of resources is deemed too much to save the life. At the same time, little is done to protect pedestrians at many intersections or cars at many train crossings. Much is spent to treat a child with cancer, while little is spent on an elderly person who needs custodial care. The huge risks associated with cigarette smoking and highways are viewed with relative indifference, while the much smaller risks associated with toxic waste dumps or the release of tiny amounts of ionizing radiation from nuclear power plants are viewed as a crisis (Fischhoff et al., 1981, 1978).

All of these inconsistencies are reflected in congressional debate over risk management. Some statutes take an extreme position; for example, the Delaney clause in the Food, Drug, and Cosmetic Act instructs the Food and Drug Administration (FDA) not to allow any additive to food that is found to be carcinogenic in animal or man (Lave, 1981a). Thus, no risk from carcinogenic food additives is to be tolerated. Other statutes instruct the agency to balance the risks against social benefits; for example, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) requires such a balancing. Finally, in failing to act on a number of areas, Congress has implicitly declared they are not worthy of attention; for example, the threats of lung cancer and mesothelioma from exposure to asbestos in existing buildings.

If the public had in mind a set of quantitative risk goals, or if Congress were willing to articulate goals, then regulatory agencies, manufacturers, consumers, and workers would be in a better position to make their own personal decisions about risk. However, this is an area where rhetoric seems to overcome reason. Unless there is a compelling need to be more thoughtful, Congress seems to react to risk by declaring that it should be reduced to zero, as in the Delaney clause. The eradication of a pest and at the same time adhering to the principle of zero risk are mutually exclusive goals. When faced with such dilemmas, the responsible agencies have generally developed sensible compromise strategies.

Rather than attempting to specify, or even investigate past attempts to set goals more explicitly, it is more fruitful to examine the risk management frameworks that Congress and society more generally have specified for various hazards. From this examination will emerge some notion of the goals that society has stated in various areas. From an examination of the perceived success of the various risk management frameworks, there will emerge some notion of how successful the frameworks and their implicit goals have been. This is done below.

The management options can be divided between regulatory (active government involvement) and nonregulatory (passive government involvement or nongovernment management). The former are almost entirely products of the last two decades and consist of standard setting and banning, with sanctions such as criminal penalties, fines, and stopping operation. Whatever the regulatory decision, someone inevitably feels aggrieved. Attempts to redress the grievances can take the form of testimony, written reports, petitions to the regulatory agency, or attempts to get Congress or the courts to overturn the regulation. Rarely is there much to be gained either by the agency or the aggrieved party by compromise to resolve conflict. All parties look forward to litigation and attempt to build a strong case. Thus, the almost inevitable litigation occurs, with its delays and costs.

There are a large number of nonregulatory risk management options, including using the courts under the doctrines of nuisance, trespass, negligence, and strict liability. Other options include voluntary standards, reports by consumer groups, insurance companies, and licensing and occupational certification. These nonregulatory options are explored below.

Decision Analysis

A characteristic of all risk issues is uncertainty. Uncertainty can obscure the nature of the hazards, the probability of occurrence, or the population at risk and its special characteristics. Potentially the most important source of uncertainty is interaction with risk agents outside those of a particular issue. For example, carcinogens are characterized as initiators and promotors (U.S. Office of Technology Assessment, 1977; Marcus, 1983). The latter are harmless unless someone has already been exposed to an initiator. Indeed, many chemicals are known to interact, either potentiating or dampening the effect of another. Although these interactions, as well as effects for susceptible individuals, could be encompassed within the process of defining hazards and probabilities of occurrence, they are more fruitfully examined as interactions and susceptible individuals (Omenn and Friedman, 1980).

The elements of the problem must be pulled together in a decision analysis (Raiffa, 1968; Keeney, 1973; U.S. Office of Technology Assessment, 1980; Stokey and Zeckhauser, 1978). An extensive literature exists on decision and policy analysis of situations involving risk (Clark and Van Horn, 1978). Unknown or uncertain aspects must be modeled in terms of subjective probabilities or explicit parameters. In the analysis, most uncertain aspects turn out to make little difference. Generally a few elements of uncertainty emerge as central. The modeling must also identify particular goals and preferences. The purpose of this decision analysis is to work through the issues, identifying crucial uncertainties and dominant solutions.

Strategies for Reducing Loss

There are a number of ways of reducing the adverse effects of some unfortunate event: (1) One can try to reduce the probability of the event occurring. For example, there is less of a chance of an auto crash if one does not drive during hazardous conditions. (2) One can try to change the nature of the unfortunate event. For example, driving more slowly under hazardous conditions both reduces the probability of a crash and reduces the damage should a crash occur. (3) One can take actions to assure that, once a mishap has occurred, further damage will be reduced to a minimum. For example, providing well-equipped ambulances, hospital emergency teams, and first aid training to police will have the effect of minimizing the consequences of a particular injury in a crash. (4) Finally, one can take steps to lessen the financial loss associated with any given level of physical damage. For example, people can buy insurance to cover the cost of repairing damaged property and paying medical bills.

If untoward events are considered random occurrences (accidents) because their causes are not understood or subject to manipulation, the first class of actions is impossible. In less developed societies, the last two possibilities may be the only ways of mitigating loss. A simple system of accomplishing these ends is to have an extended family pool their resources and efforts. They can provide direct help to nurse someone who is injured or sick or can repair a house that has been damaged. By pooling their financial resources, the family can tide individuals over unfortunate financial events. A neighborhood or small community can perform the same functions at a more aggregate level. Finally, a nation or community of nations can provide the same types of services in case of epidemics, floods, or other natural disasters.

The critical assumption that makes such pooling of risks efficacious is independence of the risks. A neighborhood gains nothing by pooling the risks of flood, if all would be affected in precisely the same way by floods. This principle leads insurance companies to limit their risks to some common disaster, for example, limit the amount of flood insurance sold in a particular neighborhood. Insurance companies seek to form a large pool of independent risks.

Another principle of risk management is that behavior is related to the expected loss of an action. Thus, someone with fire insurance is likely to be less careful with storing paint, newspapers, and other flammable materials than someone with no insurance. One casual observation is that people change their driving behavior after being warned that any more crashes will lead to cancellation of their insurance. Such changes in behavior are characterized by the term *moral hazard,* meaning that people will take less care to avoid an unfortunate event if the cost to them is reduced. In the extreme, when insurance offers greater compensation than not having a fire, someone may be tempted to commit arson.

As an example of these principles, suppose that the undesirable event is getting cancer from exposure to a chemical carcinogen. The event could be made to occur less often by reducing exposure to the carcinogen. The nature of the event could be changed by postponing

it for many years. For example, lowering the exposure level would mean that it would take longer to accumulate a dose sufficient to cause the cancer; there is also evidence that the latency period is extended by lowering the dose. The physical damage could be reduced by developing better methods to treat the cancer. The financial damage could be reduced by insuring against the medical bills and lost income. Two workers exposed to the same chemicals would not constitute independent risks whereas workers in different industries would. Thus, two workers doing the same job would gain little by agreeing to mutual assistance in case one contracted an occupational disease. Finally, if widows and children received a really generous settlement in case the individual contracted cancer, some individuals might be led to take actions that amount to suicide.

FRAMEWORKS FOR REGULATING RISK

A number of frameworks have been mandated by Congress or developed by regulatory agencies for reducing risk (see Lave, 1981a). Each implies a particular way of thinking about the problem and managing it. Indeed, each tends to have implications for whether a particular situation will be regarded as a problem. However, before setting out these frameworks, it is worth considering what criteria should be used to evaluate them and judge one to be superior to its alternatives.

Criteria for Evaluating Frameworks

Four criteria are relevant in judging whether a risk has been properly managed or for choosing among management alternatives. The first is the extent to which the risk has been reduced to a level of acceptability. Since the point of the exercise is reducing risk, this is the first and primary criterion. Unfortunately, it requires a clear definition of goals and what is deemed to be an acceptable residual risk. As noted above, clear goals rarely are stated and so applying this criterion is more akin to making a judgment and then seeing whether that judgment is accepted broadly. In general, acceptability is defined in terms of the benefit of having the product or activity and the social costs of reducing risk. Even small risks are not acceptable for a worthless product, while large risks are accepted for a product perceived to be highly useful and for which people perceive no easy way of reducing the risk.

The second is efficiency. Each of the frameworks and methods of implementation have implications for economic efficiency. The quantitative deviation from Pareto optimality of each proposal needs to be measured, as well as the resulting distributions of income and wealth. Furthermore, static efficiency must be supplemented by examination of dynamic efficiency. Much of the discussion of the "dead hand" of regulation refers to problems with efficiency over time. For example, environmental regulations have allegedly slowed productivity and innovation, thus imposing high long-term costs (Denison, 1979).

The third is equity. Each of the frameworks and methods of implementation have implications for equity, both at present and for future generations. While there is no consensus on the desired amount of income redistribution or the desired distribution of consumption, equity plays an important role in regulatory decision making. *Ad hoc* decision making examines the implications for children, the old, the poor, minorities, and other identifiable groups. In each case some decision is reached in which equity considerations played an important role.

The fourth is administration simplicity. Complicated frameworks and methods of implementation require many resources, are difficult to explain, difficult to administer, and

subject to legal challenge. Simplicity is not merely a virtue, it is a necessity; complicated frameworks will not work.

No Risk

The first of the decision frameworks, no risk, is exemplified by the Delaney Clause of the Food, Drug, and Cosmetic Act, which proscribes the addition of any carcinogen to food (Merrill, 1978, 1980, 1981; Hutt, 1978). Similarly, the Clean Air Act Amendments of 1970 instruct the U.S. Environmental Protection Agency (EPA) to set primary air quality standards which protect the most sensitive group with an angle margin of safety. These statutes embody the notion that no unnecessary risk is acceptable, even one that is miniscule. No improvements in the appearance, taste, and convenience of food are sufficient to justify even the smallest risk of cancer.

The U.S. Supreme Court wrote in the benzene decision that all human activity involves risk (Industrial Union Dept., 1980). People willingly assume greater risks in order to increase their income, increase the appeal of their food, and even to increase their pleasure in recreational activities. This framework would lead agencies to force people to be safer than they desire, to ban products and activities that people enjoy. While "no risk" has appeal as rhetoric, it is a pernicious guide to regulatory decisions. Trying to make people safe in spite of themselves is doomed to failure, as Prohibition demonstrated.

While a uniform attempt to achieve zero risk must fail, society could focus on a number of cases, such as carcinogenic food additives, and insist on zero risk. However, the controversies over saccharin and sodium nitrite demonstrate that there is no consensus here (Lave, 1981a).

Risk–Risk

This framework was proposed by the FDA because the Delaney Clause appeared to require it to take actions that would cost more lives than it would save (U.S. Dept. of HHS, 1978; Green, 1978). Some toxic substances, such as food additives and fungicides, protect our food against contamination. Their use requires balancing the good they do in expanding the food supply and lowering its cost against the inherent toxicity of the substance. Even if someone believes that health was paramount and that no risk would be justified by an expansion of the food supply or decrease in its cost, one would still need to balance protection against toxic effects of the substance.

Technology-Based Standards

Technology-based standards have been the basis of EPA's water regulation and have played important roles in air regulation, particularly the control of new sources. This approach asks the agency to determine, and then require, the best control technology, with no explicit consideration of either costs or benefits. The framework might be paraphrased as ordering the agency to do all that is technologically feasible to do. It thus has great appeal because it does not make sense to order controls that are not technologically feasible and because it has a plausible goal which does not require much data or analysis.

However, in practice the framework is not so simple to administer. A whole list of technology standards have been developed, from best available control technology (BACT) to least achievable emissions rate (LAER). The code words appear to have meaning to the engineers who set the regulations, with each conveying a slightly different meaning about

how stringent the control technology must be, what level of control costs are allowable, and whether the technology must be currently available or only potentially available. Although no formal analysis of control costs is required, the agency must make a judgment about whether the industry will be bankrupted by the proposed requirements.

The Nuclear Regulatory Commission uses the concept of "as low as reasonably achievable" (ALARA). Generally, ALARA has a specific numerical guideline, such as "reduce radiation exposure as long as it costs less than $1000 per man-rem." Because it has an anchor point, ALARA is less arbitrary and subject to less variation in interpretation than the technology-based standards set by EPA or the U.S. Occupational Health and Safety Administration (OSHA).

Risk–Benefit

The three previous frameworks do not allow consideration beyond health effects such as the quantity and price of food, or its appearance, taste, and convenience. The folly of refusing to consider these effects is illustrated by examining our own choices. For example, most of us are willing to risk the minute chance of biological contamination rather than overcook food such as pork (to ensure microorganisms have been killed). We are not even willing to boil our water in order to eliminate the minute possibility that chemical water treatment failed to kill all harmful bacteria.

This framework proposes to account for cost, convenience, and even preferences in an attempt to balance these against risk (Starr, 1969; NAE, 1972; Hutt, 1978; Merrill, 1981; Clark and Van Horn, 1978). Unfortunately this term is used loosely to describe a vast array of frameworks, from narrow conceptions of balancing benefits against risk without considering other attributes to general hand waving. The framework has an immediate appeal to congressmen and regulators because it is a vague instruction to consider all factors in arriving at a decision. While no one can oppose considering all relevant factors, no one has specified precisely how this is to be done.

Cost-Effectiveness

Cost-effectiveness analysis examines different ways to achieve some goal given the constraint of a fixed budget (Hitch and McKean, 1965). Formal development was closely associated with the Department of Defense; the goal was paraphrased by President Eisenhower's secretary of defense, Charles Wilson; "Get the most bang for the buck." Most organizations must live within a fixed budget for the next planning period and so this framework poses the correct question. More importantly, almost all organizations, other than those directly producing some goods or service, cannot measure their output or contribution to the institution they serve; their budget is determined by some informal process encompassing past expenditures, perceived contribution, and current availability of funds. When budget is not directly related to current output, cost-effectiveness is the relevant framework for guiding actions.

Regulatory Budget

This framework is a variant of cost-effectiveness (DeMuth, 1980). Congress would set a budget for each regulatory agency, determining the total costs that implementing its actions could impose on society. At present, few regulatory agencies face any constraints other than the time of their staff and their ability to defend their actions in litigation. The regulatory

budget would provide an additional constraint. It would focus each agency's attention on the costs it imposes on the economy to act as a counterbalance to its mission of improving health and safety.

There is much to be said for this framework. It poses an understandable constraint on the agencies and asks Congress familiar questions. Without doing anything so objectionable as requiring that the agencies or Congress state the amount society should spend to avert a premature death, it provides a constraint on the agencies. This is not to say that implementation would be easy. It is extremely difficult to estimate the cost to an industry of some regulation; one could be confident that each agency would select a cost estimate at the lower bound of credibility, or even below that. However, the most important virtue is that this framework poses the proper question in a felicitous fashion, one that is familiar and acceptable to both the agencies and Congress.

Benefit–Cost Analysis

The best-developed, quantitative framework is benefit–cost analysis (Prest and Turvey, 1966; Mishan, 1976). It asks for a full specification of the social effects of a proposed action, quantification of these, and then a comparison of them using some common metric, generally dollars, so that the net social effect can be estimated. One of the most controversial aspects of its application is putting an explicit dollar value on human life, or rather on prolonging life (Linnerooth, 1979; Viscusi, 1983); another is the social rate of discount (Baumol, 1980).

Some economists advocate this framework as the sole basis for making decisions (see Executive Order 12291). If so, every effect must be encompassed, even though some cannot be quantified with confidence. The approach requires quantitation and valuation of effects as nebulous as redistribution of income or extinction of some species. In practice there is no hope of doing so in a way that would be widely accepted. While benefit–cost analysis cannot be the only basis for decision making, it is an important input. The scientific facts are invariably incomplete, but they indicate what is known, what has been disproven, and what is being conjectured. Although incomplete, benefit–cost analysis provides an important input to decision making since it stresses what is known and measurable.

ALTERNATIVES TO REGULATION

Prior to government regulation of risk, a number of approaches were used for risk management (Baram, 1982; Lave, 1981b). Many are still the primary methods of managing risk.

Market Management of Risk

The primary institution for managing risk in the United States is the marketplace. The decisions of producers about occupational risks and product safety combine with the decisions of individual workers and consumers to determine virtually all risk levels. The risks inherent in production and in consumer products are determined predominantly by market forces. Economic theory has specified the conditions under which the marketplace is efficient, in the sense that no one can be made better off (by rearranging the products offered, the quantity of each product produced, or who produces and consumes each product), without making at least one other person less well off. This theory has been generalized to encompass risk.

The assumptions of these theories are not realized in the real world. The nature of the

violations provide a clue as to the government intervention required to obtain economic efficiency. Obtaining efficiency (in the absence of risk) requires first that each economic agent regard himself as a price taker, without any noticeable influence on price. Attempting to ensure competition has been a major goal of public policy since the 1880s. This policy has the general title of antitrust policy, but it includes mergers, collusion, predatory behavior, and even false advertising, as well as monopoly behavior.

The second major assumption is that there are no nonmarket interactions among economic agents, no externalities. Controlling externalities, such as air and water pollution, has been the task of health, safety, and environmental agencies in the past two decades. Regulation of risk management decisions generally falls under this heading.

When risk is allowed to enter the model, complicating the usual assumptions of complete information and simple production and consumption, additional conditions are needed to ensure efficiency. The assumptions leading to economic efficiency under conditions of risk include widespread information on the nature and magnitude of risks and a continuum of markets and products so that each actor can exercise his preferences for risk versus other goals. Agencies such as the Federal Trade Commission (FTC) attempt to ensure that advertising gives correct information while other agencies have attempted to require that safe products and safety options be offered to consumers. Some agencies have rules requiring labeling of dangerous products or hazardous chemicals.

Unfortunately, the assumptions needed to prove that the market place is efficient are not good characterizations of the U.S. economy; the above theorems can only be considered guides. One approach is to attempt to have the economy better approximate the theorems by using antitrust laws to ensure competition, various means to deal with externalities, and to provide information and a range of choices to handle risk. While these interventions cannot lead to the assumptions being realized, they can lead to "workable" competition that approximates the economically efficient outcome. Alternatively, one might conclude that further, or indeed any, actions are likely to cause as many problems as they solve. If so, one must accept the deviations from economic efficiency and hope they are unimportant or temporary.

Another approach to making competition work is to be more imaginative in defining property rights. For example, no one has property rights to the air. However, if these property rights were vested in consumers, polluters would have to negotiate the right to emit pollutants. In situations where a small number of parties are involved and where there is general knowledge of the implications of various alternatives, one of the results from economic theory is that vesting property rights can lead to efficiency despite externalities. Vesting the property rights in any party, even in the polluter, can lead to an efficient outcome. Vesting the rights in one party versus another changes the final distribution of income, but not the efficiency of the solution. This result, first stated by Coase (1960), can be powerful in situations with a small number of actors, such as risk in a small plant. However, it is irrelevant when the number of actors is so large that negotiation is essentially impossible.

Legal Mechanisms for Risk Management

A tort is a civil wrong independent of contract. Although the fault of a responsible party generally causes a tort, an inadvertent act or negligent failure can be the precipitating event (this section is based on Transportation Research Board, 1983). The question is whether a party charged with committing the tort acted or failed to act as would a reasonably prudent person under all of the circumstances in a particular case.

Recovery when a tort is committed is limited to direct damages (such as medical

expenses, lost income, and the cost of repairing or replacing damaged property) and "incidental" damages such as pain and suffering. However, compensation of pain and suffering often exceeds that for direct damages.

A number of legal doctrines can be used to remove a risk or at least to compensate the victim. For example, the doctrines of trespass and nuisance can be used to end an action before actual harm has been done, for example, after air pollution is seen to cause problems but before actual health effects are manifest. More generally, the doctrines of product liability, negligence, and strict liability manage risk, at least after the hazard is manifest, by forcing the responsible party to pay for the damage. In facing financial penalty, the party responsible for the damage is motivated to reduce risk.

In practice these legal remedies work imperfectly. Long delays occur between damage and the paying of compensation. In many cases the victim cannot afford to wait and so is forced to accept a small settlement or to abandon the case entirely. These suits are complicated and risky, with little assurance that a case will not be lost due to procedural difficulties, an idiosyncratic judge, or a prejudiced jury. Furthermore, the adversarial nature of the system gives an advantage to the side with the better lawyer; often the victim cannot afford a lawyer as good as the one hired by the defendant.

Legal remedies can also be threatening to a defendant corporation. The jury may regard the defendant's "deep pocket" as sufficient reason to make an award, even though they do not believe the firm's actions caused the problem. Juries may give awards vastly greater than any reasonable amount in order to punish the defendant or to reward a suffering plaintiff.

Despite these difficulties, the legal remedies are powerful means of reducing risk. For example, the bankruptcy of a profitable company, Manville Corporation, due to worker suits for compensation after exposure to asbestos, is a dramatic example of the power of this mechanism. Another example is the jury award of $128 million to the heirs of the victims of a Ford Pinto crash who died in the ensuing fire (see Baram, 1982, Chapter 8). The Ford Motor Company was found to have known about the fire hazard resulting from a rear-end collision for the Pinto, but did not remedy the action because the cost was considered too great. The award was reduced to $6 million on appeal, but continues to be influential. Also the bankruptcy of Manville dramatizes the power of the negligence doctrine, while cases like Ford Pinto dramatize the power of the product liability doctrine. Thus, even if the awards are delayed and uncertain, substantial awards compel companies' attention and reduce risk.

The doctrine of strict liability represents an extreme case of using legal remedies to compel risk reduction. Under this doctrine some actions and products are considered to be so inherently dangerous that any resulting damage is considered to be the fault of the manufacturer (or shipper) without need for explicit proof of negligence. All that is required is to show that the harm resulted from the untoward event; negligence need not be shown. Strict liability could be extended to include virtually all occupational hazards and consumer products, thus shifting the burden to manufacturers and employers to ensure the safety of their products and workplaces. Extending the strict liability doctrine in this way would go far toward reducing risk, although it would have a number of undesirable implications. It is currently applied in some states to child labor laws, federal and state pure food laws, railway safety statutes, and the dumping of hazardous wastes under superfund.

The Justice Department has proposed a new criminal code that would make consumer fraud and endangerment serious crimes. The latter felony is defined to occur "where an individual's conduct manifests an extreme indifference or an unjustified disregard for human life." Congress has already made "knowing endangerment" a crime under the Federal Solid Waste Disposal Act. These criminal violations add teeth to the deterrence effects of torts, but obviously should be saved for extreme violations.

The most perplexing implications of Coase's discussion of property rights is that the only aspect of the outcome influenced by who is assigned the property rights is the income-wealth distribution. Thus, the level of risk in a situation will not depend on who is assigned the property right. The resulting level of risk would not depend on whether manufacturers were forced to pay under the notion of strict liability or consumers were forced to pay under the doctrine of *caveat emptor*. The risk outcome (but not the distributions of wealth) would be the same as long as all parties knew in advance who had the liability. The rationale is that, through one's own actions and those of others, the parties will find the cost-minimizing solution (the most efficient one) and then the party who is liable will offer compensation to the other parties to achieve this efficient solution.

Important qualifications to this result are that uncertainty dominates risk decisions, data are expensive to collect and analyze, and negotiation between the parties can also be expensive. Thus, efficiency is more likely to result if the liability is placed on the party that can most cheaply collect and analyze the data or most cheaply take action that lowers social costs. In many cases this will be the manufacturer rather than individual workers or consumers. However, where or how the individual uses the product or behaves in the work environment is the prime determinant of risk; social cost may be minimized by imposing the burden on workers and consumers.

Safety and health regulations enter into litigation in an asymmetric fashion. If the defendant violated a standard or regulation, that fact can be introduced to show negligence or even willful negligence. However, if the company complied with all applicable standards, this fact may generally not be introduced to the jury. Thus, regulations and voluntary standards are treated as minimal requirements, but not sufficient guarantees. Inspection could be inadequate to prove that the defendant was in compliance or the standards and regulations might be inadequate to give reasonable protection.

Voluntary Standards

Prior to the experimentation with regulation during the last two decades, risk management within companies was conditioned by voluntary standards or recommendations by various groups. These standards are voluntary in that failure to adhere to them could not impose any direct sanctions. However, there were costs for not adhering to the standards as elaborated below.

Four types of groups set risk standards: (1) industry trade associations and other industry groups, (2) professional organizations such as the American Conference of Governmental Industrial Hygienists, (3) consumer groups, such as the Consumers Union, and (4) other businesses, such as insurance companies and banks. Each of these groups tends to occupy a different role and there is not a large amount of overlap.

Industry trade associations such as the American Petroleum Institute set standards related to risk. These are set with the participation of member companies and then are considered to be trade association recommendations to each company. More important is the American National Standards Institute (ANSI), which sets risk-related and other standards for a large number of industries, both for the workplace and for products. These standards are developed by a consensus process among participating firms. In more recent years, government agencies and consumers have participated in the process.

While the trade associations and ANSI have no power to enforce the standards, their publication puts considerable pressure on firms to adhere. Unions and consumers are put on notice that there is a problem and given a recommended solution. Firms that don't adhere to the recommendation are likely to receive pressure from unions and consumers. Failure

to adhere can also be used as evidence in litigation for negligence or product liability. Such evidence would carry considerable weight with juries in demonstrating that a firm knew of the risk and chose not to act.

Consumer organizations test products and make recommendations to their subscribers. One important criterion is the safety of each product. For example, Consumers Union insists that appliances be double insulated against electrical shock. Since the Union refuses to evaluate any other attributes of an appliance not meeting this specification and lists it as unacceptable, they place considerable pressure on manufacturers who want to sell to their subscribers to adhere to their criteria.

Both the products selected for evaluation and the evaluation criteria must reflect the interests of group members. Given the expense of testing and the vast array of products available, each consumer group must make hard choices concerning where to allocate resources. In practice, individual consumer groups cater to a narrow range of consumers, in terms of income and preferences. For example, the products rated by Consumers Union fall into a price range that is normally not purchased by high- or low-income consumers. Whether Consumers Union standards accurately reflect the preferences of middle-income consumers, their ratings are an important influence on product sales. Manufacturers wishing to sell to this group must determine CU's criteria and attempt to show up well on their tests. In essence, these groups can be regarded as sources of marketing information for firms. Their standards of quality and safety are the relevant ones for selling to the market that pays attention to their reports. These consumer groups relieve firms from having to collect expensive marketing information. Professional organizations specify standards, particularly for exposure to toxic substances and safety. While these organizations have no direct connection with firms, the professionals in the firm are often members of the association and collaborate in the development of standards. The greater independence of these associations from the companies gives their standards greater credibility.

In setting premiums for insurance, companies influence risk. For example, an insurance company might refuse to insure a building unless it was constructed with materials certified by Underwriter's Laboratory, where applicable. Premiums differ by type of construction and by the presence of various types of protection equipment, such as sprinklers. The premium structure influences safety behavior by, for example, inducing the installation of sprinklers. Similarly, if lenders refuse to give a loan on a building with particular characteristics, they influence safety behavior. For fire insurance, there are generally prevailing standards within the insurance community. However, for most types of risks, each insurance company must set its own policies and premium structure.

Workers' Compensation is a type of insurance that has played a major role in reducing occupational risks. The various state statutes impose strict liability on the employer, making him financially responsible for all hazards that occur at the workplace or are occupationally related. They also prohibit the employee from suing for negligence, instead giving compensation according to a fixed formula. Strict liability did much to increase employers' concern for increasing safety; it even got employers to train their employees in safety and to insist that they follow safe practices. Since an employer's premium for Workers' Compensation is related to industry experience, each employer is somewhat motivated to reduce the accident and occupational disease rates. The motivation would be greater if firms were individually experience-rated.

Of these four groups, standards set by professional groups are generally confined to the area of expertise of the organization, e.g., toxic substances for toxicologists and industrial hygienists, safety for safety engineers. Consumer groups confine their recommendations to consumer products. Insurance companies and banks confine their recommendations to the

specific lines of business and specific cases they deal with. Trade association and ANSI standards can cover virtually every aspect of risk management. When OSHA was created in 1970, Congress authorized it to incorporate into regulations those voluntary standards that were deemed worthwhile. OSHA reacted by incorporating virtually all applicable ANSI standards and many other voluntary standards, even those that were meant to serve as guides rather than as minimum standards. With a few notable exceptions, these standards have served OSHA well in its attempt to enhance worker health and safety.

Other Nonregulatory Methods

Many other government actions influence risk. For example, when professionals are certified or licensed, they are required to demonstrate competence; this is intended to reduce risk. For example, physicians and professional engineers must demonstrate via examination, training, and experience that they are competent to perform their licensed tasks.

Another type of governmental action is the implicit or explicit subsidy of insurance. For example, many states require that all drivers have at least a minimal level of insurance. This requirement acts to reduce risk. At the same time, most states generally set a maximum price on what can be charged for this insurance and require that insurance be offered to all drivers at this price or lower. This legislation has the effect of having safe drivers subsidize reckless ones and tends to increase risk. Consider, for example, the risk level that would result if all drivers were required to have insurance but there was no ceiling on the price of this insurance. Risky drivers would find they could not afford their high premiums and would have to stop driving (or would drive illegally and, if caught, be punished criminally).

Government explicitly subsidized the insurance of nuclear power plants under the Price–Anderson Act. The act was an attempt to promote nuclear power by shifting much of the risk to the federal government. Insofar as the act had this effect, this subsidy increased risk. Other government actions include the publication of risk-related information. For example, the Consumer Product Safety Commission publishes information about the hazards associated with various products. These reports influence consumers not to buy the products or to use them more carefully. The National Highway Traffic Safety Administration (NHTSA) publishes data on the crashworthiness of cars. Early reports had a substantial influence on the design of small cars, particularly small Japanese cars. Some manufacturers whose cars had performed badly modified them so they would perform better on the NHTSA tests. This is another example of manufacturers designing for a particular standard, even though General Motors, which did relatively well on the tests, criticized them as misleading.

The U.S. government is the largest purchaser in the economy. When the General Services Administration (GSA) puts out specifications for its products, it influences most manufacturers. Although the specifications apply only to government purchases, they influence all goods. For example, when the GSA specified seat belts on all government cars in the 1960s, auto manufacturers tended to put the belts on all their cars.

One last major influence of the government comes in the preliminary announcements of regulatory agencies. For example, OSHA published a list of 10 suspected carcinogens that it was considering regulating. The effect of publication was to alert workers to the possible problems with these chemicals and to bolster private action prior to government action. In many cases private action has vitiated the need for government regulation. Often, the government never got around to regulation, but private actions reduced the risk, at least somewhat.

Where the data are accurate and the enumerated risks merit action, the notice that the government may decide to regulate can speed private action and is beneficial. When the

government announcement is uninformed, the resulting controversy and private actions will waste resources. It is important that government get its facts right before any announcement.

BRIEF CASE STUDIES

The above notions can be made more concrete by applying them to a few instances where regulatory agencies have acted or failed to act. Each case will begin with a brief description of the issues, then go on to consider the steps for risk management, including the effect of choosing one of the frameworks for managing risk.

Saccharin

This nonnutritive sweetener was discovered more than a century ago and has long been suspected of being a carcinogen (NAS, 1978, 1979; Grobstein, 1981; Williamson, 1981; Merrill, 1978, 1980; Lave, 1981a). A large number of animal bioassays have been done on saccharin, with most showing no increase in cancer incidence. These results indicate that saccharin probably is a carcinogen in humans, although it is one of low potency. In 1978 the FDA acted to ban saccharin under the Delaney Clause. Since there was no other nonnutritive sweetener licensed by FDA at that time, there was a major public outcry and Congress quickly acted to forbid FDA to implement this ban. How to manage the risks from saccharin has been a major public issue, with numerous high-level reviews and differing conclusions by thoughtful people. For example, Canada banned saccharin prior to FDA action and that ban has not been rescinded.

The risks of saccharin were discovered by laboratory experiments. Many animal bioassays were conducted specifically to investigate carcinogenicity. Over time, the bioassays were changed to make them more sensitive to detecting carcinogenicity.

A risk assessment shows that tens of millions of Americans regularly consume saccharin, some in fairly substantial quantities. Since there is presumed to be a long latency period between first exposure and the appearance of the resulting bladder cancer, children are deemed to be a high-risk group. Epidemiological studies found that cigarette smokers seemed to be at particularly high risk for bladder cancer when using saccharin; they are the other high-risk group. The National Academy of Sciences panel refused to estimate the number of Americans who can be expected to develop bladder cancer as a result of ingesting saccharin. However, they specified that the range was from zero to 2000 new cases per year. One can infer from the lack of significance in the epidemiological studies that the number cannot be in the top end of the range.

Saccharin is a particularly bothersome case since millions of Americans desire a nonnutritive sweetener. Saccharin is at worst a carcinogen of low potency and the risk is borne by consumers of the product, most of whom are aware of the risk. I will apply the various decision frameworks in the hope of enlightening the choice that society should make concerning saccharin use.

The first set of frameworks foregoes the use of regulation. The current system for managing saccharin risks is essentially market regulation, with a labeling requirement. Saccharin can be used in any product and anyone may consume it, as long as the product is clearly labeled as containing saccharin and there are warning posters where the product is sold that saccharin has been found to be a carcinogen. The result of adopting this system

is that producers and consumers have wide access to saccharin and that some number of bladder cancers can be expected each year.

Although it is doubtful that a saccharin consumer who developed bladder cancer could collect from a manufacturer in a tort suit (because the consumer has been warned), society could decide to compensate bladder cancer victims. If saccharin manufacturers were required to pay this compensation, they might elect to withdraw saccharin from the market. More likely, the price of saccharin would rise to reflect this compensation. Some consumers would stop consuming it, but more generally, saccharin users would be paying the costs of bladder cancer, most of which had little to do with saccharin.

The proposal has two problems. The first is that saccharin users would be paying for something that had relatively little to do with their habits and so the compensation would be "inequitable" in that those who benefit would be asked to pay far more than was warranted. The second is that the number of bladder cancers induced by saccharin would be unlikely to fall. Individuals would be compensated and so be somewhat less wary of consuming saccharin. Those who were not capable of protecting themselves, the young, feebleminded, etc., would not be protected, although they would not have to bear the costs of treating the cancer. The one thing the proposal accomplishes is to have those who contract bladder cancer not bear the monetary costs. However, this is done at the cost of paying for several times as many bladder cancers as are caused by saccharin, by laying these costs on a group not particularly responsible for the disease.

The first of the regulatory decision frameworks is no risk. This framework was used by the FDA in banning saccharin in 1978. Actually, FDA only banned the use of saccharin in prepared foods; it would have permitted the sale of saccharin over the counter without a prescription. A rigorous application of the framework would have banned it completely, since there is risk whether the saccharin is contained in prepared foods or added later.

The second framework is risk–risk. Most people who use saccharin do so in the belief that it helps them reduce their weight. If saccharin did have the effect of reducing obesity, it would lead to less heart disease, less diabetes, and less health problems. These effects would likely be much larger than the increased risk of bladder cancer from consuming saccharin. Thus, a risk–risk framework would tolerate the risk of bladder cancer in order to reduce other health risks. However, there is no evidence that saccharin consumption results in a lower weight. This does not mean that it does not, but there is at least suggestive evidence that it does not. The NAS panel concluded that there was no demonstrated health benefit from saccharin consumption and so would have ruled out the risk–risk analysis conclusion.

The technology-based standards framework is not applicable to an additive such as saccharin. There is no technological reason why the saccharin content of foods could not be zero. Thus, presumably this framework would ban saccharin.

I don't know how to implement risk–benefit analysis and so will pass on to cost-effectiveness. According to both the cost-effectiveness and regulatory budget frameworks, other causes of bladder cancer, such as cigarette smoking, are more important and should receive greater attention. More importantly, there are other causes of cancer, such as cigarette smoking and diet, that are much more important than saccharin consumption and would be the focus of attention. These frameworks would focus agency attention on other matters and lead to no near-term action on saccharin.

The most comprehensive framework, benefit–cost analysis, would ask for a quantification of the consumer-perceived benefits of having a nonnutritive sweetener. A consumer surplus estimate of these benefits would run to tens of billions of dollars each year. Certainly, the social costs of the bladder cancers would be much smaller than the estimated benefits.

Thus, this framework would not ban saccharin, and presumably would ratify the current solution of wide availability with labeling.

If one thinks that saccharin should be banned, then no-risk or technology-based standards appear to be the correct frameworks. If one thinks that saccharin should not be banned, the other frameworks offer several options. The FDA solution was to ban saccharin in prepared foods and sell it as a drug. This action would require individuals to add saccharin to food and end automatic use; children would presumably use less saccharin. No one of the frameworks would give this solution. The other frameworks tend to ratify the current solution, although the cost-effectiveness and regulatory budget frameworks would eventually ban saccharin, after more important carcinogens had been controlled.

Ionizing Radiation

The second case study is occupational and general population exposure to ionizing radiation (Marnicio, 1982). Since radiation is known to cause cancer, sterility, mutations, and other diseases, it is strictly regulated (BEIR, 1972; AMA, 1981). In extremely large doses, it can be fatal within a few days. In lower doses, the effects occur after a latency period of some years. Permitted doses have been lowered over time.

Workers are permitted an exposure of 5 rem each year. Since 10,000 person-rem accumulated over time for a population are expected to lead to one cancer, this means that a worker receiving 5 rem would have 1 chance in 2000 of getting cancer. Over a working lifetime of 40 years, a worker would have 2 chances in 100 of getting cancer, if he received the maximum allowable dose each year. The general public is allowed to receive an exposure of 25 millirem from the nuclear fuel cycle (75 millirem to the thyroid). Over a lifetime of 70 years, this means that an individual receiving the maximum dose would have 1.8 chances in 10,000 of getting cancer from the nuclear fuel cycle. This compares to a total risk of about 350 in 1000 of getting cancer from all sources, a 2000 times greater risk.

A market framework for managing risk would take care to inform all workers and members of the general public of the risks of various alternatives and let them make their choices. Undoubtedly, some workers would be willing to tolerate an increased risk in return for increased pay (Viscusi, 1983). Similarly, many people would be willing to tolerate an increased risk in return for lower electricity rates or other compensation. For example, a utility could offer reduced electricity rates to all those living within five miles of a nuclear plant or could contribute money for better schools, roads, and recreational facilities (Lave and Romer, 1983). A market solution would thus lead to somewhat increased risk (more cancers) and somewhat reduced electricity costs from nuclear power plants. Whether this solution is desirable depends on whether one believes that individual workers and members of the general population have the ability to make these choices, and whether society has an interest in protecting the unborn children of workers and families exposed to higher doses of radiation. Society might also have an interest in lowering the cancer rate because it must pay for medical care and support the dependents of the decedent, and because society does not desire to see such suffering.

The other nonregulatory frameworks have the effect of bringing these costs more directly to the plant owners or getting them to think more seriously about the risks. Insofar as the current regulations are binding, these alternatives to regulation would serve to increase the risks to some individuals and to decrease them to others.

The no risk framework would have a regulatory agency ban nuclear power and otherwise try to keep workers away from radiation. This means that medical use of X rays and nuclear medicine would be banned. However, the risk–risk framework would evaluate each use to

determine if there were offsetting health benefits. For example, does medical use of X rays save more lives than it costs? Presumably it does and this framework would tolerate medical procedures, although it would seek to reduce exposure to the extent feasible. The risk–risk framework could also be used to choose what fuel to be used in generating electricity. Many studies have shown that coal poses a greater health risk, per unit of electricity generated, than does nuclear power. Thus, the framework would advocate the use of nuclear power over coal, although it would advocate a reduction in the amount of electricity generated.

Technology-based standards would lower exposure to radiation as much as possible. The Nuclear Regulatory Commission (NRC) has analyses showing that it would be possible to reduce exposure to radiation, but only at a rapidly increasing cost. This framework would require a vast increase in cost at only a minor reduction in exposure. The NRC has a policy of "as low as reasonably achievable." What ALARA means in practice is that operators are to reduce exposure to ionizing radiation as long as the cost of doing so is less than $1000 per rem (U.S. NRC, 1982). This is a sort of hybrid technology standard, or rather it is a cost-effectiveness or hybrid benefit–cost test.

The NRC makes extensive use of cost-effectiveness analysis in developing regulations. Its explicit analyses attempt to reduce exposure at the lowest cost. The question it faces is how far to reduce exposure: the $1000 per rem is one answer. The regulatory budget framework would ask the NRC to examine the cost of reducing risk generally and compare that with the cost of reducing risk via controlling radiation. More generally, one would examine the cost of reducing radiation exposure from other sources, such as medical procedures. Finally, the agency would want to compare the costs of improving health through reducing radiation exposure with the cost of improving health through other procedures, such as better highway safety.

A benefit–cost framework would want to examine the costs and benefits of current policies. This is easiest for the ALARA policy. At $1000 per rem, the cost of preventing a cancer is $10,000,000. Rarely are there places in society where cancers are being prevented or lives saved for this much money. Many other opportunities are available for reducing risk at lower cost. Thus, a benefit–cost test would change the ALARA figure to $100 to $200 per rem. The occupational and public health standards are not easily translatable into benefit–cost analysis, since it is not evident how much is being spent to lower exposure by an increment. One might conjecture that the 5 rem per year standard would not be found sufficiently stringent and the 25 millirem standard would be found too stringent, under a benefit–cost framework.

As with saccharin, one's feelings about the amount of protection that is desired leads to a choice among decision frameworks. Someone desiring lower electricity prices and greater choice would prefer the nonregulatory frameworks. Someone opposed to nuclear power and medical use of radiation would prefer the no risk framework.

Benzene

Benzene is a basic chemical that is a constituent of many products, such as gasoline, and is a feedstock into many petrochemical processes (Bartman, 1982; Goldstein, 1977; U.S. EPA, 1978; White, Infante, and Chu, 1982). It is no longer used by consumers in pure form, and little is added to consumer products. Thus, the predominant exposure is at the workplace, although the fumes from refineries and gasoline distribution cause some general population exposure.

The voluntary industry standard of 10 parts per million (ppm) was adopted by OSHA

in 1971. Subsequently, OSHA promulgated a standard lowering permissible exposures to 1 ppm, but this standard was vacated by the Supreme Court on the grounds that OSHA had not found there was a "significant risk" and thus had no grounds for changing the standard.

Benzene induces changes in the blood-forming organs. It causes reductions in the formed elements of the blood, leading to anemia, and in the extreme to aplastic anemia and leukemia. Animal models are only now being developed and so risk assessment has depended on epidemiological studies. Since the incidence of leukemia in the general population is extremely low, it has been easy to identify an increased risk of leukemia among workers exposed to benzene. However, little is known about the exposure levels and so there is dispute about the dose–response relationship.

Market regulation would inform workers of the risk, and presumably offer those who were exposed some sort of risk premium. Undoubtedly, the effect would be some workers receiving higher exposures than at present, and thus an increased incidence of leukemia. Those workers developing leukemia might also be compensated. Employers would presumably prefer this system because they could choose between high control costs with their low exposures, and low control costs with their higher exposures and risk premiums. Presumably all workers, except those getting leukemia, would favor this system. If workers demanded a high risk premium, companies would react by lowering benzene exposure levels. If workers wanted a small risk premium, exposure levels would be higher. The social questions would be whether workers are deemed capable of making these decisions, and whether society has an interest in keeping the workers healthy beyond the level felt by each worker.

The no risk framework would attempt to lower benzene exposures as much as possible. Since it is a constituent of many chemicals, it could not be banned. But, one could lower exposure levels far below 1 ppm. The results would be increased costs of many products and only a tiny decrease in the leukemia incidence rate.

The risk–risk framework is not applicable since there are no health benefits from benzene exposure. Technology-based standards would also seek to lower exposures as much as feasible. The framework would be similar to no risk.

The cost-effectiveness and regulatory budget frameworks would compare leukemia due to benzene with other occupationally induced diseases. There are other cases where disease rates can be lowered for much less than the cost of controlling benzene, e.g., byssinosis from cotton dust. At least for now, these frameworks would direct OSHA's attention elsewhere. Both the costs and benefits of a 1-ppm benzene standard have been estimated only crudely. However, the analysis seems to indicate that the standard has costs much greater than benefits.

Passive Restraints

The last case study concerns a requirement by NHTSA that front seat occupants of automobiles be protected during a crash without their having to take actions such as fastening a seat belt (Huelke and O'Day, 1981; Blomquist and Peltzman, 1981; Nash, 1981; Graham and Gorham, 1983). The requirement has a long history, beginning with the finding that seat belts were highly beneficial in protecting occupants from serious injuries in crashes. This led to a NHTSA regulation that 1968 and later model cars be equipped with seat belts.

However, the number of people actually fastening their seat belts was never high and has declined to perhaps 10% of front seat occupants. Obviously, the belts do no good when they are not fastened. For the 1974 and 1975 model years, NHTSA required manufacturers to install an interlock device that prevented the car from being started unless occupants had

fastened their belts. This device led to a large increase in seat belt usage, but proved sufficiently inconvenient that Congress forbade NHTSA from requiring interlock devices or continuous buzzers.

The natural development was then to passive restraints. These air bags or belts protect the occupant when the door is closed. The former were an option on some models and there is limited experience with their effectiveness. The data indicate they are less effective than current seat belts, although they become more effective if worn with a lap seat belt. They are much more expensive than seat belts. It is estimated that adding air bags to all cars would lower the number of fatalities among occupants by perhaps 6000 each year at a total cost of $500,000 to $1,000,000 per fatality equivalent. Finally, there is a charge that any of these devices would be made ineffective by an expected change in driving behavior that led to more crashes and more pedestrians being killed.

The passive belts have been offered as optional devices on some automobiles and have proven about as effective as current seat belts in protecting occupants. However, some of the occupants have disconnected the belts because they find them bothersome. Assuming that all cars were equipped with these passive belts and that only 30% of the belts were disconnected, about 7000–8000 lives would be saved each year at a cost of about $500,000 per fatality equivalent. However, the device that would be offered would be extremely easy to disconnect and there is analysis indicating that the disconnect rate might be so high that there would be little increase in belt usage over the present situation.

A market solution would be to offer all safety devices as optional features and inform buyers of their efficacy. It is easy to predict that few people would purchase or use the devices and that risks would be somewhat higher than at present. The National Highway Transportation Safety Act was based on the notion that 55,000 deaths and 5.5 million injuries each year was socially unacceptable. If so, a market solution would not be acceptable. Even presuming that insurance premiums reflected the expected savings from having the devices, it is easy to predict that the resulting risk level under this market solution would be unacceptable.

Strict application of the no risk framework would ban automobiles. Highway transportation is extremely hazardous, contributing to one-third of the fatal accidents each year. No regulatory agency would attempt to ban cars, although saccharin was banned by FDA. The risk–risk framework might allow ambulances and fire trucks, but would presumably still ban cars. There is no technological reason why cars are needed and so the technology-based standards framework would probably ban cars. These three frameworks are not helpful ones for considering highway safety.

The cost-effectiveness and regulatory budget frameworks would identify cars as important to consider and presumably would identify passive restraints as cost-effective (depending on their usage rate). They would probably require passive restraints. A benefit–cost analysis would presumably find that passive restraints pass the test of benefits greater than costs. However, even more beneficial alternatives would include adding an interlock to prevent the passive restraints from being disconnected. Still more beneficial would be a mandatory seat belt law, because these safety devices are already in place and could be made effective simply by ensuring they are used.

CONCLUSION

The management of risk involves complicated scientific analysis and difficult value judgments. The former can be advanced by giving the area greater resources and making

more of an attempt to use the resulting conclusions. The former is inherently difficult, since it involves social judgments about the rights of individuals and of society. It interacts with many fundamental conceptions of how society ought to function.

While no simple prescriptions are likely to emerge, thinking of management problems in terms of the alternative decision frameworks is likely to help clarify goals and judgments. While people might choose different frameworks for managing the risks due to saccharin compared to those for automobile crashes, the frameworks help clarify the issues. Research on risk management is only in its inception and much remains to be done.

REFERENCES

Ackerman, Bruce A. and William T. Hassler, *Clean Coal, Dirty Air,* New Haven, Conn.: Yale University Press, 1981.

American Bar Association, *Federal Regulation: Roads to Reform,* Final Report and Recommendations of the Commission on Law and the Economy, 1979.

American Enterprise Institute, *Government Regulation: Proposals for Procedural Reform,* Washington, D.C.: AEI, 1979.

American Medical Association, *Risks of Nuclear Energy and Low-Level Ionizing Radiation,* Chicago: AMA, 1981.

Baram, Michael S., *Alternatives to Regulation,* Lexington: Lexington Books, 1982.

Bartman, Thomas R., "Regulating Benzene," in Lave (1982).

Baumol, W., "On the Discount Rate for Public Projects," in R. Haveman and J. Margolis (eds.), *Public Expenditures and Public Analysis,* Chicago: Markham, 1980.

Biological Effects of Ionizing Radiation Advisory Committee, *The Effects of Populations of Exposures to Low Levels of Ionizing Radiation,* Washington, D.C., National Academy of Sciences, 1972 (and 1976 and 1980).

Bloomgarden, Kathy, "Managing the Environment: The Public's View," *Public Opinion,* 6, 1983.

Blomquist, Glenn C. and Samuel Peltzman, "An Economist's View of Passive Restraints," in Crandall and Lave.

Clark, E. and A. Van Horn, *Risk–Benefit Analysis and Public Policy: A Bibliography,* Cambridge, Mass.: Energy and Environmental Center, Harvard University, 1978.

Coase, R.H., "The Problem of Social Cost," *Journal of Law and Economics,* 3, 1960.

Crandall, R. and L. Lave (eds.), *The Scientific Basis of Health and Safety Regulation,* Washington, D.C.: Brookings Institution, 1981.

Crump, K., "Estimating Human Risks from Drug Feed Additives," Office of Technology Assessment, 1979.

DeMuth, C., "Constraining Regulatory Costs—Parts I and II," *Regulation,* Vol. 4, 1 and 2, 1980.

Denison, Edward F., *Accounting for Slower Economic Growth,* Washington, D.C.: Brookings Institution, 1979.

Douglas, Mary and Aaron Wildavsky, *Risk and Culture: An Essay on the Selection of Technical Environmental Dangers,* Berkeley: University of California Press, 1982.

Fischhoff, Baruch, Sarah Lichtenstein, Paul Slovic, Stephen L. Derby, and Ralph L. Keeney, *Acceptable Risk,* New York: Cambridge University Press, 1981.

Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, and B. Combs, "How Safe is Safe Enough?" *Policy Sciences,* 8, 1978.

Food Safety Council, "Proposed System for Food Safety Assessment," *Food and Cosmetics Toxicology,* 16, December 1978.

Goldstein, Bernard D., "Hematoxicity in Humans," in Sidney Laskin and Bernard D. Goldstein (eds.), *Benzene Toxicity: A Critical Evaluation, Journal of Toxicology and Environmental Health,* Supplement 2 (1977).

Graham, John D. and Patricia Gorham, "NHTSA and Passive Restraints: A Case of Arbitrary and Capricious Deregulation," *Administrative Law Review,* 1983.

Green, L., "A Risk/Risk Analysis of Nitrite," Working Paper, Department of Nutritional Food Science, Massachusetts Institute of Technology, 1978.

Grobstein, Clifford, "A Scientist's View of Saccharin," in Crandall and Lave.

Hitch, C. and R. McKean, *The Economics of Defense in the Nuclear Age,* New York: Atheneum, 1965.

Hoel, D., "Statistical Models for Estimating Carcinogenic Risks from Animal Data," in *Proceedings of the Fifth Annual Conference on Environmental Toxicology,* Washington, D.C.: GPO, 1974.

Huelke, Donald F. and James O'Day, "A Scientific's View of Passive Restraints," in Crandall and Lave.

Hutt, P., "Food Regulation," *Food–Drug–Cosmetic Law Journal,* 33, October 1978.

Industrial Union Dept., AFL-CIO v. American Petroleum Institute, 448, U.S. 607, 1980. Interagency Regulatory Liaison Group, "Scientific Bases for Identifying Potential Carcinogens and Estimating Their Risks," Unpublished report, Washington, D.C., 1980.

IRLG, "Scientific Bases for Identifying Potential Carcinogens and Estimating Their Risks," Report of the Inter-Agency Liaison Regulatory Group, in L. Breslow, J. Fielding, and L. Lave (eds.), *Annual Review of Public Health,* 1, Palo Alto, Calif.: Annual Reviews, 1980.

Keeney, Ralph L., "A Decision Analysis with Multiple Objectives: The Mexico City Airport," *Bell Journal of Economics and Management,* 4, 101–17, 1973.

Lave, Lester B., *The Strategy of Social Regulation,* Washington, D.C.: Brookings Institution, 1981a.

Lave, Lester B., "Economic Implications of Shifting from Federal Regulation to Its Alternatives." Working paper, 1981b.

Lave, Lester B., *Quantitative Risk Assessment in Regulation,* Washington, D.C.: Brookings Institution, 1982.

Lave, Lester B. and Gilbert S. Omenn, *Cleaning the Air,* Washington, D.C.: Brookings Institution, 1981.

Lave, L.B. and T. Romer, "Specifying Risk Goals: Luherent Problem with Democratic Institutions," *Risk Analysis,* 3, 1983.

Lave, L.B., G.S. Omenn, K.D. Heffernan, and G. Dranoff, "A Model for Selecting Short-Term Tests of Carcinogenicity," *Journal of the American College of Toxicology,* 2, 1983.

Linnerooth, J. "The Value of Human Life: A Review of the Models," *Economic Inquiry,* Vol. XVII, January 1979.

Marcus, G., "A Review of Risk Assessment Methodologies," Committee on Science and Technology, U.S. House of Representatives, Ninety-Eighth Congress, First Session, Serial B, Washington, D.C.: U.S. Government Printing Office, March 1983.

Marnicio, Ronald J., "Regulation of Ionizing Radiation," in Lave (1982).

Merrill, Richard A., "Regulating Carcinogens in Food: A Legislator's Guide to the Food Safety Provisions of the Federal Food, Drug, and Cosmetic Act," *Michigan Law Review,* 77, December 1978.

Merrill, Richard A., "Regulation of Toxic Chemicals," *Texas Law Review,* 58, February 1980.

Merrill, Richard A., "A Regulator's View of Saccharin," in Crandall and Lave.

Mishan, E.J., *Cost–Benefit Analysis: An Informal Introduction,* New York: Praeger, 1976.

Nash, Carl E., "A Regulator's View of Passive Restraints," in Crandall and Lave.

National Academy of Engineering, *Product Safety,* Washington, D.C.: National Research Council, 1972.

National Academy of Sciences, Committee for a Study on Saccharin and Food Safety Policy, *Food Safety Policy: Scientific and Societal Considerations,* Washington, D.C.: NAS, 1978.

National Academy of Sciences, Committee for a Study on Saccharin and Food Safety Policy, *Saccharin: Technical Assessment of Risks and Benefits,* Washington, D.C.: NAS, 1979.

Okrent, D. "Comments on Societal Risk," *Science,* 208, April 25, 1980.

Omenn, Gilbert S. and Robert D. Friedman, "Individual Differences in Susceptibility and Regulation of Environmental Hazards," Staff paper, Office of Science and Technology Policy, 1980.

Prest, A. and R. Turvey, "Cost–Benefit Analysis: A Survey," in American Economic Association and Royal Economic Association, *Survey of Economic Theory,* Vol. III, New York: St. Martin's Press, 1966.

Raiffa, Howard, *Decision Analysis,* Reading, Mass.: Addison-Wesley, 1968.

Ruff, L., "Federal Environmental Regulation," in Committee on Governmental Affairs, U.S. Senate, *Study on Federal Regulation,* Vol. VI, December 1978.

Schelling, T.C., "The Life You Save May Be Your Own," in Samuel B. Chase (ed.), *Problems in Public Expenditure Analysis,* Washington, D.C.: Brookings Institution, 1968.

Starr, C., "Social Benefits versus Technological Risk," *Science,* 165, 1969.

Stokey, Edith and Richard Zeckhauser, *A Primer for Policy Analysis,* New York: Norton, 1978.

Transportation Research Board, *Transportation of Hazardous Materials,* Washington, D.C.: National Academy of Sciences, 1983.

U.S. Congress, House Committee on Interstate and Foreign Commerce, Subcommittee on Oversight and Investigations, *Federal Regulation and Regulatory Reform,* Report. 94 Cong. 2 sess. Washington, D.C.: Government Printing Office, 1976.

U.S. Department of Health and Human Services, Food and Drug Administration, "Assessment of Estimated Risk Resulting from Aflatoxin in Consumer Peanut Products and Other Food Contaminants," FDA, January 1978.

U.S. Environmental Protection Agency, *Assessment of Health Effects of Benzene Germane to Low Level Exposure,* Research Triangle Park, N.C.: EPA, 1978.

U.S. Nuclear Regulatory Commission, *Safety Goals for Nuclear Power Plants,* NUREG-0880, Washington, D.C., 1982.

U.S. Office of Technology Assessment, *Cancer Testing Technology and Saccharin,* Washington, D.C.: Government Printing Office, 1977.

U.S. Office of Technology Assessment, *The Implications of Cost-Effectiveness Analysis of Medical Technology,* U.S. Government Printing Office, No. 052-003-00765-7, 1980.

Viscusi, W. Kip, *Risk by Choice,* Cambridge, Mass.: Harvard, 1983.

White, Mary C., Peter F. Infante, and Kenneth C. Chu, "A Quantitative Estimate of Leukemia Mortality Associated with Occupational Exposure to Benzene," *Risk Analysis,* 2, 1982.

Wildavsky, Aaron, "No Risk Is the Highest Risk of All," *American Scientist,* 67, 1979.

Williamson, Oliver E., "An Economist's View of Saccharin," in Crandall and Lave.

Wilson, J., "The Politics of Regulation," in J. McKie (ed.), *The Social Responsibility,* Washington, D.C.: Brookings Institution, 1974.

Wilson, J. (ed.), *The Politics of Regulation,* New York: Basic Books, 1980.

Zeckhauser, R. and A. Nichols, "The Occupational Safety and Health Administration—An Overview," in Committee on Governmental Affairs, U.S. Senate, *Study on Federal Regulation,* Vol. VI, December 1978

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Consent and the Justification of Risk Analysis

Douglas MacLean

CONSENT AND CONSENSUS

In a democracy, government is made legitimate by the consent of the governed. But figuring out what counts as consent where opinions are divided and why consent should be so valued poses deep problems, whether we are considering authority in general or are focusing our attention on a particular application of authority through government. Decisions about risk and safety that must be centralized, usually in regulatory agencies, provide some dramatic examples of this problem. The agencies must determine acceptable levels, distributions, and kinds of risk. Most of these agencies were established by legislation, but they were not established to do whatever they please. What should they do? How can they appeal to the consent of the governed to justify their decisions?

Individuals cannot always make their own decisions about risk and safety; for many reasons, they must rely on the government instead. First, there are isolation and coordination problems, situations where individuals can reduce risks only by coordinating their activities, but where no natural mechanisms exist to ensure the cooperation of others. Where an unacceptable risk results from the aggregated activities of many individuals, as in automobile emissions, or where a risk is spread over many people, as in power plant emissions, the transaction costs of coming together to fix a problem are too high for individual actors to bear, and so again we need centralized solutions. These are examples of what economists call market externalities, which provide one justification for government intervention.

Another reason for centralized decisions about risk is scientific. Many risks are complex and poorly understood. This is especially true of environmental and technological risks. In some cases, no individuals or even firms could afford to do the research needed to learn enough about these risks to figure out what, if anything, we should do about them. Indeed, good information may also be beyond the abilities of many of us to comprehend.[1] So regulatory agencies have come to be, among other things, repositories of experts in whom we have no choice but to place enormous trust.

Douglas MacLean • Center for Philosophy and Public Policy, University of Maryland, College Park, Maryland 20742.

Finally, to these economic and scientific problems, we must add another issue about the justification of government regulation, which is social and political. Economics and science aside, people simply disagree about which technologies and what levels and kinds of risk are acceptable in society. They also disagree about what role the government should play and what should be left to markets and other forms of private solutions. This latter issue involves not only questions of trust and confidence but also some deeper questions about whether, for philosophical and ideological reasons, some decisions, which might be made through markets, belong instead in the public realm where they will be matters of social consciousness or expressions of national character or citizens' concern.

People disagree about issues of risk and safety, about technologies, and about the environment. On the one hand, centralized decisions, which require sophistication and expertise, must be made; on the other hand, individuals have rights which may include not being exposed to risks of death and disease without their consent. Risk decisions will determine the answers to important questions about our society's values, but opinions differ about which risks are acceptable and why. Taken together, these facts seem to give us little room in which to act. The question is whether, despite the differences in opinion, we can find ways of making decisions that we can justify by appealing to social consent.

It is useful to realize that the basic normative problem is not unique to risk issues. These are simply an important illustration of a central problem in the history of political philosophy, about the relationship between authority and consent. Rousseau, writing in 1762, asked: "Why, unless the choice were unanimous, should the minority have ever agreed to accept the decision of the majority? What right have the hundred who desire a master to vote for the ten who do not?"[2]

Rousseau's answer to this question is long and astonishing. It has perplexed generations of interpreters. Very roughly, his idea was that government cannot simply adjudicate between conflicting private interests, for then government decisions could not be justified to the minority whose interests are thwarted. Government decisions must instead pursue something public and common, a general will that unites all citizens. To the extent that it can define and promote this general will, the government will be acting in everybody's interest, and when its decisions conflict with our private interests, we will see that these private interests are at odds not only with the private interests of others but also with our own conception of the public good we see as citizens. What we want or desire privately can conflict with what we know by reason to be right or good.

> When a law is proposed in the assembly of the people, what they are asked is not whether they approve or reject the proposal in question, but whether it is or is not in conformity with the general will, which is their will. It is on this point that the citizen expresses his opinion when he records his vote, and from the counting of the votes proceeds the declaration of the general will. When, therefore, a view that is at odds with my own wins the day, it proves only that I was deceived and that what I took to be the general will was no such thing. Had my own opinion won, I should have done something quite other than I wished to do, and in that case I should not have been free.[3]

If the society is fundamentally divided in its conception of basic social values, then we might never achieve the kind of consensus that Rousseau was seeking in his rather mysterious and abstract concept of a general will. But if we can defend our ideas of justice and of the ways that laws and policies express respect and concern for people, for their rights and interests and indeed for their lives and health, then we might be able to agree on ways of making governmental decisions regulating risk and safety. We might rise above conflicting private interests to find some common ground of value.

This is the subject I want to explore here. I will not try to explain Rousseau's conception of the general will in detail, nor will I try to defend his idea. But I will address the problem

of risk and consent in what I take to be a Rousseauian spirit. I want to argue that consent to risk analysis cannot simply be an agreement to any procedural rules for settling conflicts of interest that happen to be neutral, but that acceptable analytic methods or procedures must express and give meaning to some common social values. The stronger such arguments for the justification of our methods are, the more likely we are to attain something approaching a social consensus that supports their use.

VALUES IN RISK ANALYSIS

I will use the term *risk analysis* in a comprehensive sense to include all the measuring and comparing that goes into risk management decisions. This includes estimating risks, estimating the costs of achieving different levels of safety, and comparing all the relevant costs and benefits. Now it is common to subdivide risk analysis further into two basic kinds of activities, which are supposed to correspond roughly to the distinction between fact and value, or to what falls within the domain of science and what involves ethics and politics.[4]

First, according to this dichotomy, comes the science, the discovery of the nature and extent of risks in an activity or a technology, and a technical determination of what can be done about them. This will be called risk estimation or assessment. Second, and perhaps separately, comes risk evaluation, where preferences and values enter the decision about what to do.

The distinction between fact and value in our activities is nowhere very clear, however, and so this dichotomy, which isolates risk analysis from risk management, is misleading in several important ways. Consider first the attempt to discover and estimate risks involved in different levels of an activity. We must rely very heavily on the sciences that contribute to risk analysis, of course, but it is an illusion to think we can find even here some haven of scientific neutrality where we can avoid difficult moral and social judgments.[5]

In recent congressional hearings on the Clean Air Act, for example, committee members and expert witnesses each disagreed on whether eye, throat, and nose irritation should count as adverse health effects. In another controversy, which reached the courts, experts on nuclear power plant safety voiced considerable disagreement about whether increased anxiety, decreased liberty, or possible effects of nuclear technologies on a preferred way of life ought to be deemed risks or harms that must be estimated and included in risk assessments used for regulatory decisions.

These are problems requiring evaluation that arise at the level of simply identifying the risks to be estimated. Another problem at this level is in deciding how to isolate a risk from its broader context. Consider, for example, the risk of lung cancer from smoking. This may be given as the average annual risk to adult U.S. residents, or it may be broken down to distinguish between amount smoked, brands of cigarettes, tar and nicotine content, other cigarette additives, age, sex, and occupation of smokers, urban or rural dwellers, and so on.[6] Whether it is justifiable or even intentional, our judgment of the acceptability of a risk might be affected by factors such as these, which will be determined at the first steps in risk estimation.

Now consider another component of risk analysis, the determination of what feasibly can be done to change a level of risk and safety, and what it will cost in money and other terms to do these things. At this stage too we must make evaluations, including judgments of what is feasible and what to count as costs and benefits.

Some analysts will consider that preventing smoking among workers in asbestos plants, or in other environments where cigarette smoke is known to act synergistically with other

substances to which workers are exposed, is the most feasible and least costly way to reduce risks. But other analysts might feel differently because of the possibilities for discrimination in this approach, and they might determine that work, not smoking, causes cancer, and that expensive engineering controls in plants are the only feasible means of reducing risk.[7] (I recently attended a meeting where the resident jester suggested that Canada should solve its own acid rain problem by changing the direction of the wind that blows from the United States. His suggestion was dismissed as facetious.) Judgments are made here, too, even though determining the balance of safety and cost in designs is traditionally (and, perhaps, correctly) the work of scientists and engineers.

Finally, however, we should also look at what is thought of as risk evaluation, where the costs of greater safety are compared to other costs and benefits that make competing demands on our limited resources. Risk analysts will readily admit that we are now dealing with judgments about moral and social values, for we must make trade-offs between increased safety and other things. These are decisions that society must make, to be sure, but here I think it is important to emphasize the essential role of the scientist and engineer in this stage of risk analysis.

Economists and psychologists know how to reveal and measure different values and preferences[8]; sociologists and anthropologists attempt to show, through perhaps less quantitative but no less scientific methods, how different technologies, risks, and risk decisions will affect people, or why people show selective concerns about risks.[9] These are all important scientific contributions to our understanding of people and the risks they face, and they are essential elements in the analysis of risks that lead to justifiable centralized decisions.

It should be clear, therefore, that the idea that risk analysis can avoid normative judgments and become a neutral activity, protected from moral and social criticism, is illusory. We can state more precisely why this is so.

A risk analysis can be narrowly focused on safety and not attempt to measure economic and other values, or it can be more comprehensive and attempt to present in a single comparable form all the information that would influence a regulatory decision. Different methods of risk analysis are designed with narrower or wider scopes. Likewise, these methods are designed with different uses in mind. Some of them are able to analyze only the safety component of a decision problem, and they would be intended to be only a source of one kind of information that an official would incorporate into the decision-making process. Others are meant to give the official a decision procedure to apply to a regulatory problem; their intended use is thus more ambitious. The diagram in Figure 1 illustrates these differences. The tendency in regulatory agencies is to move toward the lower right quadrant in their reliance on risk analysis, as the arrows indicate.

NEUTRALITY AND EFFICIENCY

Defenders of risk analysis have not often addressed the issue of social consent in arguing that these methods should be used to make risk management decisions. Instead, they usually argue that risk analysis is a neutral method, or that it pursues a neutral value like efficiency. These arguments will not succeed, for either risk analysis will not be neutral or else the concept of neutrality will have to be so vague and comprehensive that it will not bear this justificatory burden.

One strategy for defending the neutrality of risk analysis is to limit it, to restrict it to the seemingly safe preserve of the upper left quadrant in Figure 1, where its scope is narrow and its use modest. As we have seen, there is no way to isolate the scientific issues in ways

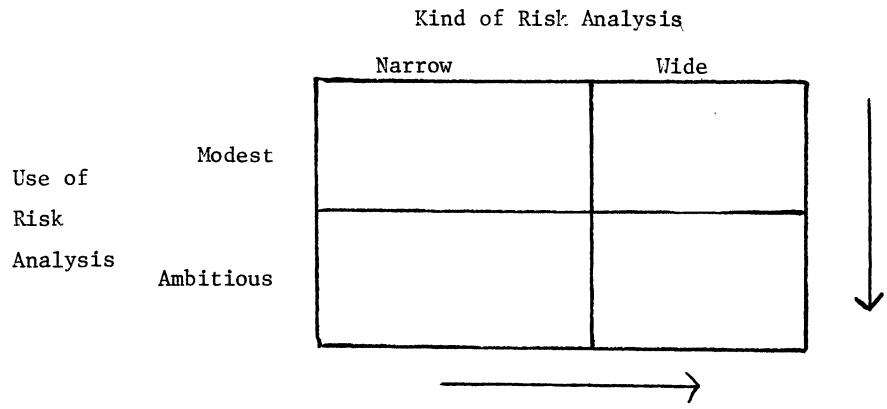

Figure 1. Kinds of risk analysis and their uses.

that can guarantee their neutrality as this information is used in risk management. Another, more serious problem, however, is that good science is needed everywhere, even in uncovering and measuring important social values and in comparing risks and benefits. It would be irresponsible for scientists and engineers to retreat from this task simply because it is bound to be controversial.

The more interesting and important neutrality arguments, therefore, are bolder arguments, like those of Starr and Whipple[10] and of Keeney.[11] They claim that comprehensive and ambitious risk analyses are also neutral. According to these arguments, methods like risk–benefit analysis or decision analysis are purely procedural. They do not favor any particular values over any other.

One way to characterize neutrality, which would surely be unacceptable, is simply to say that any procedure is neutral if it does not rule out any values explicitly or if it would not prejudice results in favor of some values and against others. To see why this idea is unacceptable, consider the rather extreme example of the decision procedure recommended to Jacob Horner, the protagonist in John Barth's *The End of the Road.*

> If the alternatives are side by side, choose the one on the left; if they're consecutive in time, choose the earlier. If neither of these apply, choose the alternative whose name begins with the earlier letter of the alphabet. These are the principles of Sinistrality, Antecedence, and Alphabetical Priority—there are others and they're arbitrary but useful.[12]

Horner's decision procedure is objective, and it yields consistent choices. It meets Starr and Whipple's criterion of being "logically sound and sufficiently flexible to accept any value system."[13] It is neutral, that is to say, because it ignores all values equally and is prejudicial toward none. It would also be irrational in the extreme to use it.

What Starr and Whipple and Keeney have in mind, of course, is something different. When they characterize methods like risk–benefit analysis and decision analysis as neutral, they mean that these methods are procedures that will include and weigh any values as their contents. The problem of identifying and assessing the importance of subtle social values, these theorists agree, is a real problem, but it is one we must confront, no matter how we make our decisions. Ambitious risk analyses give us a nonprejudicial way to structure these decisions.

It is worth emphasizing this point. What we want are methods that are sensitive to our values, that give them the amount and kind of importance that we think they must have. The only plausible way to determine a method's acceptability, it would seem, is to ask

whether it is the most reasonable way of weighing and comparing values. This is to ask whether reasonable people would consent to its use.

Consider some of the familiar objections to methods of risk analysis. Risk–benefit analysis, for example, has been criticized for monetizing all values. The relative importance of different benefits is measured by people's willingness to pay for them. Now, because almost everything we value, whether our children or religious worship or our automobiles, has an economic tie to the world or involves economic commitments, it follows that we show a willingness to pay for whatever it is we value. Thus, a willingness-to-pay criterion rules out no values in advance. But what the critics charge is that the way we value something economically is not an accurate measure of the importance we assign different things.[14] The critics argue, therefore, that it is unreasonable to consent to decision procedures that rely solely on a monetizing standard for measuring values.

But defenders of risk–benefit analysis need not argue that all values can be analyzed or reduced to willingness to pay; they need only claim that, despite the problems, a willingness-to-pay standard is better than any other for making government decisions about allocating resources to risk reduction. They argue, or they should argue, that reasonable people, when they consider the alternatives, would consent to decisions based on risk–benefit analysis.[15]

In other words, the strongest argument for using risk–benefit analysis appeals to consent, not to neutrality. It does not need to emphasize that the procedure is perfectly sensitive, but only that it gives us better decisions than we would make without using it. The issue is consent, not neutrality or efficiency. To argue that a method like risk–benefit analysis is neutral, rather than that it accurately reflects and expresses our society's important values, is to be a victim of what one critic of risk analysis has recently called "the pernicious trepidity of the current intellectual debate on risk."[16]

Some other methods, which avoid a single monetizing standard for comparing values, are more flexible than risk–benefit analysis. Some of these other techniques insist only that people can rank the values affected by a decision in order of importance, leaving it to the individuals to determine what that means. Objections to these methods are of two kinds. First, it can be argued that not all values are commensurable on a single scale, but any method of risk analysis treats values as if they are all commensurable. Thus, the structure of our values places limits on the acceptable applications of risk analysis. Risk analysts tend not to find this objection very compelling, because, as they correctly point out, we must make trade-offs. The objector must insist that the need to make a trade-off does not imply that we are able to measure and compare the relative importance of conflicting values.[17] In such situations, a trade-off means simply that we must make a choice in a particular situation, not that we can make that choice by determining which values are more important. The burden is on the critics to make this argument compelling. I will return briefly to this issue later.

The second criticism is that some values require, as their appropriate expression, that certain procedures be used or avoided in making some decision. Thus, it is sometimes urged that analytic approaches to valuing human life are repugnant, because they are too cold and calculating.[18] Is there any merit in such criticisms, or are they simply sentimental outbursts against the need to make difficult choices about allocating resources? The issue here is about the value of efficiency. The critic wants to insist that a reasonable person would not consent to efficiency as a criterion for all decisions.[19] He wants to allow certain inefficiencies to be tolerated in order to make some decisions in ways that respect intangible things like tradition or symbolic meanings, those things which, as one critic of efficiency-driven theories put it, "nourish the public conscience."[20]

These criticisms of risk analysis, obviously, are not decisive objections against its use.[21] They are not meant to be. Their purpose, rather, is to help focus on the important normative issues. What I hope to have shown is that the issue is not about whether risk analyses give decisions that are neutral and efficient, but whether they give us decisions that are best, all things considered, and whether reasonable people can agree with those decisions. The criticisms suggest, moreover, that sometimes efficiency is not the major issue in public policy. We might recall that efficiency was mentioned but did not play an important role in the debate whether to make Martin Luther King's birthday a national holiday. The question was whether this was an appropriate way to honor the man and to express our commitment to the goals he fought for. These criticisms also suggest that social values might not all be objects or goals to be measured by some neutral procedure but might instead require or prohibit certain procedures for making decisions, independently of reasons of neutrality or efficiency. We have election procedures, trial procedures, and procedures for determining what the police can do, none of which make sense in terms of efficiency. We have these procedures because other social values require them.

The fundamental normative questions, then, are Rousseauian in an important sense. Rousseau saw the purpose of government, which is created by a social contract, as determining the general will, not as adjudicating disputes or furthering private interests. The normative questions about the justification of risk analysis, similarly, are not simply about whether it weighs and balances interests neutrally, but about what our basic values are and what kinds of actions, policies, and other forms of expression they require of us. We are forced to ask what demands our common values place on procedures for making decisions regarding risks to human life, risks to the environment, and the social impacts of technological change. Acceptable procedures must be fair to the interests of the different individuals involved, to be sure, but if there are also common or general values regarding human life and the environment, then it is rational to insist that public policies reflect them, too.

To cast the problem in Rousseauian terms, however, is only to rephrase the question. It is to ask whether we can find shared social values that will serve as the basis for consent. It may be that our culture is too deeply divided to find a common ground of values that underlies our differences. It may also be, as I will suggest, that our common values can themselves make conflicting demands on us. In the end, I think it is this latter reason that keeps the controversy over risk analysis alive. To explain this, I must consider the ideas of consent and social values more closely.

INDIRECT CONSENT

Our paradigm of consent is direct, explicit consent given by someone who is informed, under conditions that we regard as unconstrained or uncoerced. Explicit consent is usually sufficient and often necessary for justifying activities that impose risks. Nothing short of explicit, informed, and uncoerced consent would entitle a William Tell, for example, to practice archery by shooting apples off his assistant's head. Arguments that the risks are small and the benefits great are beside the point. Thus, it does not matter how skilled an archer William Tell is, or what he pays his assistant.

Explicit consent is often impossible to obtain, however, and this may lead us to look for indirect consent. Certain behavior might be interpreted as giving tacit or implicit consent to a risk–benefit trade-off. In normally functioning markets, people reveal certain preferences, including preferences for risk and safety, which are taken to indicate their consent to cen-

tralized decisions in other cases. Risk analysts look to labor markets, for example, to determine what wages workers demand in exchange for hazardous work.

These indirect consent models all depend on some very controversial assumptions, which are necessary for making the inference from consumer behavior to justifiable centralized risk decisions. These assumptions (which I cannot explore in detail here[22]) are of two general types. First, the risk analyst assumes that actual market behavior is an instance of free and informed consent to risks. Second, the risk analyst must make certain rationality assumptions to justify inferences, say, from decisions to drive on the highway or work in a factory to preferences about how government should regulate some new technology or control toxic substances from entering groundwater. The problem with the first assumption, obviously, is that we all know how uninformed our purchases often are and how our consumer preferences are shaped by the options available to us and by other external influences. The problem with the second assumption is that the different areas may be different in many ways, and so a person might show different preferences in each area without being inconsistent or irrational. I might shop with one set of values and vote with another.

In order to respond to such difficulties and to deal with situations where we have no behavior that we can even plausibly interpret as giving implicit consent, we are sometimes forced to the even more indirect notion of hypothetical consent, which some would argue is not consent at all. A hypothetical consent model asks what a rational person would consent to, either as a decision or as a procedure for making decisions. At this level, we can resolve disagreements only by arguing that some preferences and values are rational, and others are not. One of the advantages of actual consent is that it tends to free us from the responsibility of making judgments about values. We let individuals decide for themselves. Where decisions must be centralized, however, we cannot always take this more desirable course of justification. We cannot always defend our decisions as neutral, as giving people what they do want; we must sometimes defend our decisions as right, as giving people what they ought to want. We appeal to the hypothetical consent of rational agents to explain and justify these decisions. If we are also humble enough to allow other opinions about rational values to influence us, and to implement policies in sensitive ways, we can perhaps hope to build and maintain an actual consensus for what we are trying to do. The consensus must be built on what people regard as right and fair, not on what serves their interests. It must appeal to their rationality and not just their desires.

One way to view the difference between an efficiency argument and hypothetical consent argument is this. Efficiency arguments take the point of view of the whole society and argue that some decision is best from this aggregated viewpoint. Hypothetical consent arguments, in contrast, do not appeal to the perspective of everyone taken together, but to that of each individual, taken singly, insofar as he is being rational and not being influenced by circumstances which would not count as reasons for each other rational individual. Efficiency-based methods might be defended by hypothetical consent arguments, but where efficiency is not only the goal but the justification, the argument is basically utilitarian and based on interests or preference satisfaction. It is then susceptible to Rousseau's objection that the will of a hundred does not justify violating the will of ten. Hypothetical consent is consistent with social contract theory in requiring unanimous consent. This consent is not based on interests, however, which are in conflict, but on reason and our reflective views about values.

Why do we insist on justifying risk policies in terms of consent, especially when consent is so shadowy a thing as indirect or hypothetical consent?[23] One reason is skepticism. If people are better judges of their own interests and preferences than they are of the interests of others, if individuals are more reliable sources of what is important to them than government researchers are, then by insisting on a person's consent to decisions that affect him,

we are taking the most reliable course toward assuring that we heed their interests and satisfy their preferences. But this argument works only where consent is direct and explicit; otherwise, claims of consent must rely on just the kinds of assumptions that worry the skeptic in claims about what maximizes satisfaction.

A second reason for valuing consent, therefore, is its intrinsic importance. People have rights about decisions that affect them, especially decisions affecting their health and life. Respect for individuals demands that their reasons and judgments be taken seriously, and not merely that their preferences be measured. For these and other reasons, we come to see that government is not simply a mechanism for correcting imperfect market procedures or an exercise in social engineering but a public forum for generating consensus for some basic values which can unite us. Government policies are vehicles through which we can show respect for one another and for our shared values even as we pursue our individual and often conflicting interests.

SOCIAL VALUES

Arguments based on consent, therefore, provide better justifications for using risk analysis than arguments based on neutrality or efficiency; but I do not take this claim to mean that appeals to indirect or hypothetical consent will make it easy for us to discover appropriate limits to using risk analysis, the true importance of efficiency, or exactly which social values are important and what they require of us. These are bound to remain difficult and controversial issues. In the quest for consent justifications, however, I believe we can begin to consider these issues in the ways they matter to people, for we will be asking what kind of society and what kind of public policies we want. The role of risk analysis will enter that debate, as it should, where its merits as a tool for serving our best social and political goals can be examined.

Consider the role of risk analysis as a general guide for allocating resources to programs that save lives.[24] If we want to be efficient, which means allocating resources so that we save the most lives for the least cost, then we not only need good risk analyses, but we would probably do best by adopting as a decision procedure something like risk–benefit analysis. That is, we will want to do what analytic procedures are explicitly designed to help us do, to maximize the expected value of resources allocated to lifesaving, where this value is something we can quantify, e.g., in terms of life expectancy. If we further want to know how much we should allocate overall to these programs and when to put resources to other uses instead, then we can measure willingness to pay for risk reduction and pursue efficiency in this more general way as well.

Would a rational person consent to this basis for making policy choices? This decision procedure would call our attention to wasteful and inefficient programs, which is good. The problem is that this procedure will also inevitably prescribe choices that make us uncomfortable. Sometimes we have embarked on expensive lifesaving programs not strictly because we are ignorant of the costs but because we were responding to the demands of social conscience. Heroic rescue missions are an example. In some of these cases, it may even seem that a too conscious cost-accounting approach leads to callousness and shows a lack of concern for human life. In some cases, we might be responding to fear and dread with costly or ineffective programs, or we might have adopted some programs more as an expression of hope or for symbolic reasons than for reasons of effective lifesaving.

Analytic approaches to risk management will not be able to take into account all these differences. They will frown on programs that are merely wasteful and on programs that

are symbolic responses alike. The many kinds of expressions and gestures we make through public policies simply cannot be quantified in any meaningful way.

Now what is a rational response to cases like these? I think a rational person will be torn, or as Allan Gibbard has put it:

> Arguments like those [embodied in risk analysis] confront us with a genuine dilemma in our public moral life, which neither incorporating deontological values into a formal decision analysis nor appeal to expertise can resolve. Any coherent moral view adequate to the complexities of public decisions will have morally shocking consequences. That is because of the way we human beings are: neither able to abandon without penalty demands for coherence . . . , nor able to summon coherent responses to complex situations.[25]

What Gibbard is describing is not strictly a cognitive dilemma or a psychological quirk, but a genuine problem about our values and about social morality.

We might describe this problem by saying that the social value of human life is a complex value, and that this single value can make different demands which conflict with each other, not to mention the many ways that valuing human life can conflict with other values. On the one hand, to value life is to try to save and prolong it, and the more lives the better. This is why risk–benefit analysis is an important means for expressing our value of human life. On the other hand, valuing human life might also require occasional inefficient actions and programs in order to give public and symbolic expression to the special concern for individual human lives that is fundamental in our society. This second demand is inconsistent with the first, however, and we can meet it only by tolerating pockets of inefficiency in our policies, by saving fewer lives than we could otherwise save.

A rational person must be concerned to reduce risks and save the greatest number of lives possible. This is beyond doubt. But a rational person must also be concerned about these subtler qualities of social values and their importance in contributing to the quality of social life. These are delicate issues, and sometimes they are confused with programs that may simply be sentimental relics of an ignorant past. Analytic decision procedures, then, pose a challenge to us, and it is proper that they put us on the defensive in limiting their recommendations when they cannot be squared with deeply held moral intuitions. And yet a rational person could only consent to policies that attempt to balance these two conflicting tendencies in us: the tendency, on the one hand, to be analytic and to regiment our values according to clear general principles, and, on the other hand, the tendency to be sensitive and nuanced in responding to the heart's commands.

In the end, therefore, a rational person would probably be most concerned to see that procedures for making important policy decisions be open to both kinds of considerations. He should probably want to see the ambitious use of risk analysis curtailed to this extent, while wanting actual policies to come closer into line with what these analyses would recommend. The conflict in debates over proposals should come to resemble the conflicts we feel within ourselves. If the general will is to be our will, as Rousseau says, then it should find itself divided in ways that no decision procedure can adequately resolve.

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Joshua Menkes and Susan Wolf for their many suggestions and helpful discussions about risk and consent.

NOTES*

1. Baruch Fischhoff, "Cognitive and Institutional Barriers to "Informed Consent," in *To Breathe Freely*, edited by Mary Gibson (Totowa, N.J.: Rowman and Allanheld, 1985).
2. J.J. Rousseau, *Du Contrat Social,* Book I, chapter 5. The translation is attributed to one Mr. Hopkins and appears in *Social Contract,* edited by Sir Ernest Barker (London: Oxford University Press, 1947), page 179.
3. *Ibid.*, Book IV, chapter 2, page 273.
4. This division is partly due to the influence of an excellent book by William Lowrance, *Of Acceptable Risk* (Los Altos: William Kaufmann, Inc., 1976), especially pages 8–11.
5. See Mary Gibson, "To Breathe Freely: Risk, Consent and Air," Center for Philosophy and Public Policy Working Paper RC-2, University of Maryland, College Park, Maryland, 1982.
6. See James Repace, "Risks of Passive Smoking," CPPP Working Paper RC-8; in *To Breathe Freely*, edited by Mary Gibson (Totowa, N.J.: Rowman and Allanheld, 1985.
7. See Mark MacCarthy, "Reform of Occupational Safety and Health Policy," CPPP Working Paper RC-4; in *To Breathe Freely,* edited by Mary Gibson (Totowa, N.J.: Rowman and Allanheld, 1985.
8. For work by economists, see Charles Brown, "Equalizing Differences in the Labor Market," *Quarterly Journal of Economics* 94 (1980): pages 113–134; also Martin Bailey, *Reducing Risks to Life* (Washington, D.C.: American Enterprise Institute, 1980). For work by psychologists, see Baruch Fischhoff et al., *Acceptable Risk* (Cambridge: Cambridge University Press, 1981).
9. See Mary Douglas and Aaron Wildavsky, *Risk and Culture* (Berkeley: University of California Press, 1982); also see *The Language of Risk*, edited by Dorothy Nelkin (Beverly Hills: Sage Publications, 1985).
10. Chauncey Starr and Chris Whipple, "The Risks of Risk Decisions," *Science* 208 (6 June 1980): pages 1114–1119.
11. Ralph Keeney, "Ethics, Decision Analysis, and Public Risk," *Risk Analysis,* 4(1984): pages 117–130.
12. John Barth, *The End of the Road* (New York: Avon Books, 1958), page 89.
13. Chauncey Starr and Chris Whipple, "The Risks of Risk Decisions," page 1115.
14. See Mark Sagoff, "Economic Theory and Environmental Law," *Michigan Law Review* 79 (1981): pages 1393–1419.
15. This view is persuasively argued in Herman Leonard and Richard Zeckhauser, "Cost–Benefit Analysis Applied to Risks: Its Philosophy and Legitimacy," in *Values at Risk* edited by Douglas MacLean (Totawa, N.J.: Rowman and Allanheld, 1986).
16. Michael Thompson, "To Hell With the Turkeys!" CPPP Working Paper RC-5; forthcoming in *Values at Risk.*
17. See Ian Hacking, "Hume's Species of Probability," *Philosophical Studies* 33 (1978): pages 21–37.
18. See Stuart Hampshire, "Morality and Pessimism," *Public and Private Morality,* edited by Stuart Hampshire (Cambridge: Cambridge University Press, 1978), pages 1–22.
19. Ronald Dworkin, "Why Efficiency?" *Hofstra Law Review* 8 (1981): pages 576–578.
20. The phrase is part of a well-known quote attributed to Lord Ashby, although I have been unable to find its origin. For the full quote and discussion, see Douglas MacLean, "Quantification, Regulation and Risk Assessment," Proceedings of the Philosophy of Science Association, *PSA 1982,* Vol. 2, edited by Peter Asquith and Thomas Nickles (East Lansing: Michigan State University Press, 1983), pages 243–260.
21. See Douglas MacLean, "Valuing Human Life," in *Uncertain Power,* edited by Dorothy Zinberg (New York: Pergamon Press, 1983), pages 89–107.
22. I have described these models of indirect consent more fully in Douglas MacLean, "Risk and Consent: Philosophical Issues for Centralized Decisions," *Risk Analysis* 2 (1982): pages 59–67.
23. The remarks in this and the following paragraph draw heavily on Samuel Scheffler, "The Role of Consent in the Legitimation of Risky Activity," in *To Breathe Freely,* edited by Mary Gibson (Totawa, N.J.: Rowman and Allanheld, 1985).

* In much of this paper I am describing, borrowing from, and responding to the work of participants in a research project on risk and consent conducted by the Center for Philosophy and Public Policy. Many of the references in this paper are to that work, but I caution the reader that I have borrowed freely and interpreted liberally. The views in this paper are my own. They should not be taken to represent the views of the authors of the cited papers.

24. My remarks in this section draw heavily on Annette Baier, "Poisoning the Wells"; Allan Gibbard, "Risk and Value"; and Douglas MacLean, "Social Values and the Distribution of Risk"; all in *Values at Risk,* edited by Douglas MacLean (Totowa, N.J.: Rowman and Allanheld, 1985).
25. This quote is from an earlier draft of Allan Gibbard's "Risk and Value" which he presented to a working group on risk and consent. It does not appear in the chapter published in *Values at Risk* edited by Douglas MacLean (Totowa, N.J.: Rowman and Allanheld, 1985).
26. Douglas MacLean (ed.), *Values at Risk* (Totowa, N.J.: Rowman and Allanheld, 1986).
27. Mary Gibson (ed.), *To Breathe Freely: Risk, Consent, and Air* (Totowa, N.J.: Rowman and Allanheld, 1985.)

IV

Overview of Risk Evaluation Management

Risk analysis and risk management have emerged so quickly as topics of legitimate intellectual concern and interest that it is easy to lose perspective on the field. The two papers in the final section attempt to counterbalance this tendency by providing overviews on risk analysis and risk management. The first paper grapples with the problem of how scientists and professional analysts can best contribute to decision making about risks, with special emphasis on how risk analysis can be useful and how it can be made more useful. The second paper takes a historical perspective, examining differences and similarities between past and present in how risks have been thought about and managed.

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Science and Analysis
Roles in Risk and Decision Making

John D. Graham, Howard Raiffa, and James W. Vaupel

INTRODUCTION

Decisions with consequences for human health, safety, and the environment are made by consumers in the marketplace, by workers in the factory, by business executives in production decisions, by administrators of regulatory agencies, and by ordinary citizens in their daily lives. In most cases these decisions are based primarily on common sense, ordinary knowledge, and nonscientific analysis. It is frequently impossible to identify any single decision maker as decisions evolve out of dynamic processes of social interaction. Interaction refers to, say, the simple communication between a consumer and seller as well as the complex bargaining between adversaries in an environmental dispute. All people participate in such interactive decision making about risks in their daily lives even though they do not think about it as "social interaction."

The purpose of this paper is to indicate how scientists and professional analysts can contribute to decision making about risks. We attempt to articulate how risk analysis can be useful and how it can be made more useful. Where possible, we advocate a decomposition of risk analysis into the distinct tasks of risk assessment and risk evaluation. Decomposition is often difficult to accomplish but, if achieved, it can enhance the credibility of the analytical product while pointing to critical value questions that should be resolved by politically accountable decision makers and institutions.

THE LIMITED ROLE OF ANALYSIS

Most risk problems are associated with scientific complexities and uncertainties and it might be argued that an ideal decision-making process for these issues would be decision

John D. Graham • Harvard School of Public Health, Boston, Massachusetts 02115. *Howard Raiffa* • Harvard Business School, Cambridge, Massachusetts 02138. *James W. Vaupel* • Hubert Humphrey School of Public Affairs, University of Minnesota, Minneapolis, Minnesota 55455.

making by scientists and professional analysts. In our view, this model is unattainable and undesirable as applied to both public and private decision making about risks. The role of science and analysis in decision making is (and should be) limited for the following reasons.[1]

First, decisions about social problems—such as those involving risks—invariably entail some conflicts of interests among people. It is the rare case when a decision can be simultaneously the best for all parties concerned. Even in those rare cases when all people are made better off by a decision, some win more while others win less. Although analysis can help identify the total benefits and costs of various policy alternatives, it cannot objectively resolve conflicts of interests. In a democracy, these distributional issues should be sorted out by political processes.

Second, some policy problems that in principle are analyzable—that is, would respond to an intellectual resolution if they could be pursued long and painstakingly enough—are not, in fact, analyzable because they run beyond anyone's cognitive capacities or beyond society's store of information. Again, these issues require political as well as intellectual contributions to their solutions.

Third, analysis can be done and is done by persons other than risk analysts. For example, public servants and business managers would, on some kinds of issues, be better off to conduct their own informal analysis of a risk problem, without any professional analysis, because they can draw upon a fund of practical experience and can better cope with and respond to the realities of a particular organization.

Fourth, professional risk analysis, even when it is more competent than any other method of assessment or evaluation, is fallible and inconclusive. How far to trust it, when and when not to trust it, are questions that should be decided by accountable authorities. For example, in the public sector the use of risk analysis should ultimately be subject to the control of the electorate and political officials. In some cases Congress decides (for arguably good or bad reasons) that certain elements of an academically respectable risk analysis should not be considered by public decision makers when considering risk-coping strategies.[2]

Finally, professional risk analysis is expensive and time-consuming. It is simply impossible to subject every important aspect of a policy decision to professional analysis. There are not enough professionals to go around, nor would there be if their numbers were many times multiplied. And many issues are not worth the cost of analysis, or the issues have to be decided before an analysis can be completed.

HOW ANALYSIS CAN BE USEFUL

While the role of analysis is inherently limited, it can nonetheless be useful to decision makers engaged in various types of social interaction. Risk analysis, whether done formally or informally, can provide missing pieces of information, indicate the quantitative bounds on some critical decision parameter, or simply help decision makers structure their thinking about a problem.

Some of the most useful analyses are not comprehensive but rather are tailor-made for the purposes of a client with a specific choice problem. Such carefully targeted studies are especially valuable because they conserve scarce scientific and analytical resources. Efficiency is promoted when the analyst focuses on those few elements of a decision problem that decision makers find most perplexing or about which they most want assistance.

Many decision makers are involved in the complex process of selecting risk-coping strategies, and many decisions are made in addition to deciding what risk-coping strategies to advocate. Decisions are made about how to enlist the support of interest groups in the

policy process, about how to defend policy positions in court and at legislative hearings, about what new information to gather, about what kinds of authority to delegate and to whom, and so forth. Tailor-made analyses, if responsive, judicious, and incisive, can help decision makers with this entire range of choices.

Some analyses are conducted for multiple purposes and for multiple audiences. These studies, which are often done in universities or by think tanks or nonprofit research organizations, can usefully serve to raise the level of discourse about some policy issue in the political process. They are often, however, not only used but misused as political weapons in the adversarial process. Hence, it is important that such analyses be reviewed by others and not be considered above the political battle.

In addition to aiding a decision maker in the selection of an alternative within a well-specified range of choices, analysis can be useful in two other important, but neglected, ways. First, there are frequently situations where adversarial parties in, say, an environmental dispute, are not in a zero-sum game (that is, what one party wins, the other loses). Analysis can help organize and lay the groundwork for bargaining between parties so that potential joint gains are actually realized.[3] Second, analysis can sometimes lead to the design of superior policy alternatives. By better understanding the reasons various alternatives are relatively strong or weak in their details, creative new alternatives can be devised. The policy debate might not be resolved, but instead of a dispute between lackluster policy alternatives A and B, the debate could lead to a dispute between innovative and superior alternatives C and D.

A back-of-the-envelope analysis about whether a formal analysis is worthwhile to pursue may often be helpful, but too often is not done.[4] Of course, one quickly reaches a point of diminishing returns when doing analysis about whether to do analysis, but still some preliminary thinking can often indicate the potential gains one might expect from deeper levels of analysis.

EXTENT OF FORMAL ANALYSIS

Qualitative (as contrasted to quantitative) analyses can often be quite effective. Just by establishing a conceptual framework of thought, by structuring the sequences of decisions that have to be made, by exhibiting the most important consequences of policies under review, by using crude qualitative rankings of how various policies fare on various attribute concerns (e.g., do emphysema patients fare better, mildly better, mildly worse, or worse with policy A or B), by crudely describing what is known about the uncertainties in the problem, by all of these (or even by some of these) decision makers could be aided in their choices.

Decision makers might want additional help by having some of their problems more formally analyzed. Uncertainties may be clarified by the use of statistical and probabilistic models and calculations. Judgments about uncertainties might be elicited from experts and combined formally with statistical evidence.[5] Sensitivity studies might be employed to see how changes in one input variable reverberate through the system and effect intermediate output measures. An array of costs and benefits of different policies may be derived from a host of different quantitative techniques. For example, regression and more elaborate econometric techniques might be used to generate insights from empirical data that are often frustratingly incomplete.

Partial simplifications of the array of costs and benefits may be made by collapsing sets of similar costs and benefits—not necessarily collapsing 20 different cost figures and 30

benefit figures down to 1 cost and 1 benefit figure but collapsing, say, 20 cost figures into 4 cost indices and, say, 30 benefit figures into 6 benefit indices. By simplifying a morass of data into a manageable set of summary indices, decision makers may be in a better position to concentrate their attention on complex trade-offs among a few incommensurable indices. Risk analysis can be used to highlight just where political and social judgments have to be made; analysis should not be used to bury these judgments in the interstices of an incomprehensible model.

It is often stated that risk analysis is not very helpful when it comes to making painful value judgments. We disagree. Value judgments will have to be made by decision makers either implicitly or explicitly. There are formal techniques that can be used to help decision makers think systematically about complex value trade-offs. These techniques elicit, via a Socratic method, basic judgments from decision makers and exhibit for their review any incoherencies in judgments that are generated. The aim is to compel decision makers to probe their basic preferences and values. These psychometric scaling techniques—known most commonly under the name of multiattribute utility theory—are not designed to be a substitute for judgment, but rather as an aid to bring judgment to bear on the problem.[6] People's basic trade-offs differ and these formal techniques can be used to highlight these differences, if that is what decision makers want.

Occasionally there are decision makers who may want to work especially closely with professional analysts and formalize all aspects of their choice problem. This cannot be done without introducing subjective estimates and value judgments into the formal model. One aspect of such an approach is that these subjective inputs, when formalized, can then be scrutinized by others.

Alternatively, analysts can sometimes create a complete decision edifice on a computer that fixes everything but a dozen or so critical subjective inputs [e.g., probability judgments, trade-off values, exogenous macrovalues like future Gross National Product (GNP) growth, risk-aversion attitudes]. This allows decision makers to examine how the output decision is affected by these subjective inputs. The computer itself is activated (e.g., to optimize a complex, interactive set of operations) once the critical subjective judgments are introduced. Decision makers can then explore the dependence of the optimal solution (calculated by computer) on the input values selected by decision makers.

Decision analysis, policy analysis, risk–cost–benefit analysis, operations research, management science, econometric analysis, and systems analysis all purport to offer some help to the decision maker. Many of these techniques can be used as partial decision aids but none should be substituted for common sense. All techniques have been used profitably for some past decisions but all have been misused pitifully on past occasions. Analytical techniques have a tendency to emphasize hard data (e.g., monetary costs) at the expense of underplaying fragile and amorphous concerns (e.g., aesthetics and psychological well-being). It is easy for these techniques to be misused (consciously but mostly subconsciously) in the technical decisions and assumptions made by the analyst.

A COMPREHENSIVE RISK ANALYSIS

Although few decisions about risks are subjected to comprehensive professional analyses, it is useful to ponder the ingredients of such studies, even if no such analyses exist. By devising a checklist of items for "risk analysis in the large," one can speak more

intelligently about what smaller, more realistic, and more useful analyses might look like. In the following section, we have devised a checklist of analytical issues which might be of concern to a government decision maker, say, the administrator of the Environmental Protection Agency (EPA). The administrator might, for example, have to decide whether or not his agency should regulate an allegedly toxic substance, and if so, how. This checklist for "risk analysis" is not materially different from what it would be for many policy analyses that are not concerned about adverse consequences to health and safety. In basic structure a risk analysis is similar to other types of policy analysis.

Generation of Alternatives and the Dynamics of Choice

Decision makers rarely have to decide everything now once and forever; choices can often be delayed (perhaps at a cost) and in the intervening period, new information can be gained through experimentation, experience, and further study; and then future choices can be made contingent on the information learned along the way. The choice of whether or not to defer taking action now thus depends in part on our perceptions of what might be learned in the future.

The decision maker may want to reflect on and obtain information about (1) the interdependence of this problem and other problems (e.g., any precedent-setting effect that will occur by solving this problem); (2) the managerial, political, and physical irreversibilities (strict and partial) of the decisions to be made; (3) the loci of where actions can be taken (that is, at a lower level of government, in a different agency, in a decentralized manner that exploits market mechanisms, and so on); and (4) the institutional decision network (that is, who has to decide what and when, who has to be convinced, pressured, and influenced).

In many situations the most critical point in a decision-making process is the selection of policy alternatives for consideration. A risk analysis can be useless if it addresses irrelevant alternatives or if it is not available to decision makers at the critical time.[7] A comprehensive risk analysis would indicate the manner in which policy alternatives were selected and the timetable for decision making.

Consequences of Various Policy Alternatives

A comprehensive risk analysis would consider the full range of potential consequences of policy choices: health, political, economic, international, etc. Of course, in a given problem the viable alternatives under consideration might result in essentially the same outcomes for a whole class of effects, e.g., international effects, and hence these effects need not be explicitly evaluated and compared. Table 1 illustrates the broad range of potential consequences of a risk management decision. Since the primary concern in this paper is adverse health effects, the list gives greater attention to health effects.

Even if a risk analysis is restricted (say, for some statutory reason) to health effects, in the short run and long run, both direct and indirect, then many of the items listed under nonhealth effects in Table 1 should be considered. For example, unemployment and inflation will effect the health and psychological well-being of individuals. In order to trace out secondary, tertiary, and long-range (general equilibrium) effects of all kinds, analysts might have to employ dynamic models of interactions and interdependencies. Although we have emphasized the health effects of policy choices, we do not wish to underplay the importance of nonhealth impacts, which in some circumstances deserve equal or primary importance.

Table 1. A List of Potential Impacts of Risk-Management Decisions

Health impacts of a policy decison
How many people are (will be) affected?
In entire population
In sensitive groups
In occupational groups
How much are they affected?
Mortality
Permanent disablement
Temporary disablement
Acute vs. chronic
Discomfort
Anxiety
Who is affected?
Age distribution
Income status
Race/ethnic origin
Sex
Occupation
Geographical location
Quality of life/health status
Religious affiliation
When will they be affected?
Now
With some time lag
Future generations
How catastrophic could be the potential adverse consequences? That is, are the health effects clustered in geographical regions or are they spread diffusely through the population?
Are there any synergistic health effects? That is, does exposure to two or more substances add or multiply the probability of adverse health effects?
Non-health impacts of a policy decision
Aesthetics
Effects on nature (e.g., plants and animals)
Economic costs (and to whom?)
Employment effects?
Inflationary effects?
Productivity effects?
Impact on innovation?
Impact on market competition?
Effects on other countries
Effects on distribution of wealth and income
Effects on public confidence in government
Effects on public fears and anxiety levels

Uncertainties

For many of the categories of consequences or effects in Table 1, it will suffice for the decision maker to have rough estimates. Sensitivity studies may indicate, however, that some effects will play a critical role in decision making and rough estimates are not satisfactory. For such sensitive decision factors, decision makers may request probabilistic assessments of these uncertain effects and information on the volatility of these assessments (that is, how might new information change the assessments, and the feasibility of getting new information in different time frames) and the degrees of disagreement among experts.

Information about uncertainties is often crucial in a decision problem. Rarely is it possible or desirable to try to take account of all the possible uncertainties. In order to account for such inherent unpredictabilities, the resilience of policy alternatives should be considered. Decentralized, flexible options might be adopted even though the analysis (with uncertainties taken into account) might find these options to be less efficient than other options. The administrator might want to hedge by keeping alive inefficient options just in case something unexpected happens. The presence of uncertainty in decisions also suggests that mix and variability are important considerations. For example, the administrator certainly wants to prevent disasters but some analysis might be reserved for thinking about coping with disasters if they do occur.

Value Trade-offs and Ethical Considerations

The consequences of policy choices are rarely describable in a single, commensurable commodity like money but rather in a host of incommensurable qualities—deaths, suffering, anxiety, unhappiness—and these impacts are differentially distributed over the population. In this section, we identify some of the value concerns that make it so difficult to choose among risk management options. Many of these value concerns arise because of the need to make value trade-offs among incommensurable qualities. Our purpose in this section is not to suggest answers to questions but to raise questions. Earlier we remarked that risk analysis is not unlike other policy analysis; however, some of the value concerns we raise are distinct for risk analysis.

Lives and Dollars. The society has chosen (not necessarily deliberately or consciously) to be inefficient about saving lives in the sense that many more lives could be saved by the reallocation of the existing total budget for lifesaving. Studies have estimated the marginal cost of saving an additional life in various federal agencies and the results are strikingly different: from $10,000 to $10 million per life saved, a thousandfold difference.[8]

How much should society spend on lifesaving activities depends on other needs. The more affluent a society becomes, the more money society has to spend on lifesaving activities, and an argument can be made that, as the country grows collectively more affluent, it can afford to spend a larger proportion of the total wealth on lifesaving activities. But deciding just how much should be spent to save a life involves a difficult value trade-off.

Lives and Life Years. In our view it would be desirable if risk analyses would express mortality effects in terms of life years saved as well as in terms of lives saved.[9] It is important to keep in mind that the expected curtailment of life of a victim of an automobile crash is approximately 45 years whereas the expected curtailment of life by a random individual stricken with cancer is approximately 15 years.[10] Lives are important but life years should not be ignored in accounting procedures for policy choice.

People differ sharply, however, about the answers they would give to the following questions: "If you had to make the uncomfortable choice of saving an anonymous 1-year-old or an anonymous 20-year-old, which would you choose?" Thus, "expected life years saved" may not be a widely acceptable index in making choices that involve expenditures for the very young. This is an extremely emotional issue but one that fortunately does not command central importance in our society and therefore is perhaps better left unresolved. Yet this does raise the question of societal responsibilities for the very young unfortunates who can be kept alive only through heroic medical intervention. And to add an ethical concern, one could push the age limit back across the threshold of birth and raise the question of our societal responsibilities to the conceived yet unborn child. Continuing in this direction one could raise the question of our responsibilities to future generations, an issue raised separately below.

Trade-offs between Health States. Risk analyses often concentrate exclusively on mortality effects. Thus, for example, in tallying up the negative health impacts of air pollution, studies often cite the "hard" data about premature deaths even though the collective misery from various morbidity states (e.g., asthma attacks, emphysema) may be of equal or greater importance than mortality effects. Moreover, the psychological well-being that is associated with blue skies may be of comparable importance (for policy choice) with morbidity and mortality.

Suppose that a risk analysis presents to a decision maker a reasonably comprehensive account of the health impacts of various policies. A given policy choice might be evaluated by its impact on a dozen or so morbidity states, on mortality effects of different kinds, and on a few psychological indices of well-being. Imagine the plight of the decision maker who is inundated not only by health impacts but also by economic impacts over time, environmental indices, not to mention political evaluations as well. The decision maker might be well served if some order were made out of the chaos of numbers and qualitative ratings by summarizing the health effects in terms of one or two summary indices. This would necessitate making value trade-offs between, say, the severity of an asthma attack on a 30-year-old and a bout of emphysema on a 60-year-old. This would not be a simple task. We are not talking here about trade-offs between morbidity states and dollars but between one morbidity state and another. Such summary indices are useful because much more difficult trade-offs may have to be made later on between health, economics, the environment, and political affairs. By collapsing health effects into a few numbers (not unlike the way the state of the economy is collapsed into an index for GNP, for balance of trade, for employment, and for inflation) the decision maker can better balance health impacts with other types of impacts. This collapsing of health effects into summary measures does, of course, require that difficult judgments be made.

Temporal Trade-offs. A dollar received in the future may be worth less to a person than a dollar received today if the dollar received today can be invested (eventually in productive activities) to yield more than a dollar in the future. Streams of cash flows are conventionally collapsed into a summary figure (a net present value amount) by discounting future dollars. In public finance there is a debate about what that discount figure should be; this is especially problematical in times of uncertain inflation rates. But discounting of economic factors is still generally practiced, even in socialist economies.

How about the discounting of future lives saved? Is a life year saved 20 years from now less important than a life saved now? Some argue that society can invest the resources not expended on lifesaving activities today in order to accumulate the resource capacity to

(possibly) save more lives in the future; and assuming that resources can be just as effectively (some say "more," others say "less" effectively) used for lifesaving in the future as today, one should discount the saving of future lives. This argument holds even if one believes that the "intrinsic worth" of a life in the future should be evaluated the same as a life today.

The controversy gains critical importance when one discusses the present generation's responsibility to future generations (e.g., the storage of high-level nuclear wastes). Some argue that if the future is discounted at 2 or 3%, then a billion deaths far enough out in the future (1000 years, say) may have a present value of less than one death today. And this is clearly wrong, they say. (There is evidence that the real rate of return has been approximately zero for the past 50 years or so.) Others argue that discounting may indeed be plausible but that the seriousness of a billion deaths may entail a societal trauma that far transcends the loss of life—it may involve the continuity of life—and that concern must be factored prominently into the analysis. The same arguments for discounting or nondiscounting of lives have parallels in the discussion of future environmental effects.

Human versus Nature. Some people take an anthropomorphic view and argue that society should protect the natural universe because the future quality of the environment is what future people will have to live with. To these individuals, environmental concerns are a proxy for (deferred) human concerns. Others argue for nature's concerns *per se*, regardless of their possible indirect effect on people. Sometimes individuals with different outlooks can agree on policies that protect the environment but for vastly different reasons. At other times people are called upon to make sacrifices for the environment and value trade-offs result.

For example, the burning of fossil fuels has contributed to the rise of carbon dioxide in our atmosphere and experts predict that with a gradual increase in coal usage, CO_2 levels may double by the middle of the next century and cause a warming of the planet. This could have profound effects on the environment: on rainfall patterns, on monsoons, on semiarid lands, on ocean levels, and so on. The effect on people will be varied: some countries like Canada and the Soviet Union may even be better off but others will suffer. Should concern for the effects of the man-made rise of CO_2 levels be primarily focused on its effects on people? Do people have the responsibility of maintaining present ecological balances, for ecology's sake?

Very few of us would be willing to save a single species (like the snail darter) from extinction in order to forego the benefits of a major energy resource. But people are today extinguishing vast numbers of species in the development of tropical forests for the use of humans. In thinking about these problems, should concern for the environment be solely motivated by concern for future people?

Efficiency versus Equity. When a new risk management policy is proposed in lieu of the *status quo* position, it is not surprising that some people will consider themselves "winners" and others "losers." Even in those rare cases where all are "winners," the problem may still not be trivial since the small winners may be envious of the big winners. The losers or small winners might fight for their interests and try to block the new policy. In theory, if a policy is "efficient," it is possible for the winners to compensate the losers so that no party is made worse off and at least one party is better off under the proposed policy. However, compensation schemes are often politically infeasible or too costly to implement efficiently.

Economists argue that to seek acceptability in each project by compensatory schemes may make good sense in political terms but it may not be good in the long run for society.

Their argument is that we are not dealing with an isolated choice but with a series of choices and a representative individual will win some and lose some. If we are efficient about each policy choice, then most individuals will come out overall net winners. Those few persons that are overall net losers can be compensated by a massive transfer payment. Economists argue that if one tries to compensate the losers deal by deal, everyone will get bogged down in an administrative or political morass and desirable, innovative projects will never come to fruition and "almost all" of us will be losers.

A counterargument is that equity issues must be considered for each project because a massive transfer payment for losers is politically unrealistic. Moreover, in many decisions involving health and safety the losers feel so strongly that they will not buy the efficiency argument, project by project. Such losers and their allies will demand attention to equity concerns, project by project. These people often form an effective blocking coalition, and the pragmatic alternative for the winners is to try to compensate the losers for their losses.

The tension between efficiency and equity, while pervasive in all policy problems, is of central concern in the emotionally charged arena of risk problems where some people might suffer adverse consequences to life and health. Once again a crystal ball to eliminate scientific uncertainties is of limited help here. Indeed the efficiency–equity debate may be exacerbated when the sides are clearly drawn and all persons know whether they are on the winning or losing sides.

Freedom and Paternalism. Many health and safety risks are caused by self-hazardous behavior (e.g., smoking, overeating, and nonuse of seat belts). Analyses of policies to reduce self-hazardous behavior cannot avoid the debate about freedom and paternalism. Does society have the right to force people to behave in a certain way for their own good or is that such an infringement on their freedom of choice that such interventions are inappropriate? Is the answer to this question different when children or adolescents are the potential victims? These are ethical issues that are pervasive in risk analysis.

THE DECOMPOSITION OF RISK ANALYSIS

"Analysis" comes from the Greek, *ana* + *lysis,* and means a loosening or dissolving or breaking up of any whole into its parts. In complex policy problems where no single individual has command of all facets of the problem, decision makers and their advisors may wish to decompose the overall problem into parts and call on appropriate experts to help advise on various facets of the problem. Sometimes decomposition of a problem into component tasks can be achieved in more than one way and the method of decomposition may depend on the array of experts who can assist with the component parts. If the problem is important enough, more than one type of decomposition may be employed.

There is one type of decomposition of tasks that seems quite natural, one that is employed extensively by federal agencies such as the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA). Risk analysis is decomposed into assessment and evaluation tasks. Risk assessment involves identifying and quantifying the magnitude of a particular health risk, including consideration of uncertainties about the available evidence. In contrast, risk evaluation includes analytical efforts to identify appropriate risk-coping strategies. The risk evaluator (like the policy analyst) is concerned about value trade-offs, law, policy design, and politics.

Figure 1 presents in schematic form the decomposition we have in mind in the case of a government agency. The administrator and his staff (box 5) are responsible for the task

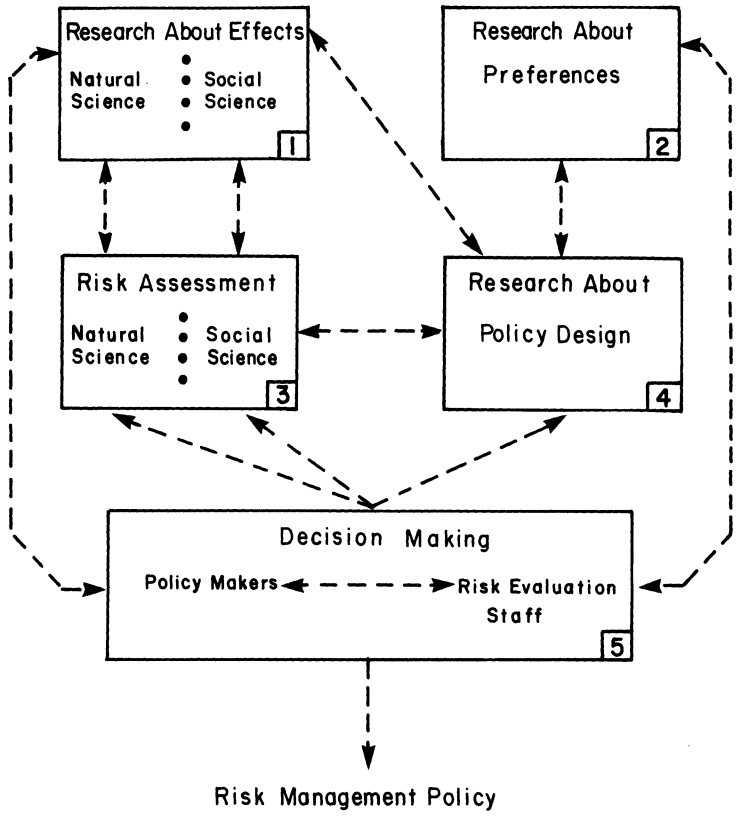

Figure 1. Analytical roles in governmental risk management.

of risk evaluation but they may draw on available scientific research on policy design (box 4) and public preferences (box 3). In many cases the task of risk evaluation does not result in a published document that is available for review by outsiders. In contrast, the task of risk assessment in government agencies is becoming increasingly formal, with peer review and extensive participation by advisory panels and consultants. The enterprise of risk assessment (box 2) relies on scientific research (box 1) on the physiological effects of the chemical or pollutant in question. Risk assessment is sometimes housed inside the government agency and sometimes in a separate institution. A recent National Academy of Sciences (NAS) panel looked closely at the question of whether risk assessment should be separated institutionally from risk evaluation and decision making.[11] In our view the issue of analytical separation is more important than the question of institutional separation.

Suppose that the administrator of EPA, on the basis of common sense, political concerns, and statutory constraints, decides that he has three choices regarding pollutant X: (1) a uniform 60% removal standard, (2) a uniform 80% removal standard, and (3) a 95% removal standard with a provision for variances in hardship cases. The administrator knows a primary issue will be a trade-off between morbidity and economic costs, but he knows that he lacks good information on the magnitude of the two crucial consequences. The administrator might establish two assessment groups, one to estimate the magnitude of the health benefits of the policy choices and the other to estimate the economic consequences of the policy choices. The two assessment groups could work independently of each other (with some loose coordination linkages).

The administrator might instruct the two assessment groups to try to exclude value or policy judgments from their deliberations. The administrator intends to integrate their reports with a myriad of other factors in arriving at a balanced decision. The administrator wants to tap their expertise solely as natural and social scientists and not to have them deliberate about political concerns, about value trade-offs, and about policy choices.

The administrator may decide that the assessment reports do not suffice to help him decide on a course of action. A host of value trade-offs and political constraints must now be considered. Thus, the decision maker might also wish to appoint a panel of policy evaluators or risk evaluators to help him sort out his thinking about what should be done.

Why Decompose Assessment and Evaluation Tasks?

Individuals who must frequently decide between complex alternatives—doctors, businessmen, investment analysts, judges, and juries—usually do not decompose their thinking into separate compartments and formalize each task separately. They generally do not, for example, formally assess probability distributions of key uncertainties and systematically combine these assessments with value trade-offs. Rather, they gather bits and pieces of facts and synthesize them somehow in the mysterious intricacies of their brains. They would be hard pressed to give a coherent articulation of their thought processes. If forced to justify their actions, their articulated rationalizations may not accurately reflect their deeper insights. Even those decision analysts who espouse the "divide and conquer" philosophy of decomposition and recomposition acknowledge that formal analysis requires experience and (at least initially) the formal process may not compete favorably with informal thrashing around and with letting one's mind work in its mysterious and synoptic ways. We note here four arguments for formalizing the assessments of uncertainties (as a prelude to decision making) and trying to keep these separate from the evaluation task.

First, the scientific facts about risks may be complicated and no one has a mastery of all the facts. Many experts might have to pool their individual wisdom together to arrive at a collective wisdom. Some formalization of these interactions might help the exploitation of bits and pieces of the puzzle.

Second, the more one structures the problem and articulates the rationale for conclusion about component parts, the easier it is for others to criticize constructively the reasoning employed, and to criticize destructively as well. Peer review is facilitated by explicitness.

Third, analysis is not static. New insights are gleaned; new theoretical understandings are discovered; new experimental findings are accumulated. It is often easier to modify and update an analysis if it is structured. Learning may be facilitated by explicitness. If scientists are aware of just where the arguments are weakest, this might encourage the necessary research to partially fill the gaps.

Fourth, the process of decision making is intricate and an assessment of uncertainties that tries to keep out policy values may be a useful input to many different types of decision makers, both in and out of the government. In contrast, a risk analysis that mixes values and scientific uncertainties is less useful to other parties.

Linkages between the Assessment and Evaluation Tasks

If assessment tasks are to be separated from evaluation tasks, some individual or group has to decide what type of information would be helpful in the policy process (that is, what risks to consider or which uncertainties to analyze). Consider some examples of possible interactions between the evaluation group and the assessment group.

The evaluation group wants to know about X, the uncertainty analysts would rather report about proxies Y1 and Y2 (because they can be assessed more objectively), and they collectively might decide on reports about proxies Z1, Z2, and Z3. The Zs may not be exactly what the decision makers want to know but it may be close enough, and the assessors may feel that a direct report about X will strain their scientific credibility; it will require too many nonscientific judgments.

The policy group may just want to know whether it is reasonable to expect that X is below some level, X*. If yes, then the policy problem might be clear. If no, or if the answer is ambiguous, then the request for information about uncertainties might be modified.

There are many other reasons to have linkages between assessment groups and evaluation groups. For example, risk assessors (uncertainty analyzers) might be able to collect information (e.g., conduct experiments, build new models, reanalyze complex data), but at a cost. Is the expected value of this additional information worth the costs? This question cannot and should not be answered without thinking about the wider policy problem. What are the alternatives, the time constraints, the competing uses for research money, and so on? So requests for information about the desirability of further research could also flow from an assessment group to the evaluation group.

Natural and social scientists who have been asked to do an assessment analysis may be in a position to suggest a restructuring of the policy alternatives and may, in an interactive fashion with the risk evaluators, suggest an entirely different menu of questions they should address. Acquisition of information often does not resolve problems but restructures them, and this means that an active interplay between assessment and evaluation may be extremely desirable. Yet this does not mean that value trade-offs should enter into the assessment process. The more intense the interaction between assessment and evaluation, however, the more prone the assessors will become to the intrusion of values from the policy process. This creates a tension between the separation and integration of functions. There is no neat solution. If one becomes so paranoid about the contaminating influences of policy values on assessments and demands their strict separation, then other egregious analytical errors will result.

What Happens When Decomposition Is Unwise?

There are two classes of problems that we want to treat separately. The first class is where it may conceptually make sense to treat the assessments of scientific uncertainties separately from evaluation concerns but where administratively it may not be pragmatic to do so. The second class is where the decomposition may be conceptually murky and therefore not worth doing.

In some situations it may be impossible for the assessment group to withstand the pressures of policy values and then it may not be of service to pretend that the assessments of uncertainties are value-neutral. Assessments may be so interlinked with values that to sort it out may be hopeless or not credible to any outside critic. In this case the decision maker, who may be under time pressure to act, might convene a panel of experts to give him advice on the problem as a whole, not separated into parts. It still may be possible for members of such a composite committee to seek collective wisdom in a collegial, nonadversarial fashion. Committee members with a particular expertise might attempt to structure their side of the debate for the benefit of other members less knowledgeable in their domain. But now the component parts of the debate become less sharp and reports by subcommittees become less structured than would be the case where the process is formally decomposed. It now becomes harder for external groups to critique component parts of the informal

analysis and for systematic learning to take place because those component subanalyses never get formally done or are submerged in the general debate.

An open adversarial process is often an effective mechanism to help focus a debate and, even within the confines of a committee appointed to help a policy maker, an adversarial process may artificially and productively be created to sharpen the discussion. Adversarial debates can be interspersed with collegial inquiries as a way of seeking collective wisdom.

A consensus about policy recommendations might emerge from a composite committee even though individual members might disagree with the reasons leading to those recommendations. For policy purposes, this might suffice. If the composite task were to be decomposed (say, into assessments and evaluations), then disagreements about assessments (especially if they are publicized) might effectively block any policy recommendations.

Consider the class of problems where decomposition into assessment and evaluation is not a conceptually convenient breakdown, for example: (1) Should there be a science court? (2) Should abortions be supported with public funds? (3) Should an attempt be made to equalize the marginal value of lifesaving across federal agencies? or (4) Should more foreign aid be given to those countries that better preserve the global environment?

Such policy problems involve assessment of uncertainties but these problems do not neatly decompose into assessment and evaluation tasks. Perhaps after much thrashing about and devising of concrete alternate plans some component part of a problem can be isolated for a separate report. Decomposition of these tasks might eventually take place, but there is no obvious framework that would be hospitable to many of these problems. Although we recognize that decomposition is sometimes impossible or unwise, there are many problems in the domain of risk and decision making where it is conceptually natural to do so and where it is currently being done.

THE ROLES OF SCIENTISTS AND SCIENTIFIC INSTITUTIONS

Many scientists play an active role in public debates about risk and decision making. Scientists are citizens and they should not be disenfranchised from the political process. Indeed, it can be argued that scientists who can understand the intricacies of complex social and natural science problems have a special obligation to serve society by speaking out on how they stand on controversial issues. But there is a price society pays for this openness. When lay people hear passionate claims by equally eminent scientists on diametrically opposed sides of a policy debate they may find such debates bewildering. The media may exacerbate this problem by focusing attention on extreme opinions that are accompanied by ringing rhetoric. It is hard to sort out what are scientific judgments and what are value judgments. In some cases scientists cloak controversial value judgments in scientific jargon, both consciously and subconsciously. As a result, the prestige of science and public confidence in science suffers. This dilemma has profound implications for science. It may affect—some say that it already has affected—funding for science, the selection of professions by college students, and the willingness of scientists to participate in the policy process. Furthermore, scientific progress may hold one of the keys to better and healthier lives for all—especially those in the disadvantaged, developing world—and ironically scientists, although meaning well, by engaging in heated debates involving nonscientific value judgments, may be undercutting their own role in the future amelioration of the world's ills.

Scientists engaged in debates about risk and decision making should attempt to say where their scientific expertise ends and where their nonexpert value judgments begin. Of

course, a scientist may not know where the boundary between the two may fall; scientific expertise and value judgments may fuse, but an attempt should be made to disentangle the two. Again, of course, there may be a continuum of states of fuzziness, but an attempt should be made to communicate this fuzziness.

Committees of specialists working under the aegis of scientific institutions, who have been asked to perform some risk analysis, have a responsibility to the committee's client, to the public, and to the committee's parent institution. These responsibilities are jeopardized when tasks are accepted that are inappropriate for the committee and its parent institution. For example, a committee of physical scientists sponsored by an engineering institute may not be the appropriate committee to recommend policies that should balance concerns about health and safety risks with value trade-offs and political constraints. Some scientists comprising the committee may be knowledgeable about policy concerns, but if their expertise is sought and their institution's imprimatur is given on the basis of their professional expertise as physical scientists and not as policy analysts, then it may be inappropriate for them to make pronouncements that extend beyond their disciplinary expertise. Certainly, if they feel compelled to offer policy recommendations, such excursions should be clearly demarcated in the report. Outside of the committee, the members have the right (and yes, duty) to speak out on the issues, but the committee is not serving its parent institution, the broader scientific community, or the public if it expands its consultative role from the (descriptive) assessments of scientific phenomena to the (prescriptive) evaluations of policy choices—when this was not their assigned task.

Committees are often specifically asked by their clients to suggest recommendations for policy choice "all things considered." Depending on the composition of the committee this may not be unreasonable. Yet committees should be careful lest they become used and manipulated in a political process. Sometimes a good decision might result from shifting the burden of choice from a politically charged regulatory commission to some quasi-scientific body of conglomerate experts. But it might be done at the expense of confusing the role of the parent scientific institution. Scientific institutions do and should sometimes say to a potential client that its role is confined to nonprescriptive, nonevaluative scientific assessments.

In order to talk about assessment and evaluation (their separation and integration) in risk analysis, we purposely draw sharp lines around each. These lines are difficult to draw and many members of scientific committees do not think deeply about these distinctions. If the agreed upon scope of a committee is to concentrate its attention on (descriptive) science, the committee may slide into consideration of prescriptive, evaluative elements of an analysis, not as a conscious decision but because it is just natural to think that way. Our suggestions are not stark. We are not saying, "Do not mix evaluation with assessment." Rather, we are saying, "Be conscious of what you are doing. If evaluative components are prominent in your report, was this intended? Has the committee been appropriately chosen for this task? Did the committee spend enough time considering the dynamics of choice, value trade-offs, and political and legal constraints, before they arrived at their policy conclusions?" These questions suggest there may be a conflict of interest between the needs of a client and the reputation of scientific institutions.

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NOTES

1. For a more extensive discussion of the limitations of professional analysis in problem solving, see Charles E. Lindblom and David K. Cohen, *Usable Knowledge: Social Science and Social Problem Solving*, Yale University Press, New Haven, Conn., 1979.
2. One type of risk analysis, cost–benefit analysis, is either not sanctioned or is expressly prohibited by statute as an input into the decision making of some federal regulatory agencies. See, generally, Michael S. Baram, "Cost–Benefit Analysis: An Inadequate Basis for Health Safety, and Environmental Regulatory Decision Making," *Ecology Law Quarterly*, Volume 8, 1980, pp. 473–531.
3. On the need for more analytical contributions to negotiations, see Howard Raiffa, *The Art and Science of Negotiation*, Harvard University Press, Cambridge, Mass., 1982.
4. On the utility of "quick analysis" for decision making, see Robert D. Behn and James W. Vaupel, *Quick Analysis for Busy Decisionmakers*, Basic Books, Inc., New York, 1982.
5. On the elicitation of subjective probabilistic estimates of risks from experts, see M. Granger Morgan, Max Henrion, and Samuel C. Morris, *Expert Judgments in Policy Analysis*, Brookhaven National Laboratory, Upton, N.Y., 1980.
6. On multiattribute utility theory, see, generally, David E. Bell, Ralph L. Keeney, and Howard Raiffa, eds., *Conflicting Objectives in Decisions*, John Wiley, Chichester, Great Britain, 1977.
7. In the U.S. Supreme Court's recent decision on air bags and car safety, the federal government's attempt to repeal the passive-restraint regulation was blocked because the agency's risk analysis failed to contain a reasoned discussion of "obvious" policy alternatives. *Motor Vehicle Manufacturing Assn. vs. State Farm Mutual Automobile Insurance Co.*, U.S. Supreme Court, Case Number 82-354, June 24, 1983 (slip opinion).
8. John D. Graham and James W. Vaupel, "The Value of a Life: Does It Make a Difference?" *Risk Analysis*, Volume 1, 1982, pp. 89–95.
9. On analytic approaches to estimating both "life years" saved and "quality-adjusted life years" saved, see Richard Zeckhauser, "Procedures for Valuing Lives," *Public Policy*, Volume 23, 1975, pp. 419ff., and Richard Zeckhauser and Donald Shephard, "Where Now for Saving Lives?" *Law and Contemporary Problems*, Volume 40, 1976, pp. 5–45.
10. See reference 8.
11. For several useful case studies in risk assessment, see Lester B. Lave, ed., *Quantitative Risk Assessment in Regulation*, Brookings Institution, Washington, D.C., 1982.
12. *Risk Assessment in the Federal Government: Managing the Process*, National Research Council, Washington, D.C., 1983.

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Risk Analysis and Risk Management

A Historical Perspective

Vincent T. Covello and Jeryl Mumpower

INTRODUCTION

In the Tigris–Euphrates valley about 3200 B.C. there lived a group called the Ashipu. One of their primary functions was to serve as consultants for risky, uncertain, or difficult decisions. If a decision needed to be made concerning a forthcoming risky venture, a proposed marriage arrangement, or a suitable building site, one could consult with a member of the Ashipu. The Ashipu would (1) identify the important dimensions of the problem, (2) identify alternative actions, and (3) collect data on the likely outcomes (e.g., profit or loss, success or failure) of each alternative. The best available data from their perspective were signs from the gods, which the priestlike Ashipu were especially qualified to divine. The Ashipu would then create a ledger. For each alternative, if the signs were favorable, they would enter a plus; if not, they would enter a minus. After the analysis was completed, the Ashipu would recommend the most favorable alternative. The last step was to issue a final report, etched upon a clay tablet (Oppenheim, 1977).

According to Grier (1980, 1981), the practices of the Ashipu mark the first recorded instance of a simplified form of risk analysis. The similarities between the practices and procedures of modern risk analysts and those of their Babylonian forebears underscore the point that people have been dealing with problems of risk for a long time, often in a sophisticated and quantitative way.

This chapter reviews the history of risk analysis and risk management giving special emphasis to the neglected period prior to the 20th century. It is hoped that this review will serve to (1) dampen the prevailing tendency to view present-day concerns about risk in an ahistorical context, (2) shed light on the intellectual antecedents of current thinking about risk, (3) clarify how contemporary ideas about risk analysis and societal risk management

Vincent T. Covello • Division of Policy Research and Analysis, Policy Sciences Section, National Science Foundation, Washington, D.C. 20550. *Jeryl Mumpower* • Department of Public Administration, State University of New York at Albany, Albany, New York 12222.

differ significantly from the past, and (4) provide a basis for anticipating future directions in risk analysis and management.

This chapter is divided into five major sections. The first discusses the early antecedents of quantitative risk analysis, with an emphasis on the development of probability theory. It would be difficult, if not impossible, to separate contemporary risk analysis from mathematical notions of probability. Yet our review indicates that probability, expressed quantitatively, is a relatively recent idea. Although precursors of contemporary risk analysis can be identified as far back as early Mesopotamia, it was not until the emergence of probability theory in the 17th century that the intellectual tools for quantitative risk analysis became available.

The second section discusses the development of scientific methods for establishing or demonstrating causal links or connections between adverse health effects and different types of hazardous activities. Such methods are no less essential to modern risk analysis than is probability theory. Despite their importance, however, progress in developing such methods was exceedingly slow. Several possible explanations are considered.

The third section focuses on mechanisms for coping with risks and discusses the principal antecedents of contemporary societal risk management strategies. Four major strategies are discussed: insurance, common law, government intervention, and private sector self-regulation. In each instance, examples are cited that closely resemble but considerably predate modern practice.

The fourth section discusses nine changes between the past and the present which we consider to be among the most significant for risk analysis and risk management.

The final section attempts to anticipate some likely future directions in risk analysis and risk management.

QUANTITATIVE RISK ANALYSIS AND PROBABILITY

Unlike modern risk analysts, who express their results in terms of mathematical probabilities and confidence intervals, the Ashipu of ancient Babylonia expressed their results with certainty, confidence, and authority. Since the Ashipu were empowered to read the signs of the gods, probability played no part in their analyses. Faulty predictions, as in other forms of divination, were readily rationalized according to initial premises and posed no threat to the system (Thomas, 1971; Turner, 1961). The search for the origins of modern quantitative risk analysis must, therefore, look elsewhere.

An important thread leading to modern quantitative risk analysis can be traced to early religious ideas concerning the probability of an afterlife. This should hardly be surprising, considering the salience and seriousness of the risks involved (at least for true believers). Beginning with Plato's *Phaedo* in the 4th century B.C., numerous treatises have been written discussing the risks to one's soul in the afterlife based on how one conducts oneself in the here and now.

One of the most sophisticated analyses of this issue was carried out by Arnobius the Elder, who lived in the 4th century A.D. in North Africa. Arnobius was a major figure in a pagan church that was competing at the time with the fledgling Christian church. Members of Arnobius's church, who maintained a temple to Venus complete with virgin sacrifices and temple prostitution, led a decadent life in comparison to the austere Christians. Arnobius taunted the Christians for their lives of pointless self-abnegation, but, after a revelatory vision, renounced his previous beliefs and attempted to convert to Christianity. Suspicious of Arnobius's motives, the bishop of the Christian church doubted the sincerity of his

conversion and refused him baptism. In an effort to demonstrate the authenticity of his conversion, Arnobius authored an eight-volume monograph entitled *Against the Pagans*. In this work, Arnobius made a number of arguments for Christianity, one of which is particularly relevant to the history of probabilistic risk analysis. After thoroughly discussing the risks and uncertainties associated with decisions affecting one's soul, Arnobius proposed a 2 × 2 matrix. There are, he argued, two alternatives: (1) "accept Christianity" and (2) "remain a pagan." There are also, he argued, two possible, but uncertain, states of affairs: (1) "God exists" and (2) "God does not exist." If God does not exist, there is no difference between the two alternatives. (With the minor exception that Christians may unnecessarily forgo some of the pleasures of the flesh enjoyed by pagans.) If God exists, however, being a Christian is far better for one's soul than being a pagan.

According to Grier (1981), Arnobius's argument marks the first recorded appearance of the *dominance principle,* a useful heuristic for making decisions under conditions of risk and uncertainty. Through his student Lactinius, and later St. Jerome and St. Augustine, this argument entered the mainstream of Christian theology and intellectual thought. When Pascal introduced probability theory in 1657, one of his first applications was to extend Arnobius's matrix. Given the probability distribution for God's existence, Pascal concluded that the expected value of being a Christian outweighed the expected value of atheism.

In addition to Pascal's seminal work (Ore, 1960), the late 17th and 18th centuries witnessed a remarkable spurt of intellectual activity related to probability theory (Lightman, 1983). In 1692 John Arbuthnot argued that the probabilities of different potential causes of an event could be calculated. In 1693 Halley proposed improved life expectancy tables. In 1728 Hutchinson examined the trade-off between probability and utility in risky choice situations. In the early 18th century Cramer and Bernoulli proposed solutions to the St. Petersburg paradox. Then in 1792, LaPlace developed a true prototype of modern quantitative risk assessment—an analysis of the probability of death with and without smallpox vaccination (LaPlace, 1812).

What caused this unprecedented surge of activity in the mathematical theory of probability? For decades, historians of science have grappled with this question. In 1865, Isaac Todhunter wrote a work entitled *A History of the Mathematical Theory of Probability from the Time of Pascal to That of LaPlace*. Only 6 of the 618 pages in the text deal with Pascal's predecessors. The dearth of material was not a simple omission by Todhunter. Nor was it due to a lack of historical diligence and scholarship. Instead, it appears that formal quantitative concepts of probability were not apprehended to any substantial degree before the time of Pascal. Prior to Pascal, there was virtually no history of probability theory. Yet after LaPlace, the laws of probability were so well understood that a bibliography of early work on the subject would cover several hundred pages.

How can this be? What makes the situation even more difficult to understand is that man's fascination with games of chance appears to be nearly as old as man himself. As David (1962) has shown, games of chance may have been one of the first inventions of primitive man. In sites throughout the ancient world, archeologists have uncovered large numbers of tali, a predecessor of modern dice. Shaped from the "knucklebone" or heel of deer, horses, oxen, or sheep, a talus is so formed that when it is thrown on a level surface it can come to rest in only four ways. Well-polished and often engraved examples of tali are regularly found in ancient Egyptian, Sumerian, and Assyrian sites. Tomb illustrations and scoring boards make it virtually certain that these were used for gaming. During the Roman era, Marcus Aurelius was so obsessed with throwing dice that he was regularly accompanied by his own master of games. It would seem to follow that the mathematical calculation of relative frequencies and averages should be as old as the rolling of such ancient

devices. Yet mathematical theories of relative frequency, betting, randomness, and probability only appear 1500 years later in the work of Pascal, Bernoulli, and others.

Several tentative explanations have been offered, none of which is entirely satisfactory (see, e.g., Hacking, 1975; Sheynin, 1974). First, it has been argued that mathematical probability theory developed in response to specific economic needs. According to this argument, the rapid development of probability theory in the 17th and 18th centuries can, in part, be traced to the rise of capitalism and to the desire of the new mercantile class for improved methods of business calculation and for greater economic security in the form of insurance. But early probability theorists were generally not involved in commerce, nor was their work readily applicable to business.

A second argument, related to the first, argues that the development of mathematical probability theory was related to the growth of firms dealing in life annuities. This argument falters, however, when one considers that by the 3rd century A.D., the selling of annuities was already a common practice in Rome.

A third argument is that prior to the 17th century mathematics was not sufficiently rich in concepts and ideas to generate a theory of probability. According to this argument, the mathematics of probability became possible when limit theorems became possible. This argument falters when one considers that the concept of probability requires little besides simple arithmetic. In response, supporters of this argument claim that prior to the 17th century the arithmetic symbolism needed for easy addition and multiplication did not exist, and that such a symbolism is a prerequisite for probability.

A fourth argument is that the conditions leading to the emergence of a mathematical theory of probability are the same as those leading to the emergence of modern science in the 16th and 17th centuries. While it has long been commonly accepted that theoretical and methodological developments during this period, particularly in England and France, constituted a scientific revolution, it is not at all clear why or how this came about. Numerous theories have been proposed, from the theories of Marx (Bottomore and Rubel, 1956) concerning changes in the economic means of production; to Merton's theory (Merton, 1938) concerning the link between religion, the Protestant reformation, and scientific developments; and to relatively recent theories which link the emergence of modern science to a complex chain of scientific, technological, political, economic, religious, institutional, and ideological changes (e.g., White, 1967:1204; Ben-David and Sullivan, 1975; Needham, 1956).

A fifth argument, offered by Grier (1981), is that the preconditions for the emergence of probability theory were established approximately a century and a half before Pascal, largely because of a change in attitude of the Catholic Church. Grier notes that in the 14th century the Catholic Church experienced a serious cash flow situation. On the one hand, money was needed to pay the massive debts arising from the Crusades, which had been extraordinarily, almost ruinously, expensive. On the other, money was also needed to pay for new church construction in response to growing population pressure. Money was, however, in short supply, since the Church prohibited usury. In order to reconsider the matter, the Church formed an advisory panel of scholars. At the same time, the financial community hired John Ecks, a university professor, to argue on their behalf. In 1518, the Laettian Council adopted a scholars' report that redefined usury in such a way that interest was permitted as long as there was risk incurred on the part of the lender. Although this definition was rescinded in 1586 (and the Church did not sanction interest again until 1830), Grier argues that the 68 years of sin-free interest rates were enough to stir up intellectual thought about probability. The real change, he argues, was not in law or morality, but in making risk a legitimate topic of discussion. Much of the intellectual thinking about probability in

the 17th and 18th centuries, he believes, had its roots in the discussions of risk in the Church's debates over interest rates.

Whatever the true explanation or explanations, it did not take long for the new theories of probability to be applied to the human condition. Within 100 years of Pascal's discovery, several individuals were using mathematical theories of probability to examine life expectancies. Prior to this work the only life expectancy tables of note were those developed by the Roman Domitius Ulpianus in 230 A.D. Similar efforts were not made until Graunt published his life expectancy tables in 1662. In explaining this large gap, it appears that philosophical objections played a major role. As David (1962:99) points out, there "seems to have been a taboo on speculations with regard to health, philosophers implying that to count the sick or even the number of boys born was impious in that it probed the inscrutable purpose of God."

Graunt's work represents the first recorded attempt to calculate empirical probabilities on any scale. The raw data for his tables were parish records of births and deaths. In the conclusion of his work, Graunt offers several remarks that might apply equally to the work of contemporary risk analysts:

> It may be now asked, to what purpose tends all this laborious puzzling and groping? . . . I might answer; That there is much pleasure in deducing so many abstruse and unexpected inferences out of these poor despised Bills of Mortality; and in building upon that ground, which hath lain waste these eighty years. And there is pleasure in doing something new, though never so little, without pestering the World with voluminous Transcriptions. But, I answer more seriously, . . . that a clear knowledge of these particulars, and many more, whereat I have shot but at rovers, is necessary in order for good, certain, and easy Government, and even to balance Parties and factions both in Church and State. But whether the knowledge thereof be necessary to many, or fit for others, than the Sovereign, and his chief Ministers, I leave to consideration. (Graunt, 1662:84)

Not long after Graunt published his tables, Halley (better remembered for the comet that bears his name) published an article (1693) containing mortality tables based on the records of births and deaths at various ages in the city of Breslau. Halley's probabilistic analysis of the data convincingly disproved popular theories about the effect of phases of the moon on health, and his results, as will be discussed later, provided the foundation for one of the pillars of modern societal risk management—life insurance.

One of the earliest systematic attempts to apply probability theory to a risk problem was by Von Bortkiewicz in the 19th century (Campbell, 1980). Von Bortkiewicz built on previous work done by Poisson to calculate theoretically the annual number of Prussian soldiers dying from kicks by horses. He studied records covering a span of 10 years to determine whether an observed rash of kicking accidents represented a random event or a change in circumstance requiring action (e.g., a rise in carelessness by soldiers or an increase in the number of wild horses). The analysis indicated that the occurrences he observed were indeed random events and that no special disciplinary actions were required.

METHODS FOR ESTABLISHING CAUSALITY

Modern risk analysis has its twin roots in mathematical theories of probability and in scientific methods for identifying causal links between adverse health effects and different types of hazardous activities. For unraveling these links, researchers throughout history have relied principally on methods of observation. The most basic form of such methods, and the most universally practiced, is experience based on trial and error. Since primitive times,

human beings have upon occasion simply undertaken a new activity of interest (e.g., tasted a strange plant or launched a new boat) and have observed the adverse effects, if any. A slight variant of this method has been to distance oneself and conduct the experiment on a surrogate (e.g., feed new foods to animals). On a more complex level, researchers have used (1) indirect observational methods, such as the burn tests developed by Pliny the Elder in 1st-century A.D. Rome to detect food adulteration (Hutt, 1978), and (2) epidemiological observational methods, i.e., methods that seek to establish associations or cause–effect relationships through the observation of adverse health effects in clusters of cases. Although the early researchers in this second tradition did not adhere to the rigorous scientific and statistical standards of modern epidemiological studies (Shimkins, 1979, 1980), the historical record is replete with examples. The association between malaria and swamps, for example, was established in the 5th century B.C. even though the precise reason for the association remained obscure. In the book *Airs, Waters, and Places,* thought to have been written by Hippocrates in the 4th or 5th century B.C., an attempt was made to set forth a causal relationship between disease and the environment. As early as the 1st century B.C., the Greeks and Romans had observed the adverse effects of exposure to lead through various mediums (Nriagu, 1983; Gilfillan, 1965). The Roman Vitruvious (cited in Hughs, 1975:109), for example, wrote:

> We can take example by the workers in lead who have complexions affected by pallor. For when, in casting, the lead receives the current of air, the fumes from it occupy the members of the body, and burning them thereon, rob the limbs of the virtues of the blood. Therefore it seems that water should not be brought in lead pipes if we desire to have it wholesome.

Unfortunately, the observations of the ancient Greeks and Romans were soon forgotten and work did not begin anew until the 16th, 17th, and 18th centuries. Among the many studies conducted during this period, several stand out:

- A study by Agricola in 1556 linking adverse health effects to various mining and metallurgical practices.
- A study by Evelyn in 1661 linking smoke in London to various types of acute and chronic respiratory problems.
- A study by Ramazzini in 1700 indicating that nuns living in Appennine monasteries appeared to have higher frequencies of breast cancer (Ramazzini suggested that this might be due to their celibacy, an observation that is in accord with recent observations that nulliparous women may develop breast cancer more frequently than women who have had children—e.g., see MacMahon and Cole, 1969; Sherman and Korenman, 1974).
- A study by Hill in 1781 linking the use of tobacco snuff with cancer of the nasal passage.
- A study by Sir Percival Pott in 1775 indicating that juvenile chimney sweeps in England were especially susceptible to scrotal cancer at puberty.
- Studies by Ayrton-Paris in 1822 and Hutchinson in 1887 indicating that occupational and medicinal exposures to arsenic can lead to cancer.
- A study by Chadwick (1842) linking nutrition and sanitary conditions in English slums to various types of ailments.
- Studies by Unna in 1894 and Dubreuilh in 1896 linking sunlight exposure with skin cancer.
- A study by Rehn in 1895 linking aromatic amines with bladder cancer.

Despite these studies, progress in establishing causal links between adverse health effects and different types of hazardous activities was exceedingly slow. It appears that at least two major obstacles impeded progress. The first was the paucity of scientific models of biological, chemical, and physical processes, especially prior to the 17th and 18th centuries. Related to this was the lack of instrumentation and the lack of rigorous observational and experimental techniques for collecting data and testing hypotheses. Shapiro (cited in Baram, 1973:472) described two revolutionary intellectual developments affecting science (and law):

> The first was the drive for systematic arrangements and presentation of existing knowledge into scientifically organized categories. . . . The second . . . was the concern with degrees of certainty . . . or probability. . . . By the end of the 17th century . . . traditional views . . . had been upset and new methods of determining truth and investigating the natural world had replaced those that had been accepted for centuries . . . there was a strong movement toward arranging both concepts and data into some rational ordering that could be easily communicated and fitted into the materials of other fields so that a universal knowledge might emerge.

Although often taken for granted in today's world, even basic medical knowledge is a relatively recent development. It is surprisingly easy to forget that it was not until the work of Pasteur in the late 19th century that scientists first began to comprehend adequately the concept of infection or the causal relationship between the environment and biological agents of infectious disease.

The second obstacle was the belief, rooted in ancient traditions, that most illnesses, injuries, misfortunes, and disasters could best be explained in social, religious, or magical terms (e.g., by the will of the gods, by some moral transgression, or by the malevolence of an unseen enemy). In 16th- and 17th-century Europe, witch hunting resulted in death by fire for an estimated half-million people, as the Church attempted to eradicate a perceived source of crop failures, disease, death, and other ill fortune (Clark, 1980). In 1721, an influential critic of medical experimentation in Boston insisted that smallpox is "a judgment of God on the sins of the people" and that "to avert it is . . . an encroachment on the prerogatives of Jehovah, whose right it is to wound and smite" (White, 1955:6). For many such critics, the direct physical agent that caused the harm was of considerably less interest than the moral status of the victim. In the mid-19th century, for example, critics opposed to health reforms in the Lowell, Massachussetts, textile factories (including a large number of influential physicians) blamed symptoms of disease among factory workers on the workers' "improvident" style of life (Rosen, 1944:494–497).

SOCIETAL RISK MANAGEMENT

In response to identified risks, individuals and groups have historically employed a number of techniques for reducing or mitigating adverse health effects. These include (1) avoiding or eliminating the risk, e.g., prohibiting the use of a potentially dangerous object or substance; (2) regulating or modifying the activity to reduce the magnitude and/or frequency of adverse health effects, e.g., by constructing dams, levees, and seawalls; (3) reducing the vulnerability of exposed persons and property, e.g., by requiring the use of safety devices, by elevating buildings in floodplains, by immunizing the population, by implementing quarantine laws, or by establishing disaster warning systems; (4) developing and implementing postevent mitigation and recovery procedures, e.g., by establishing search and rescue teams, by stockpiling food, by providing first aid training, or by providing fire-extinguishing equipment and services; and (5) instituting loss reimbursement and loss dis-

tribution schemes, e.g., by establishing insurance systems or incentive pay schedules for high-risk activities. Although all of these techniques are still practiced, most of our current ideas about societal risk management are rooted in four basic strategies or mechanisms of control: insurance, common law, government intervention, and private sector self-regulation. Each is discussed below.

Insurance

Insurance is one of the oldest strategies for coping with risks (Pfeffer and Klock, 1974). Its origins can be traced to early attempts at setting interest rates, which first arose in Mesopotamia. Records of interest rates in that area predate 3000 B.C. The practice appears to have originated when successful farmers loaned a portion of their excess production in exchange for a share of the return. At first, loaned goods were returned in kind along with the interest charge, but barley and subsequently silver became the media of exchange. Differences in interest rates quickly emerged, ranging from zero for personal loans among friends to 33% for presumably much riskier agricultural loans. Inasmuch as interest rates reflected the perceived riskiness of the loan, they represented one of the earliest attempts to quantify and manage risk (Grier, 1981).

The connection between interest rates and insurance can be traced to ancient Babylon. A natural trade center, Babylonia occupied a place as the center of world economy in the pre-Greek period. Imports and exports flowed through Babylonia to and from both the east and west. Traders faced numerous hazards in the form of bandits, pirates, fire, storms, and assorted other misfortunes. Loans extended on cargo in transit ordinarily included risk premiums as large as 200% in excess of interest. Because the borrower often posted as collateral all his property and sometimes his family, misfortune could prove truly catastrophic. Under these conditions trade declined, until insurance emerged as a more effective risk management technique. The Code of Hammurabi, issued about 1950 B.C. (Johns, 1904), established several doctrines of risk management and laid the basis for the institutionalization of insurance. It formalized the concept of *bottomry* and *respondentia,* which were maritime contracts on vessels and cargoes. These contracts had three elements: (1) the loan on the vessel, cargo, or freight; (2) an interest rate; and (3) a risk premium for the chance of loss and consequent cancellation of the debt. Bottomry quickly spread throughout the ancient world and represents one of the oldest attempts to cope with risk in a systematic, quantitative fashion.

By 750 B.C. bottomry was highly developed, particularly in Greece. At that time almost all voyages were covered by bottomry contracts, with 10–25% risk premiums, depending upon the perceived riskiness of the venture. (It is interesting to note the etymology of the English word *risk.* According to the *Unabridged Random House Dictionary,* the word *risk* comes to us through the French, Italian, and Latin, originating from the Greek word *rhiza,* in reference to the hazards of sailing around a cliff.) During this same period, the concept of *general average,* which called for all parties to share proportionately in any loss suffered during a venture, was also developed. This device established a mechanism for risk sharing and provided a foundation for the first insurance exchange that developed and flourished in Athens.

With the decline of Greek civilization the Western development of insurance institutions also declined, although the Romans continued the practice of bottomry. The Romans did institute a rudimentary form of life and health insurance, however, in the form of *collegia.* Although burial societies had existed in Greece, the collegia of the Romans were much

more highly developed. Members made regular contributions, a fund was maintained, and burial and last expenses were paid by the collegia.

Insurance almost disappeared in the West after the fall of the Roman Empire. Although the European guilds provided some protection to their members against various calamities, it was not insurance *per se*. Marine insurance reappeared in the Italian port cities, perhaps as early as 1000 A.D. and certainly by the 12th to 14th centuries, becoming progressively more widespread and better developed. The Hanseatic League and Lombards, in particular, developed detailed sets of regulations pertaining to marine insurance, as evidenced by the Laws of Wisby (1300), the Ordinance of Barcelona (1435), and the Guidon de la Mer (circa 1600). In 1688 Lloyd's was established and London emerged as the nucleus of the global marine insurance market, later extending into other areas of insurance.

From the 17th century on, the insurance industry flourished in England. Fire insurance, for example, developed in London in response to the Great Fire of 1666 and quickly achieved great success. Life insurance in something resembling its modern form emerged during the 16th and 17th centuries in England, France, and Holland, although the first life insurance policies may date back to 1800–1200 B.C. Grier (1981) points out that life insurance policies existed in Spain by about 1100 A.D. and that *tontines* were highly popular in 17th-century France. (Members of tontines made payments into a general fund; if one lived long enough one received a share of the pool; and if one were the last member of the tontine to remain alive one could become quite rich.) In England, the first recorded life insurance policy was issued in 1583. Life insurance then grew rapidly under the sponsorship of the various so-called Friendly Societies.

Historical records show that the failure rates of the English Friendly Societies were initially exceedingly high. In 1867, for example, an official of the British government estimated that during the previous 75 years fully one third of the Friendly Societies had failed. The reason for the high rate of failure seems clear. Methods of probabilistic assessment were either not known or not utilized, and comprehensive sets of vital statistics were not available. Without appropriate tools for quantitative thinking about risk or the requisite data base, attempts to think quantitatively about risk often went awry. It was not until professional actuaries became an integral part of the industry in the 19th century that insurance companies stood on a firmer footing.

Developments in the life insurance field in the 17th century appear to foreshadow the modern debate concerning whether it is acceptable to place a monetary value on the loss of human life. The Church in particular raised serious questions about the morality of life insurance. For the Church, life insurance was an immoral—or at least highly suspect—wager on human life. Indeed, life insurance was prohibited in France until 1820. Debate about the morality of life insurance has long since died out, but similar issues are still discussed in debates about the moral status of cost–benefit analyses addressing risks to human life.

Common Law

In the English and American legal systems, the common law (that is, judge-made law) of "torts" has long permitted one citizen to recover damages from another for harms resulting from such actions as *nuisance* (use of one's own property that unreasonably interferes with the use of another's property), *negligence* (conduct that unreasonably imposes risks on another), and the pursuit of *abnormally dangerous activities*. These grounds for lawsuits amount to risk management in the sense that people must conform to a standard of reasonable

conduct (cleaning their chimneys, disposing of waste products) or face the prospect of being liable and successfully sued for damages. Common law thus provides two risk management functions—compensation and deterrence.

Hammer (1980) has argued that the origins of modern liability laws can be traced back to the Code of Hammurabi and to the Old Testament, both of which stressed the notion of *strict liability,* i.e., the concept that the manufacturer of a product is liable for injuries due to defects regardless of negligence or fault. With the advent of the Industrial Revolution, however, the principle of strict liability embodied in ancient laws fell into temporary decline and proof of negligence or other fault on behalf of the defendant became an essential requirement for recovery of damages in most areas of common law. By 1850, the law stated that "the plaintiff must come prepared with evidence to show that the intention was unlawful, or that the defendant was at fault; for if the injury was unavoidable, and the conduct of the defendant was free from blame, he will not be liable." An injured party could seek redress only if there were proof of negligence and, according to the principle of *privity,* only from the party contracted to supply the product.

In the United States, it was not until 1916, in the *MacPherson v. Buick Motor Co.* case, that this historically new, narrow concept of liability was partially broadened, when it was ruled that the manufacturer had a responsibility to inspect products for defects and that the lack of privity should not affect a plaintiff's right to recover damages for his injuries. And it was not until the 1960s that the ancient notion of strict liability began to be reinstated through a series of court decisions and the passage of legislation that weakened the necessity to prove negligence in order to collect damages.

Direct Government Intervention

Since ancient times, government authorities have directly intervened to reduce, mitigate, or control risks. As Handler (1979:1) pointed out, it "has long been a function of government to shield the citizenry from those dangers against which it cannot readily protect itself; hence police and fire departments, armies and navies."

Many of earliest efforts by government authorities relied heavily on magicoreligious practices. In 5th-century B.C. China, for example, provincial officials and priests required the annual sacrifice of a maiden to propitiate the Yellow River gods and thereby control the ravages of annual flooding.

> Adorned in ceremonial regalia, the victim was flung into the stream, where she was swiftly dragged beneath the surface by her heavy accouterments. Needless to say, the maiden was invariably selected from a peasant family rather than from the local gentry, and Chinese historians record that as the years passed, farmers who had eligible daughters deserted the district in increasing numbers. Eventually, around 400 B.C., a magistrate named Hsimen Pao stepped forth and put an end to the practice with one final, highly appropriate sacrifice: He had the priests and officials hurled to their deaths in the swirling yellow waters. (Clark, 1982:40)

Paralleling, and sometimes alternating with, these magicoreligious techniques were direct government interventions based on firmer ground. The following section provides several examples of early interventions that presage present-day practices.

Natural Disasters. Virtually all of the great ancient civilizations (China, Maya, Egypt, and Mesopotamia, etc.) directly intervened to mitigate the effects of natural disasters. Historical records indicate, for example, that throughout history governments have played a major role in developing and financing elaborate systems of flood control, including dams, dikes, and canals. One of the first efforts of this kind was recorded by the Roman historian

Pliny the Elder. Pliny noted that the Egyptian authorities had successfully devised an elaborate system for dealing with the risk of famine due to the periodic overflow of the Nile. Pliny reported the system as follows:

> The Nile begins to rise at the next new moon after midsummer, the rise being gradual and moderate while the Sun is passing through the Crab and at its greatest height when it is in the Lion; and when in Virgo it begins to fall by the same degrees as it rose. It subsides entirely within its banks, according to the account given by Herodotus, on the hundredth day, when the sun is in the Scales. . . . Its degrees of increase are detected by means of wells marked with a scale. The province takes careful note of both extremes; in a rise of 18 ft. it senses famine, and even at one of $19^1/_2$ ft. it begins to feel hungry, but 21 ft. brings cheerfulness, $22^1/_2$ ft. complete confidence, and 24 ft. delight. The largest rise up to date was one of 27 ft. in the principate of Claudius [1st century A.D.] and the smallest $7^1/_2$ ft. in the year of the war of Pharsalus [48 B.C.], as if the river were attempting to avert the murder of Pompey by a sort of portent. When the rise was to a standstill, the floodgates are opened and irrigation begins; and each strip of land is sown as the flood relinquishes it.

As protection against a bad year, Pliny noted that Egyptian authorities used data on flooding and crop surpluses to adjust the taxes leveled on crops harvested in the current season.

In addition to attempts to prevent or control disasters, government authorities have also responded by providing relief after disasters occur. In 1803, for example, the U.S. Congress passed legislation to assist victims of a fire in Portsmouth, New Hampshire. In following years, Congress approved on an *ad hoc* basis more than 100 separate acts granting relief after specific disasters had occurred (Kunreuther, 1973). It was not, however, until the 20th century that the first U.S. agency was authorized to make loans to the private sector for rehabilitation, repair of damage, and alleviation of hardship caused by natural disasters.

Epidemic Disease. Throughout history, government authorities have attempted to mitigate the effects of epidemic disease. The magnitude of the problem was in many cases staggering. The 1348–1349 epidemic of the Black Death (bubonic plague), for example, killed over a quarter of the population of Europe—approximately 25 million people (Helleiner, 1967; Nohl, 1960; Ziegler, 1969). Given the lack of knowledge about the causes of diseases such as plague and typhus, government authorities often adopted one of the oldest and most direct strategies of disease control—quarantine and isolation. Fear of leprosy, for example, has throughout history caused wide-scale adoption of the practice of isolating the infected and the cleansing or burning of their garments. Fear of infection also prompted healthy communities to adopt strict measures preventing the entry of goods and persons from infected communities. In the 7th century A.D., for example, armed guards were stationed between plague-stricken Provence and the diocese of Cahors. One thousand years later, in 1720, when Marseilles was suffering a severe epidemic of the plague, a ring of sentries was placed around the city to prevent any person from escaping (Winslow, 1923; Zinssler, 1935).

In addition to quarantines and public health efforts (discussed below), the development of vaccines in the 18th and 19th centuries had a major impact on the problem. Although governments played only a minor role in these developments, it is interesting to note that the first federal regulatory health statute in the United States was the Federal Vaccine Act of 1813 (Hutt, 1984:85). The act gave the president the power to appoint a federal vaccine agent to test the safety of the newly discovered smallpox vaccine. The law was repealed, however, in 1822 on the ground of "states rights."

Pollution. Pollution of the air, water, and land has long been recognized as a problem, but efforts at pollution control have been highly sporadic. Air pollution (due to dust and

smoke from wood and coal fires) has been a ubiquitous problem in congested urban areas since ancient times (Hughs, 1975:84). The first act of government intervention did not occur until 1285, however, when King Edward I of England responded to a petition from members of the nobility and others concerning the offensive coal smoke in London; smoke arising from the burning of soft coal had long been a problem in London (White, 1967; Te Brake, 1975). Edward's response to the petition was one that is now commonly practiced by government risk managers—he established a commission in 1285 to study the problem. In response to the commission's report, several private sector actions were taken, including a voluntary decision by a group of London smiths in 1298 not to "work at night on account of the unhealthiness of coal and damage to their neighbors" (Te Brake, 1975:339). These voluntary efforts were not sufficient, however, and in 1307 Edward issued a royal proclamation prohibiting the use of soft coal in kilns. Shortly after this, Edward was forced to establish a second commission, the main function of which was to determine why the royal proclamation was not being observed.

The history of water and land pollution control has been equally sporadic. Over three thousand years ago, the governments of Minoa and Crete built community sewage drainage systems, and at least some citizens enjoyed the benefits of flush toilets and indoor plumbing (Hanlon, 1969; Rosen, 1958). Athens and other Greek cities also built sewage disposal systems and enacted laws requiring that waste matter be carried outside the walls for a certain distance before it was dumped. Fines were frequently levied and pollution of the city water supply could merit the death penalty (Hughs, 1975:84). The ancient Romans, however, are credited with developing the most extensive system, consisting of paved streets, gutters, and a complex of tunnels and aqueducts (Ziegler, 1969; Gray, 1940). Roman authorities also enacted strict laws to control foul smells and the disposal of waste products (Hanlon, 1969). After the fall of the Roman Empire, many of these laws were unfortunately forgotten and the structures fell into disrepair. A resurgence of interest did not appear again until the 14th and 15th centuries when, in response to the spread of contagious diseases, public officials in Europe created a rudimentary system of pollution and sanitary control. The system included the development of pure water supplies, garbage and sewage disposal, observation stations, hospitals, disinfection procedures, and food inspection. The extent and effectiveness of these efforts should not, however, be overestimated. As several authors have noted (e.g., Bettman, 1974), prior to the 19th and 20th centuries,

> . . . filth, squalor, and disease of community life were apparently accepted as a usual and normal state of affairs. The crude attempts to alleviate the conditions of those days were almost always local efforts. The situation was aggrevated by the Industrial Revolution, when hordes of men, women, and children flocked to the cities seeking employment in the new factories. The cities, utterly unprepared to meet the influx, had no means of housing the newcomers except in areas where living conditions were already wretched. To make matters worse, flimsy tenements were improvised without proper provision for ventilation, light, water, and waste disposal. Streets were dark, narrow, and barely passable owing to filth, stagnant pools, and the stench arising from them. Inevitably, the drinking water became contaminated, and as a result typhoid, dysentery, and cholera took a large toll of lives. (Dublin et al., 1949:141–142)

In dealing with these problems, public health efforts were seldom effective. Despite the passage of laws by many localities, such as the 17th-century ordinance enacted by colonial New Amsterdam prohibiting "the throwing of rubbish and filth into the streets and canals" (Ford, 1936), and a law passed in 1671 requiring that each peasant coming into Berlin had to leave with a load of filth (Gray, 1940), little actual change took place until the 19th century. One factor contributing to the changes that occurred in the 19th century were a number of government-sponsored reports documenting the abominable conditions in Euro-

pean and American cities. In England, Edwin Chadwick published his classic work *Report on an Inquiry into the Sanitary Conditions of the Laboring Population of Great Britain in 1842*. This report, which was commissioned by the British Parliament four years earlier, played a major role in the creation of the General Board of Health for England in 1848. Similarly, in the United States, Lemuel Shattuck's publication of his *Report of the Sanitary Commission of Massachussetts* (1850) led to the establishment of the state's Board of Health in 1869. The act creating the board directed it to "make sanitary investigations and inquiries in respect to the people, the causes of disease, and especially of epidemics, and the source of mortality and the effects of localities, employments, conditions, and circumstances on the public health; and they shall gather information in respect to those matters as they may deem proper, for diffusion among the people" (Hanlon, 1969:26). Over the next few decades, several localities in the United States and Europe created similar bodies, leading to major improvements in street paving, refuse collection, water purification, water distribution, and sewage disposal. Several important laws were also passed, including the English Nuisance Removal Act of 1855, which attempted to regulate gross pollution of the Thames River. Unfortunately these laws were seldom heeded (e.g., see Kidd, 1983), and effective pollution controls occurred only after major outbreaks of infectious diseases.

Food Contamination and Adulteration. As the basic sustenance of life, virtually all societies have been concerned about the safety of the food supply. The biblical abominations of Leviticus, particularly the prohibition against the eating of pork, are often cited as an early attempt at controlling food safety. Douglas (1966) has argued, however, that it would be a mistake to view all such attempts as simple forerunners of modern food and drug regulations. She observes that food prohibitions often serve a variety of purposes, including the affirmation of ethical norms, a means of distinguishing one group from another, and a symbolic mechanism for bringing order into a chaotic world by classification and category (see also Douglas and Wildavsky, 1982). In her discussion of Leviticus, she asks: "Why should the camel, the hare, and the rock badger be unclean? Why should some locusts, but not all, be unclean? Why should the frog be clean and the mouse and hippopotamus unclean? What have chameleons, snakes, and crocodiles got in common?" (1966:54).

In response, Douglas suggests that the abominations of Leviticus can be seen as a mix of (1) pragmatic classificatory rules and (2) the threefold classification of Genesis which divided creation into the earth, sea, and sky. "Clean" animals fully conform to the archetypes of their class: cloven-hoofed ruminants; four-legged animals of the earth that hop, jump, or walk; scaly fish of the sea that swim with fins; and two-legged fowls that fly with wings. Species that are "unclean" are those that are imperfect members of their class or whose class itself violates the biblical system.

Aside from the biblical prohibitions, it appears that the first important law to be enacted regulating food was the English Assize of Bread (1263), which made it unlawful to sell any food "unwholesome for man's body." Interestingly, Hutt (1984) has argued that this statute is practically indistinguishable from the current U.S. standard prohibiting additives which "may render food injurious to health." For nearly six hundred years, the Assize of Bread and later statutes covering other food products stayed in force, until many were repealed in the early 1800s at the height of the Industrial Revolution and a *laissez faire* philosophy of government. By the late 19th century, however, the medieval laws were resuscitated, culminating in federal legislation such as the U.S. Biologies Act of 1902, the Federal Pure Food and Drug Act of 1906, and the Federal Meat Inspection Act of 1906. (The earliest food adulteration act enacted by a state had been passed more than a century earlier in 1785 by Massachusetts.)

Building and Fire Codes. In what is perhaps the first recorded attempt to manage risks through government regulation, the Code of Hammurabi (circa 1950 B.C.) decreed that should a house collapse and kill the occupants, the builder of the house must forfeit his own life (Johns, 1904; Webster, 1947:139). Although not quite as strict, the Romans also enacted laws regulating the quality of building construction (Hanlon, 1969). Aside from construction risks, historically virtually all societies have been concerned with the risks of fire. Despite this concern, however, it appears that a concerted effort by government to deal with the problem did not occur until the 17th century. In 1626, for example, the Plymouth colony enacted a law directing that new houses not be thatched, but roofed with board or other materials (Beyer, 1968:448). In 1648, New Amsterdam prohibited the construction of wooden or plaster chimneys on new homes, and required that chimneys on existing homes be inspected regularly. An even stricter abridgement of individual freedom occurred in 1740 when the city of Charleston required that "all buildings should be of brick or stone, that all "tall" wooden houses must be pulled down by 1745, and that the use of wood . . . be confined to window frames, shutters, and to interior work" (Wertenbaker, 1942:276). The event of perhaps the greatest significance in stimulating government authorities to action was the Great London Fire of 1666, which destroyed over three-quarters of the city's buildings. Largely as a result of this disastrous fire, nearly all large cities in Europe and America established municipal fire-extinguishing companies during the next hundred years.

Transportation Accidents. Regulation of the transportation system in the interests of safety substantially predates modern mechanized transportation technologies. Traffic safety regulations, for instance, date back at least to ancient Rome. According to Hughs (1975:120) a municipal law under Julius Caesar prohibited all wheeled vehicles to operate in Rome between sunrise and two hours before sunset, except for essential public service traffic. This regulation was largely for the benefit of pedestrians, for whom the combination of narrow streets and heavy traffic created a genuine hazard.

The highly regulated character of the modern transportation system was foreshadowed by responses to earlier technological developments. Indeed, the first regulation of a technological risk in the United States occurred in 1838, when Congress passed legislation governing boiler testing, inspection, and liability (Burke, 1965; Chapter 3, this volume). This legislation was enacted in response to a series of boiler explosions on steamboats that led to thousands of injuries and fatalities during the early 19th century. The initial legislation was too lax to foster effective risk reduction, but was replaced by stricter legislation in 1858. This law specified engineering safety criteria, gave inspectors authority to examine boats and refuse licenses, and created a regulatory agency, the Board of Directors of Inspectors.

The steamboat remained the dominant form of transportation technology in the United States until the latter part of the century, when it was replaced by the railroad. Both in the United States and Europe, disputes nominally over the risks of railroads clearly reflected broader social values. The major concerns in Britain regarding this new transportation technology were described by Cohen (1983) as "horror at attaining speeds over 40 kilometers an hour, concern about the capacity of new kinds of organizations to run large operations safely, fears of social consequences of change, worries about the desecration of the Sabbath, and even concern at the ease with which dangerous radicals might travel about the country" (1983:18). At the turn of the 20th century, disputes about the automobile also reflected social concerns broader than those associated with risk (Chapter 3, this volume). For both the railroads and automobiles (and later airplanes), the substantial intrinsic risks associated with these transportation modes led quickly to the development of a regulatory scheme that, while much stricter today than in its earliest versions, is not essentially different in concept.

Occupational Injuries. Prior to the 18th and 19th centuries, occupational health and safety issues were apparently of only minor concern to government authorities. Although working conditions in most industries were generally abominable (e.g., see Agricola, 1556; Engels, 1845), it was not until the Industrial Revolution that government officials took note. Most of the first efforts by government authorities were focused on the conditions of child labor (British Parliamentary Papers, 1816–1817). As Samuelson has noted,

> No Dickens novel did full justice to the dismal conditions of child labor, length of working day, and conditions of safety and sanitation in the early nineteenth century factories. A workweek of 84 hours was the prevailing rule, with time out at the bench for breakfast and sometimes supper, as well as lunch. A good deal of work could be got out of a six year old child, and if a man lost two fingers in a machine, he still has eight left. (Samuelson, 1970:107)

In 1842, a British parliamentary commission estimated that about one-third of the mine workers in Britain were less than 13 years old. The commission's report noted that many of these children were employed as "trappers," who manned the air doors that separated the various sections of the mines. Their life consisted of sitting "in the pit the whole time it is worked, frequently above 12 hours a day. They sit, moreover, in the dark, often with a damp floor to stand on, and exposed necessarily to drafts . . . " (British Parliamentary Papers, 1842).

Most efforts at reform were initially strongly resisted by mine and factory owners, although there were a few notable exceptions. The 19th-century British millowner, Robert Owen, for example, played an important role in bringing about change through the way he operated his mills and through his writings about the responsibility of employers toward their employees (Owen, 1927).

At the same time that improvements in working conditions were being made, significant changes were also taking place in the way societies dealt with work-related accidents and occupational diseases. In the late 19th century, workers' compensation statutes were enacted in Germany under Bismarck. Within 20 years, similiar laws were passed in England and by a number of states in the United States (Weiss, 1935). Under these laws, requirements to demonstrate employers' negligence or fault were waived for most occupational injuries and an employee was entitled to compensation based on a percentage of lost wages.

Private Sector Self-Regulation

Insurance, common law, and government intervention are not, of course, the only societal strategies for managing risks. Voluntary, private self-regulation aimed at preventing or reducing potential adverse health effects has always played an important part in societal risk management efforts. In virtually all societies, there have been strong incentives for the private sector to refrain from actions that would recklessly endanger the health of the public. Such incentives range from moral and altruistic norms and values to simple self-interest based on fear of monetary loss, possible civil or criminal litigation, or punitive or restrictive government action.

Private risk management activities are intrinsically less publicly obvious than other risk management strategies. Two of the more visible forms of this strategy are (1) industrial self-regulation and (2) licensure and certification (Baram, 1982). Both these types of voluntary self-regulation, however, appear to have few clear historical precedents prior to the late 19th and early 20th centuries.

Industrial Self-Regulation. Reliance on privately developed standards is particularly widespread at the local level and in areas such as fire safety and the provision of electrical,

building, boiler, plumbing, and similar services. Baram (1982) points out that such reliance is virtually a necessity given the characteristically limited technical and financial resources available at local governmental levels. He observes that historical experience suggests two essential conditions for the successful use of this type of strategy in risk management. First, the involved risks and technologies must be well understood. Second, the potential liability must be significant enough to force a responsible industrial approach to risk reduction.

Perhaps the most important institutional mechanism for industrial self-regulation are the standard-setting organizations, professional and technical societies, trade societies, and testing laboratories that set consensus-based standards covering a wide variety of products, materials, systems, services, processes, and practices. Such organizations were for the most part founded during the late 19th and early 20th centuries in growing recognition of the hazards attending increased industrialization. Major standard-setting organizations include the American Society of Mechanical Engineers, founded in 1880; the Underwriters Laboratory, founded in 1894; the National Fire Protection Association, founded in 1896; the American Society for Testing and Materials, founded in 1898; and the American National Standards Institute, founded in 1918.

Licensure and Certification. Although over 550 occupations are currently licensed in the United States, licensing and certification appear to have been little used as a form of risk management prior to the turn of the century. Surprisingly, this appears to be true even for such clearly risky and currently heavily regulated areas as medicine. The control of physicians by licensure first began in the 18th century but was abandoned from 1820 to 1850. Our present form of physician licensure did not really begin until the late 1800s (Baram, 1982:67). The system of licensure that evolved, however, has often been criticized as serving economic self-interests (e.g., by excluding competition) as much as protecting public health and safety.

NINE IMPORTANT CHANGES BETWEEN PAST AND PRESENT

It should not be surprising that contemporary ways of thinking about and coping with risks are different in many respects from earlier times. In this century, and especially in the last few decades, major changes have taken place in the nature of the risks that society faces, as well as in the social and political context for risk analysis and risk management efforts. Nine changes between past and present that we consider among the most important for risk analysis and risk management are discussed below.

First, there has been a significant shift in the nature of the risks to which human beings are subject. In the United States, the leading causes of death in 1900 were infectious diseases—pneumonia, influenza, and tuberculosis (National Academy of Sciences, 1979). By 1940, infectious diseases had been displaced by two chronic degenerative diseases of adulthood—heart disease and cancer. Although there has been no substantial change in the rank of accidents as another leading cause of death, there has been a shift in the types of accidents to which human beings are subject. The rate of fatal accidents in British coal mines, for example, fell from 4 per 1000 workers in the mid-19th century to less than 1 per 1000 in recent decades. Similarly, the average annual rate of fatal accidents in British factories fell from 17.5 deaths per 100,000 employees 70 years ago to a recent rate of less than 4.5 (Rubens, 1972:3). Natural hazards still cause substantial property damage; but in industrialized nations such events account for only a small number of annual fatalities. While

these types of accidents have been declining in significance, other types have increased. In 1900, the number of automobile accidents in the United States was insignificant; however, in 1980, automobile accidents accounted for over 50,000 deaths (Claybrook, 1983:21).

Second, there has been a significant increase in average life expectancies. A female born in the United States in 1900 could expect to live, on the average, 51 years; a male born in the same year could expect to live 48 years (National Academy of Sciences, 1979). But a female born in 1975 could expect to live for 75 years, and a male born in the same year could expect to live to 66. Looking further back in history, the average life expectancy was about 33 years in the Middle Ages, 20 to 30 years during the Roman Empire (Durand, 1960:366–373), and 18 years in prehistoric times (Spiegelman, 1950:8–9; Durand, 1960:366–373; Atkisson, Petak, and Fuller, 1981). The factors leading to these increases are complex and not entirely understood, but certainly include substantial improvements in nutrition, hygiene, sanitation, working conditions, education, standards of living, and medical services.

Third, there has been an increase in new risks fundamentally different in both character and magnitude from those encountered in the past. These include nuclear war, nuclear power plant accidents, radioactive waste, exposure to synthetic pesticides and chemicals, supertanker oil spills, chemical plant and storage accidents, recombinant DNA laboratory accidents, ozone depletion due to emissions of fluorocarbons, and acid rain. The magnitude of many of these risks cannot easily be estimated because historical or actuarial data do not exist or are extremely difficult to collect. Moreover, cause–effect relationships are often highly problematic for these risks. Of perhaps greatest importance, many of these new risks are latent, long-term, involuntary, and irreversible. At least some are conceivably globally catastrophic, and most are derived from science and technology (in contrast to risks from "acts of nature or God").

Fourth, there has been a significant increase in the ability of scientists to identify and measure risks. These improvements include major advances in laboratory tests (e.g., animal bioassays and *in vitro* tests), epidemiological methods, environmental modeling, computer simulations, and engineering risk assessment (e.g., fault trees and event trees). Because of these advances, scientists are now routinely able to detect (1) design faults in extremely complex engineering systems, (2) even weak causal links between hazards and deleterious outcomes, and (3) infinitesimally small amounts (e.g., parts per trillion) of potentially harmful carcinogenic or mutagenic substances.

Fifth, there has been a significant increase in the number of scientists and analysts whose work is specifically focused on health, safety, and environmental risks. In recent years risk analysis has emerged as an identifiable discipline and profession, with its own societies, annual meetings, journals, and practitioners. In the last decade alone, the risk analysis literature has grown from a handful of articles and books to a formidable collection of material (e.g, see Covello and Abernathy, 1984).

Sixth, there has been an increase in the number of formal quantitative risk analyses that are produced and used. In the past, risk management decisions were based primarily on common sense, ordinary knowledge, trial and error, or nonscientific knowledge and beliefs. In recent years risk management decisions have been increasingly based on highly technical, quantitative risk analyses. Increased reliance on such analyses reflect a related trend—a growing societal preference for planning, forecasting, and early warning in contrast to *ad hoc* responses to crisis.

Seventh, there has been an increase in the role of the federal government in assessing and managing risks. There have been dramatic increases in (1) the number of health, safety, and environmental laws, with over 30 major pieces of federal legislation passed within the

last two decades; (2) the number of federal agencies charged with managing health, safety, and environmental risks, including the Environmental Protection Agency, the Occupational Safety and Health Administration, the Consumer Product Safety Commission, the National Highway Traffic Safety Administration, and the Nuclear Regulatory Commission; and (3) the number of health, safety, and environmental cases adjudicated by the courts both in the tort-liability system and in judicial review of agency decisions (National Academy of Sciences, 1982; Chapter 16, this volume; Covello and Menkes, 1982). Although attempts have recently been made to reverse the trend toward growth in federal regulatory involvement, several factors have contributed to its continuation, including the increasing health, safety, and environmental consciousness of the nation; a decline in the level of public confidence in business; the emergence of the public interest movement; and the growth of a complex, interdependent, highly technological society (National Academy of Sciences, 1982:25). Additional factors leading toward continued federal regulatory involvement include the accelerating rate of technological change, which is resulting in enormous increases in the physical and temporal scale and complexity of risks (for example, approximately 70,000 chemicals are in current use, with perhaps 1000 new chemicals being introduced each year; National Academy of Sciences, 1979:442); an increase in the speed of scientific and technological developments, so that there are shorter and shorter time lags between scientific experimentation, technological development, and entrepreneurial production; the increasing role of government as a producer of risks through its sponsorship of scientific and technological research and development; and the rising cost of technological risk control and damages—estimated by one research group (Hohenemser, Kasperson, and Kates, 1982:116) to be $179–283 billion a year.

Eighth, there has been an increase in the participation of special interest groups in the societal risk management process. Risk analysis and risk management activities have become increasingly politicized, with virtually every major health, safety, and environmental decision subject to intense lobbying by interest groups representing industry, workers, environmentalists, scientific organizations, and other groups (Chapter 3, this volume). Not only has there been a substantial increase in the number of such groups and their members, but also substantial growth in their scientific sophistication and modes of operation. These changes have contributed to at least two others. First, it has become increasingly necessary for government decision makers to consult representatives from these groups and to make risk analysis information publically available. Second, the adversarial nature of most contemporary risk debates appears to be causing increasing confusion among the public (due in part to the inscrutability for the layperson of competing technical risk analyses and the widely publicized and often heated debates between scientists).

Ninth, there has been an increase in public interest, concern, and demands for protection. Despite increases in average life expectancies, reductions in the frequency of catastrophic events, and assurances that "the health of the American people has never been better" (U.S. Surgeon General, 1979), surveys indicate that most Americans believe that life is getting riskier. A recent Louis Harris (1980:9) poll found that approximately four-fifths of those surveyed agreed that "people are subject to more risk today than they were 20 years ago"; only 6% thought there was less risk (although it should be noted that the definition of *risk* implied in the survey questions may have been considerably broader than the meaning used in this paper). Research has suggested that the primary correlates of public concern are not mortality or morbidity rates, but characteristics such as potentially catastrophic effects, lack of familiarity and understanding, involuntariness, scientific uncertainty, lack of personal control by the individuals exposed, risks to future generations, unclear benefits, inequitable distribution of risks and benefits, and potentially irreversible effects

(Slovic, Fischhoff, and Lichtenstein, 1980; Covello, 1984). Many of the most salient contemporary risks—nuclear power plant accidents, nuclear waste, airplane crashes, exposure to toxic chemicals, ozone depletion, exposure to low-level radiation, recombinant DNA, acid rain—possess precisely these characteristics. Additional factors contributing to heightened public concern include a better-informed public, the seemingly weekly scientific discovery of previously unknown risks, advances in communication technologies leading to widespread and intensified media coverage of risk problems, rising levels of affluence accompanied by expectations of decreasing risks, rising expectations about the ability of science and technology to control risks, and loss of confidence in the major risk management institutions in contemporary industrialized societies—particularly, business and government (National Academy of Sciences, 1982:11–13).

IMPLICATIONS FOR THE FUTURE

Making projections about the future is always a risky enterprise, especially in an area as complex as risk analysis and risk management. Nonetheless, a historical perspective suggests certain trends that can reasonably be expected to be important in the foreseeable future.

We expect that public concern about risk will continue to increase, and we expect this to occur in spite of the simultaneous trend toward longer, healthier lives. Part of this is due to the changing nature of the risks faced by modern society, including increases in the number of "mysterious" technological hazards offering prospects of dread, ill-understood, or potentially catastrophic consequences. But the more profound change may be the increasing prevalence of the idea that injuries, death, and diseases are not acts of God to be fatalistically accepted, but avoidable events subject to some degree of human control. This change in perspective implies that something *can* be done about most risks. Paralleling this is a change in perspective implying that something *should* be done—derived in part from changing ideas about the rights of individuals to live their lives free of risks imposed on them by others and about the role of government in protecting individuals from such risks.

Improved scientific, technical, and engineering capabilities should lead to steady improvements in our ability to control, reduce, or eliminate risks. The same set of capabilities are also expected to lead, however, to steady increases in the number of identified risks. In the near term we suspect that improved risk management capabilities will be outstripped by improved risk identification capabilities. Although improved risk management will be welcome, improved abilities to identify and measure risks will not necessarily lead to feelings of greater understanding or control. Indeed, we expect just the opposite. Already, improved science has raised more questions than it has settled about the possible risks of both new and familiar objects, substances, and activities (e.g., Ames, 1983; Epstein and Swartz, 1984). This phenomenon might be dubbed the "Hydra effect"—for every risk problem that is resolved, two new ones are raised in its place (Baram, personal communication). It is quite likely that the probabilistic and uncertain world created by modern science and technology will seem to many an increasingly risky and uncomfortable place, even in the face of overall improved prospects for a longer, healthier life.

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REFERENCES

Agricola, G. [1556], *De re metallica,* 1st ed. (Reprint, trans. by H. C. Hoover and L. C. Hoover). New York: Dover Publications, 1950.

Ames, B., "Dietary Carcinogens and Anticarcinogens," *Science,* Vol. 21, 23 September 1983, pp. 1256–1263.

Atkisson, A., W. Petak, and J. Fuller, *An Examination of Premature Death as a Target of U. S. Occupational Health Policies*. Report No. 81–82/54. Los Angeles: Public Policy Institute, University of Southern California, 1981.

Ayrton-Paris, J.A., *Pharmaecologia,* 1822.

Baram, M., "Technology Assessment and Social Control," *Science,* Vol. 180, 4 May 1973, pp. 465–473.

Baram, M., *Alternatives to Regulation: Managing Risks to Health, Safety and the Environment*. Lexington, Mass.: Lexington Books, 1982.

Ben-David, J. and T. Sullivan, "Sociology of Science," pp. 203–222 in A. Inkeles, J. Coleman, and N. Smelser (eds.), *Annual Review of Sociology*. Palo Alto: Annual Reviews, 1975.

Bettman, O., *The Good Old Days—They Were Terrible*. New York: Random House, 1974.

Beyer, G., *Housing and Society*. New York: The MacMillan Company, 1968.

Bottomore, T. and M. Rubel (eds.), *Karl Marx: Selected Writings*. New York: McGraw-Hill, 1956.

British Parliamentary Papers [1816–17], *Report of the Minutes of Evidence on the State of Children Employed in the Manufactories of the United Kingdom, together with a Report of the Employment of Boys in Sweeping Chimneys with Minutes of Evidence and Appendix*. House of Commons (Reprint). Shannon, Ireland: Irish University Press:1968.

British Parliamentary Papers [1842], *First Report of the Commissioners-Mines. Children's Employment Commission* (Reprint). Shannon, Ireland: Irish University Press, 1968.

Burke, T.G., "Bursting Boilers and the Federal Power," *Technology Culture,* Vol. 7, 1965, pp. 1–23.

Campbell, I., *Accident Statistics and Significance*. Occasional Paper 34. Safety Accident Compensation Commission, Wellington, New Zealand, 1980.

Chadwick, E. [1842], *Report on the Sanitary Condition of the Labouring Population of Gt. Britain* (Ed. with intro by M. W. Flinn). Edinburgh: Edinburgh University Press, 1965.

Clark, W., *Flood*. Alexandria, Va.: Time-Life Books, 1982.

Clark, W. C., "Witches, Floods, and Wonder Drugs: Historical Perspectives on Risk Management," pp. 287–313 in R. Schwing and W. Albers (eds.), *Societal Risk Assessment*. New York: Plenum, 1980.

Claybrook, J., "Motor Vehicle Occupant Restraint Policy," pp. 21–47 in V. Covello, W. G. Flamm, J. Rodricks, and R. Tardiff (eds.), *The Analysis of Actual versus Perceived Risks*. New York: Plenum, 1983.

Cohen, A., "Overview and Definition of Risk." Research Paper. London: United Kingdom Health and Safety Executive, 1983.

Covello, V., "Social and Behavioral Research on Risk: Uses in Risk Management Decisionmaking," *Environmental International,* Vol. 4, Dec. 1984.

Covello, V. and M. Abernathy, "Risk Analysis and Technological Hazards: A Policy–Related Bibliography," pp. 283–363 in P. Ricci, L. Sagan, and C. Whipple (eds.), *Technological Risk Assessment*. Boston: Martinus Nijhoff Publishers, 1984.

Covello, V. and J. Menkes, "Issues in Risk Analysis," pp. 287–301 in C. Hohenemser and J. Kasperson (eds.), *Risk in the Technological Society*. Boulder: Westview Press, 1982.

David, F. N., *Games, Gods, and Gambling*. London: Griffin and Co., 1962.

Douglas, M., *Purity and Danger*. London: Routledge & Kegan Paul, 1966.

Douglas, M. and A. Wildavsky, *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*. Berkeley and Los Angeles: University of California Press, 1982.

Dublin, L. A., A. J. Lotka, and M. Spiegelman, *Length of Life: A Study of the Life Table*. New York: The Ronald Press Company, 1949.

Dubreuilh, W., "Des Hyperkeratoses Circonscrites," *Ann. Dermatol. Syphilig.*, 3rd Series, 1896, pp. 1158–1204.
Durand, J., "Mortality Estimates from Roman Tombstone Inscriptions," *American Journal of Sociology*, January 1960.
Engels, F. [1845], *The Condition of the Working Class in England.* (Oxford: Blackwell) (Trans. and ed. by W. O. Henderson and W. H. Chaloner) New York: Macmillan Co., 1958.
Epstein, S. and J. Swartz, "Letter to Science on Cancer and Diet," *Science*, Vol. 224, 18 May 1984, pp. 660–666.
Evelyn, J. [1661], "Fumifugium or the Inconvenience of the Aer and Smoake of London Dissipated." Reprinted in *The Smoke of London.* Fairview Park, Elmsford, N.Y.: Maxwell Reprint Co., 1969.
Ford, J., *Slums and Housing. Vol. 1,* Cambridge, Mass.: Harvard University Press, 1936.
Gilfillan, S., "Roman Culture and Dysgenic Lead Poisoning," *Mankind Quarterly*, Vol. 5, January–March, 1965, pp. 3–20.
Graunt, J., *Natural and Political Observations Made upon the Bills of Mortality.* 1662.
Gray, H. F., "Sewage in Ancient and Medieval Times," *Sewage Works Journal*, Vol. 12, 1940, pp. 939–946.
Grier, B., "One Thousand Years of Mathematical Psychology," Paper presented at the Society for Mathematical Psychology Convention, Madison, Wis., 1980.
Grier, B., "The Early History of the Theory and Management of Risk," Paper presented at the Judgment and Decision Making Group Meeting, Philadelphia, Pa., 1981.
Hacking, I., *The Emergence of Probability.* Cambridge: Cambridge University Press, 1975.
Halley, E., "An Estimate of the Degrees of Mortality of Mankind, Drawn from Curious Tables of the Births and Funerals at the City of Breslau, with an Attempt to Ascertain the Price of Annuities upon Lives," *Philosophical Transactions of the Royal Society of London*, Vol. 17, 1693, pp. 596–610.
Hammer, W., *Product Safety Management and Engineering.* Englewood Cliffs, N.J.: Prentice-Hall, 1980.
Handler, P., "Some Comments on Risk" in National Research Council, *The National Research Council in 1979: Current Issues and Studies.* Washington, D.C.: National Academy of Sciences, 1979.
Hanlon, J., *Principles of Public Health Administration.* St. Louis: C.V. Mosby Company, 1969.
Harris, Louis and Associates, *Risk in a Complex Society.* Public opinion survey conducted for Marsh & McLennan, Inc. New York: Marsh & McLennan, 1980.
Helleiner, K., "The Population of Europe from the Black Death to the Eve of the Vital Revolution," in E. E. Rich and C. H. Wilson (eds.), *The Cambridge Economic History of Europe, Vol. 4, The Economy of Expanding Europe in the Sixteenth and Seventeenth Centuries.* Cambridge: Cambridge University Press, 1967.
Hill, J., *Cautions against the Immoderate Use of Snuff.* London: Baldwin and Jackson, 1781.
Hohenemser, C., R. Kasperson, and R. Kates, "Casual Structure: A Framework for Policy Formulation," pp. 109–139 in C. Hohenemser and J. Kasperson (eds.), *Risk in the Technological Society.* Boulder: Westview Press, 1982.
Hughs, J., *Ecology in Ancient Civilizations.* Albuquerque: University of New Mexico Press, 1975.
Hutchinson, J., "Arsenic Cancer," *British Medical J.*, Vol. 2, 1887, p. 1280.
Hutt, P., "Legal Considerations in Risk Assessment under Federal Regulatory Statutes," pp. 84–95 in J. Rodricks and R. Tardiff (eds.), *Assessment and Management of Chemical Risks.* Washington, D.C.: American Chemical Society, 1984.
Hutt, P. B., "The Basis and Purpose of Government Regulation of Adulteration and Misbranding of Food," *Food and Drug Cosmetic Law Journal*, Vol. 33, No. 10, 1978.
Johns, C. H., *Babylonian and Assyrian Laws Contracts and Letters.* New York: Charles Scribner's Sons, 1904.
Kidd, D., "The History and Definition of Water Pollution," *Bulletin of Science, Technology, and Society*, Vol. 3, 1983, pp. 121–126.
Kunreuther, H., *Recovery from Natural Disasters: Insurance or Federal Aid?* Washington, D.C.: American Enterprise Institute, 1973.
LaPlace, P., *Théorie Analytique de Probabilitiés.* Paris, 1812.
Lightman, A., "Weighing the Odds," *Science '83*, Vol. 4, No. 10, December 1983, pp. 21–22.
MacMahon, B. and P. Cole, "Endocrinology and Epidemiology of Breast Cancer," *Cancer*, Vol. 24, 1969, pp. 1146–1151.
MacPherson v. Buick Motor Co., 217 New York 382, 111 N.E. 1050, 1916.
Merton, R. K., *Science, Technology, and Society in Seventeenth Century England.* Bruges, Belgium: Saint Catherine Press, 1938.
National Academy of Sciences, *Science and Technology: A Five Year Outlook.* San Francisco: W. H. Freeman, 1979.
National Academy of Sciences, *Risk and Decision Making: Perspectives and Research.* Washington, D.C.: National Academy Press, 1982.
Needham, J., *Science and Civilization in China.* Cambridge: Cambridge University Press, 1956.
Nohl, J., *The Black Death.* New York: Ballantine Books, 1960.

Nriagu, J., *Lead and Lead Poisoning*. New York: Wiley Interscience, 1983.
Oppenheim. L., *Ancient Mesopotamia*, Chicago: University of Chicago Press, 1977.
Ore, O., "Pascal and the Invention of Probability Theory," *American Mathematical Monthly*, Vol. 67, 1960, pp. 409–419.
Owen, R., *A New View of Society and Other Writings* (J.M. Dent and Sons). London/Toronto: E.P. Dutton and Co., New York, 1927.
Pfeffer, I. and D. Klock, *Perspectives on Insurance*. Englewood Cliffs, N.J.: Prentice-Hall, 1974.
Pott, P. [1775], *Cancer Scroti: The Chirurgical Works of Percival Pott*. London: Clark and Collins, 1975.
Ramazzini, B. [1700], *De Morbia artificium*. Chapter XX. Capponi, Italy. Ueber biasentumoren bei Fuchsinarbeitern. *Arch. Clin. Chur.*, Vol. 50, p. 588. Also see Ramazzini, B., *Diseases of Workers*. 1713 ed. (Transl. by Wilner Wright) Birmingham, Alabama: Classics of Medicine Library, 1940.
Rehn, L., "Blasengeschwulste bei Fuchsin-Arbeitern," *Arch. Klin. Chir.*, Vol. 50, 1895, pp. 588–800.
Rosen, G., "The Medical Aspects of the Controversy over Factory Conditions in New England, 1840–1850," *Bulletin of the History of Medicine, Vol. XV*, 1944, pp. 483–497.
Rosen, G., *A History of Public Health*. New York: M.D. Publications, 1958.
Rubens, L., *Safety and Health at Work*. Report of the Committee. London: HMSO, 1972.
Samuelson, P.A., *Economics*, 8th ed. New York: McGraw-Hill Book Company, 1970.
Shattuck, L., *Report of the Sanitary Commission of Massachusetts*. Boston: Sanitary Commission of Massachusetts, 1850.
Sherman, B.M. and S.G. Korenman, "Inadequate Corpus Luteum Function: A Pathophysiological Interpretation of Human Breast Cancer Epidemiology," *Cancer*, Vol. 33, 1974, pp. 1306–1312.
Sheynin, O., "On the Prehistory of the Theory of Probability," *Archive for the History of Exact Science*, Vol. 12, 1974, pp. 97–141.
Shimkins, M., *Contrary to Nature*, NIT 79-720. Washington, D.C.: Department of Health and Human Services, 1979.
Shimkin, M., *Some Classics of Experimental Oncology, 1775–1965*, NIH 80-2150. Washington, D.C.: U.S. Department of Health and Human Services, October 1980.
Slovic, P., B. Fischhoff, and S. Lichtenstein, "Facts and Fears: Understanding Perceived Risk," pp. 181–216 in R. Schwing and W. Albers, Jr. (eds.), *Societal Risk Assessment: How Safe is Safe Enough?* New York: Plenum Press, 1980.
Spiegelman, M., *Health Progress in the United States: A Survey of Recent Trends in Longevity*. New York: American Enterprise Association, Inc., 1950.
Te Brake, W., "Air Pollution and Fuel Crisis in Pre-Industrial London, 1250–1650," *Technology and Culture*, Vol. 16, July 1975, pp. 337–359.
Thomas, K., *Religion and the Decline of Magic*. London: Weidenfeld and Nicolson, 1971.
Todhunter, I. [1865], *A History of the Mathematical Theory of Probability from the Time of Pascal to That of LaPlace*. Reprinted by G. E. Stechert and Co., New York, 1931.
Turner, V., *Ndembu Divination*. Manchester: University of Manchester Press, 1961.
Unna, P.G., *Die Histopathologie der Hautkrankheiten*. Berlin: A. Hirschwald, 1894.
U.S. Surgeon General, *Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention*. DHEW Publication No. 79-55071. Washington, D.C.: U.S. Government Printing Office, 1979.
Webster, H., *History of Civilization, Ancient and Medieval*. Boston: D.C. Heath and Company, 1947.
Weiss, H., "Employers' Liability and Workmen's Compensation," in J. Commons (ed.), *History of Labor in the United States 1896–1932*. New York: Macmillan, 1935.
Wertenbaker, T.J., *The Old South: The Founding of American Civilization*. New York: Charles Scribner's Sons, 1942.
White, A. [1895], *A History of the Warfare of Science with Theology in Christendom*. New York: George Brazillier, 1955.
White, L., "The Historical Roots of Our Ecological Crisis," *Science*, Vol. 155, 10 March 1967, pp. 1203–1207.
Winslow, C., *The Evolution and Significance of the Modern Public Health Campaign*. New Haven: Yale University Press, 1923.
Ziegler, Philip, *The Black Death*. Middlesex, England: Penguin Books, 1969.
Zinssler, H., *Rats, Lice, and History*, New York: Atlantic Monthly Press, 1935.

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