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Approaches to Acceptable Risk: A Critical Guide

Baruch Fischhoff
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Paul Slovic
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Stephen Derby

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APPROACHES TO ACCEPTABLE RISK: A CRITICAL GUIDE

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Abstract

Acceptable-risk decisions are an essential step in the management of technological hazards. In many situations, they constitute the weak (or missing) link in the management process. The absence of an adequate decision-making methodology often produces indecision, inconsistency, and dissatisfaction. The result is neither good for hazard management nor good for society.

This report offers a critical analysis of the viability of various approaches as guides to acceptable-risk decisions. It does so by:

(1) Defining acceptable-risk decisions and examining some frequently proposed, but inappropriate, solutions.

(2) Characterizing the essential features of acceptable-risk problems that make their resolution so difficult. These are: uncertainty about how specific decision problems are to be defined, difficulties in ascertaining crucial facts, the problematic nature of the value issues that arise, the vagaries of human behavior that render responses to hazards unpredictable, and inability to assess the adequacy of decision-making processes and the degree to which their conclusions are to be trusted.

(3) Creating a taxonomy of decision-making methods, identified by how they attempt to address the features of acceptable-risk problems listed below. The major categories discussed here are:

- Professional judgment: allowing technical experts to devise solutions;
- Bootstrapping: searching for historical precedents that embody guides to future decisions; and

• Formal analysis: theory-based procedures for modeling problems and calculating the best decision.

(4) Specifying the objectives that an approach should satisfy in order to guide social policy. These are: comprehensiveness, logical soundness, practicality, openness to evaluation, political acceptability, institutional compatibility, and conduciveness to learning.

(5) Rating the success of the approaches in meeting these objectives. Namely: How well does each approach satisfy each objective? How satisfactory are the approaches relative to one another? How might one choose the most adequate approach for different decision problems?

Conclusions

The following conclusions emerge from our analysis:

(1) Acceptable-risk problems are decision problems, that is, they require a choice between alternatives. That choice depends upon the alternatives, values, and beliefs that are considered. As a result, there is no single all-purpose number that expresses "acceptable risk" for a society.

(2) Values and uncertainties are an integral part of every acceptable-risk problem. As a result, there are no value-free processes for choosing between risky alternatives. The search for an "objective method" is doomed to failure and may blind the searchers to the value-laden assumptions they are making.

(3) None of the approaches considered here offers an unfailing guide to selecting the most acceptable alternative. Each gives special attention to some features of acceptable-risk problems, while ignoring

others. As a result, not only does each approach fail to give a definitive answer, but it is predisposed to representing particular interests and recommending particular solutions. Hence, choice of a method is a political decision with a distinct message about who should rule and what should matter.

(4) Acceptable-risk debates are greatly clarified when the participants are committed to separating issues of fact from issues of value. Yet, however sincere these attempts, a clear-cut separation is often impossible. Beliefs about the facts of the matter shape our values; in turn, those values shape the facts we search for and how we interpret what we find.

(5) The controlling factor in many acceptable-risk decisions is how the problem is defined (i.e., which options and consequences are considered, what kinds of uncertainty are acknowledged, and how key terms are operationalized). As a result, definitional disputes underlie some of the most rancorous political debates.

(6) Values, like beliefs, are acquired through experience and contemplation. Acceptable-risk problems raise many complex, novel, and subtle value issues, for which we may not have well-articulated preferences. In such situations, the values we express may be greatly influenced by transient factors, including subtle aspects of how the question is posed.

(7) Even the most knowledgeable experts may have an incomplete understanding of new and intricate hazards. Indeed, some limits on breadth of perspective may be a concommitant of acquiring a particular disciplinary or world outlook. In such cases, non-experts may possess

important supplementary information or viewpoints on hazards and their consequences.

Recommendations

No one solution to acceptable-risk problems is now available, nor is it likely that a single solution will ever be found. Nonetheless, the following recommendations, addressed to regulators, citizens, legislators, and professionals, should, if implemented, enhance society's ability to make decisions.

(1) Explicitly recognize the complexities of acceptable-risk problems. The value judgments and uncertainties encountered in specific decision problems should be acknowledged. More generally, we should realize that there are no easy solutions and not expect them from society's decision makers.

(2) Acknowledge the limits of currently available methods and expertise. Since we do not know how to get the right answers to these questions, we should concentrate on avoiding the mistakes to which various disciplines and people are attuned. The result would be a multi-method, multi-perspective approach to decision making that emphasized comprehensiveness.

(3) Improve the use of the present approaches. Develop guidelines for their conduct and review. Make their scope and presentation sensitive to all aspects of the problem and to the desires of as many shareholders as possible. Analyses should be repeated in order to incorporate the insights they engender and the critiques they provoke.

(4) Make the decision-making process consistent with existing democratic institutions. The public and its representatives should be constructively involved in the process in order to legitimate its conclusions, facilitate their implementation, and increase the public's understanding of hazard issues.

(5) Strengthen non-governmental social mechanisms that regulate hazards. Decisions reached in the marketplace and political arena provide important guidance to most approaches. Their functioning can be improved by various measures including reform of the product liability system and increased communication of risk information to workers and consumers.

(6) Clarify government involvement. Legislation should offer clear, feasible, predictable mandates for regulatory agencies. The management of different hazards should be coordinated so as to build a legacy of dependable precedents and encourage consistent decisions.

If followed, these recommendations will help create the conditions for society to learn from its day-to-day experience in making acceptable-risk decisions and living with their consequences. A final chapter of this report provides an agenda for scientific research to complement this learning by doing.

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Preface

Although written at the request of the Nuclear Regulatory Commission, the present report is not about nuclear power. Rather, it addresses problems in making decisions about all hazardous technologies. By implication, it has something to say about the usefulness of various approaches for making any societal decisions. Our focus is on the meaning of the question, "How safe is safe enough?" and on the nature of possible ways to provide answers. We have not attempted to develop a general solution to acceptable-risk problems nor answers for any specific cases. Before one can hope to solve a risk problem adequately, one must understand what the problem is and how it might conceivably be solved. Our description of possible approaches focuses on what they do and why they do it, rather than on a detailed explication of specific applications, for which other sources are available. Within this framework, the advantages and disadvantages of these approaches are discussed relative to what is desired and relative to each other. Our recommendations for policy and practice and for fundamental research are designed to improve society's ability to make responsible decisions concerning "How safe is safe enough?".

We have written this report for a broad readership, including technology promoters, public servants (regulators, legislators), professionals who manage risks (e.g., risk analysts, engineers, physicians), academics (and their students), and the growing number of lay people concerned about technological risks. We hope that it will be particularly useful to that important group of acceptable-risk decision makers already embroiled in the technical issues of setting regulatory standards.

The magnitude of this project has gone beyond the resources we originally allotted to it. Its breadth has gone beyond our own disciplinary training, or that of anyone we know. We have been fortunate enough to receive advice and constructive criticism from many talented people. They include:

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Detlof von Winterfeldt (University of Southern California)

John Ward (Sargent & Lundy)

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CHAPTER 1

"How Safe Is Safe Enough?"

Definition of the Acceptable-Risk Problem

As human beings develop from infancy to maturity, they go through alternating periods of acquiring behavioral capabilities and learning how to manage them. They learn first to crawl and later where it is safe to go; they learn to speak and then struggle to have something meaningful to say. In the first stage of these processes, their decision-making costs are minimal; they just do what they can. In the second stage, their investment in managing their own behavior increases greatly; with luck the effort spent on decision making will be recouped by avoiding costly mistakes.

An analogous process can be observed in society's generation and taming of new means of production and destruction. Building codes, labor unions, Underwriters Laboratories, regulatory agencies, and the Geneva Convention are all social institutions that have evolved, at least in part, to control the harmful properties of new technological developments. The essential question with which each of these bodies must grapple is "How safe is safe enough?" It takes such forms as: "Should there be additional containment shells around nuclear power plants?" "Is the carcinogenicity of saccharin sufficiently low to allow its use?" "Should schools with asbestos ceilings be closed?" At times, the answers are expressed in technical standards (e.g., emissions must be lower than 0.5 ppm); at times, economic formulations are used (e.g., the expected benefits of a control strategy must outweigh its expected costs); at times, specific solutions are mandated (e.g., install air bags); at times, solutions are negotiated through political processes (e.g., allowing Tellico Dam to be completed, thereby avoiding a direct test of the Endangered Species Act); at times, the issue is finessed to avoid the need for an explicit decision (e.g., reducing hydrofluorocarbons emissions by stigmatizing the users of aerosol products).

Of late, there has been growing concern that, however well these institutions may have served us in the past, the answers they provide to "how safe" questions are often inadequate. Some acceptable-risk decisions are simply not being made, in part because of vague legislative mandates and cumbersome legal proceedings, in part because there are no clear criteria on the basis of which to decide. As a result, the nuclear industry has ground to a halt while utilities wait to see if the building of new plants will be feasible, the Consumer Product Safety Commission has been unable to produce more than a few standards, observers wonder whether the new Toxic Substances Control Act can be implemented, and the Food and Drug Administration is unable to resolve the competing claims that it is allowing undue risks and that it is stifling innovation.

Those decisions that are made often appear inconsistent. Our legal statutes are less tolerant of carcinogens in the food we eat than in the water we drink or in the air we breathe. In the United Kingdom, 2,500 times more money per life saved is spent on safety measures in the pharmaceutical industry than in agriculture (Sinclair, Marstrand & Newick, 1972). According to some calculations, U.S. society spends about $140,000 in highway construction to save one life and $5 million to save a person from death due to radiation exposure (Howard, Matheson & Owen, 1978).

We seem to have undergone a revolution in the creation and identification of technological hazards and in our commitment to bringing them under societal control. As a result, thousands of new chemicals, drugs, foods, machines, treatments, and processes have swamped our decision-making capability. Even taken individually, many of these hazards have imponderable features: irreversible consequences, threats to the resilience of social units, or impacts on "silent" groups (e.g., future generations, biota) that can only be protected through the largess of powerful others. Many hazards take us into hazy areas where the facts of the matter, the shape of the problem we should be managing, and even the outcomes we want are unclear. Coping with these problems demands a decision-making revolution commensurate with the technological revolution of the last thirty years.

Acceptable Risk as a Decision Problem

Acceptable-risk problems are decision problems; that is, they require a choice between alternative courses of action. What distinguishes an acceptable-risk problem from other decision problems is that at least one alternative includes a threat to life or health among its consequences. We shall define "risk" as the existence of such threats, with the qualification that the loss of life or health not be a certainty for any individual involved.

Whether done formally or informally, examination of the alternatives in a decision problem involves the following five interdependent steps:

1. Specifying the objectives;
2. Defining the possible alternatives, including "do nothing;"
3. Identifying the possible consequences of each alternative, including, but not restricted to, risks;
4. Specifying the desirability of the various consequences and the likelihood of their being achieved; and
5. Analyzing the alternatives and selecting the best one.

This final step prescribes the option that should be selected, given the logic of the analysis. As such, it identifies the most acceptable option. If its recommendation is followed, then that seemingly best alternative will be adopted or accepted. Of course, one need not do so unless one felt that the decision-making process was adequately comprehensive and defensible.

An acceptable risk is the risk associated with the most acceptable alternative in a decision problem. Two important clarifications accompany this definition: (a) Technically speaking, we never accept risks. We accept an alternative that has some level of risk. Whenever the decision-making process has considered benefits or other costs, as well as risks, the most acceptable alternative may not be the one with the least risk. (b) Acceptable risk is situation specific. That is, there are no universally acceptable risks. The choice of an alternative (and its associated risk) depends on the set of alternatives, consequences, values, and facts invoked in the decision process. In different situations, different alternatives, values, and information may be relevant. Over time, errors in the analysis may be discovered, new safety devices may be invented, values may change, additional information may come to light, and so forth. Any of these changes could lead to a change in the acceptability of an alternative. Even in the same situation and at a single time, different people with different values, beliefs, objectives, or decision methods might disagree on which alternative is best. In short, the search for absolute acceptability is misguided.

Illustrations

A decision-making perspective offers a common language for treating some recurrent issues in acceptable-risk problems, as shown in Figures 1.1 to 1.4. Assume that a single individual is empowered to make each decision, that all risks and costs can be identified, characterized, and assessed with certainty, and that the benefits of all the alternatives are identical. The alternatives differ only in their cost and level of risk; 0 is the best level for each of these dimensions. As concrete examples, consider an individual choosing between automobiles or between surgical procedures that differ only in cost and riskiness.

Figure 1.1 shows how the set of alternatives considered affects the choice of the most acceptable option. If K and L are the only alternatives available, then the choice is between high cost with low risk (K) and low cost with high risk (L). The most acceptable risk would then be that level associated with either K or L, depending on which was chosen. If another alternative having lower cost and lower risk (M) became available, then it should be preferred to either K or L. The acceptable risk would then become the level associated with the new alternative.

Figure 1.2 illustrates how determination of the most acceptable option depends upon decision makers' values. If the goal is minimizing risk, then alternative K would be chosen. Minimizing cost, on the other hand, leads to the choice of alternative L and its higher level of risk.

Figure 1.3 relaxes the assumption of perfect knowledge. In it, new information drastically revises the decision maker's appraisal of the costs and risks of M. Had M already been selected, then the accepted level of risk would prove to be much higher than that originally anticipated. If the decision had yet to be made, then the choice would revert to K or L, with their associated risk levels.

The decision rules invoked in Figure 1.2, minimize cost and minimize risk, were rather simplistic. The two dashed indifference curves in Figure 1.4 present more believable preferences. Each point on such a curve would be equally attractive to an individual whose preferences

Figure 1.1

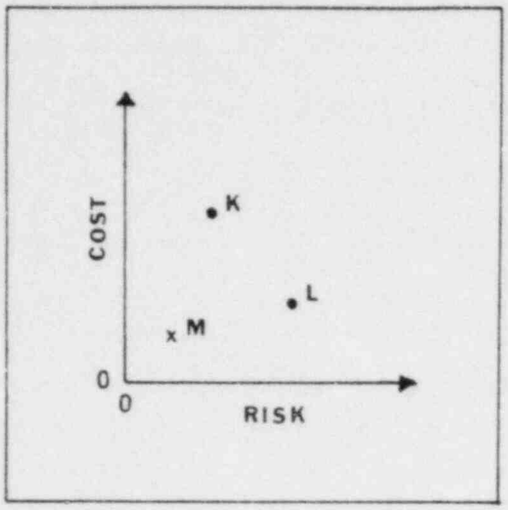


Figure 1.2

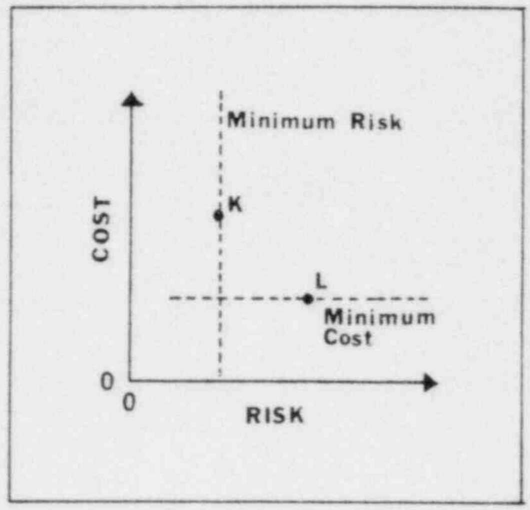


Figure 1.3

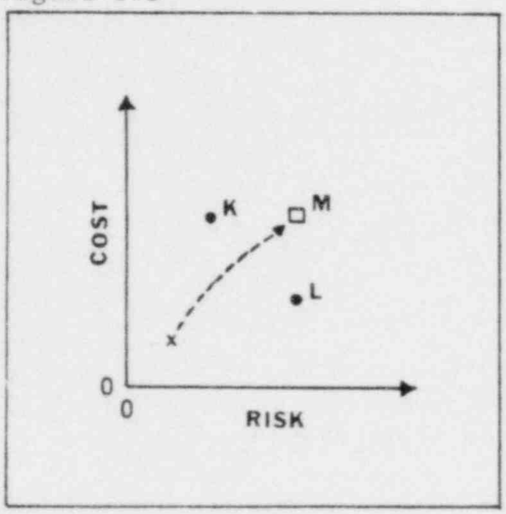
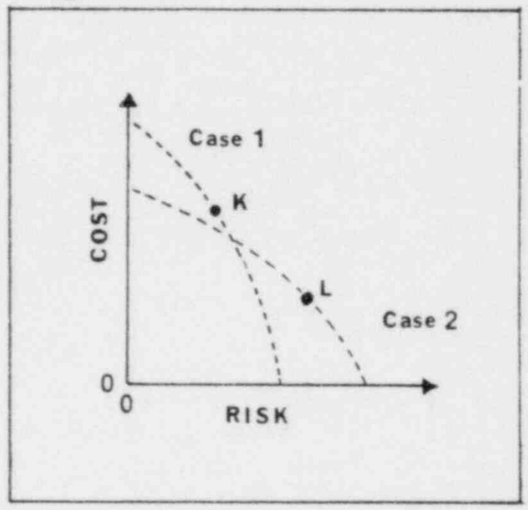


Figure 1.4



Figures 1.1 - 1.4. Exemplary choices between alternative risky options. As explained in the text, Figure 1.1 shows the effect of the options considered on the choice made; Figure 1.2 shows the effect of the decision makers' values; Figure 1.3 shows the effect of changing information; Figure 1.4 shows the effects of more complicated preferences.

it represents. Case 1 reflects a willingness to incur large costs in return for small reductions in risk. By this criterion, alternative K is preferred to L; the cost saving of L is achieved at the price of too great an increase in risk. Indeed, this individual would not incur the risks of L even if its cost was zero. Case 2 reflects less willingness to increase costs in exchange for reduced risk; alternative L is now the best choice. Although this individual can conceive of paying the cost of K, the risk level would have to be much lower than that of K.

Apparently Easy Solutions

Viewing acceptable risk as a decision problem also helps illuminate the flaws in some simplistic solutions. For example, it may be tempting to claim that no risk should be tolerated. However, the decision perspective forces one to ask "What is the cost of absolute safety?" Taken literally, total abhorrence of risk could lead to rather dubious decisions, like preferring Option A to Option B in Figure 1.5, thereby incurring great cost for a minor reduction in risk.

Rather than paying for safety, one might propose doing without the substance, activity, or technology in question. A decision-making perspective requires one to ask what alternative is chosen in its stead. When that alternative has risks of its own, the gain in safety may prove illusory. For example, if diabetics have a need for sweeteners, banning saccharin may eliminate one possible cancer risk in return for increased risk from the consumption of sugar.

A variant on the desire for absolute safety is the unqualified suggestion that the chosen alternative be as safe as possible. Option C

Figure 1.5

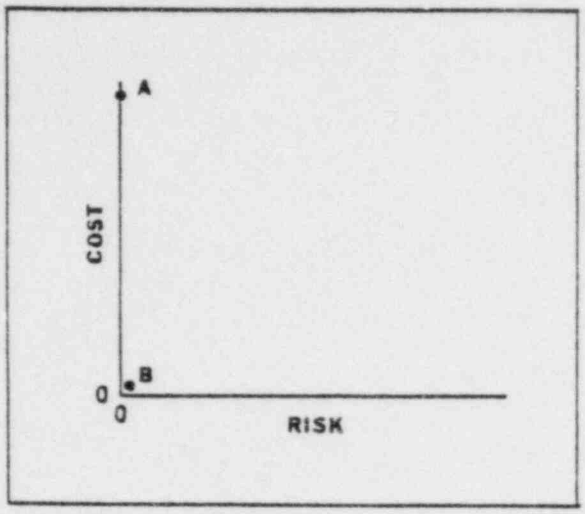


Figure 1.6

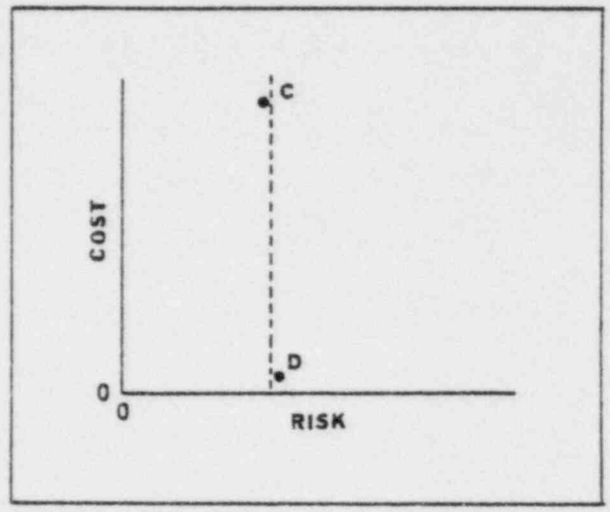


Figure 1.7

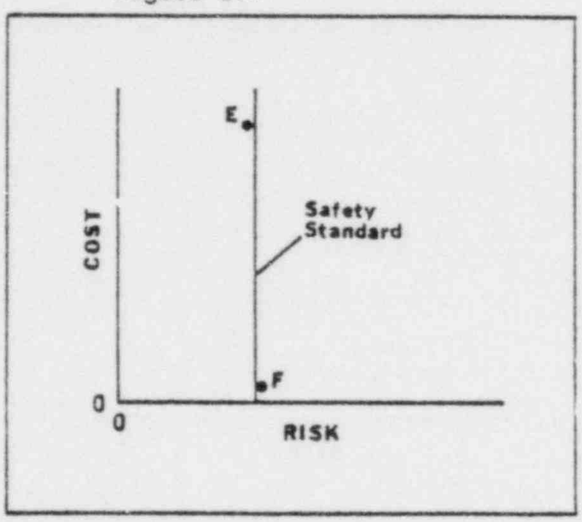
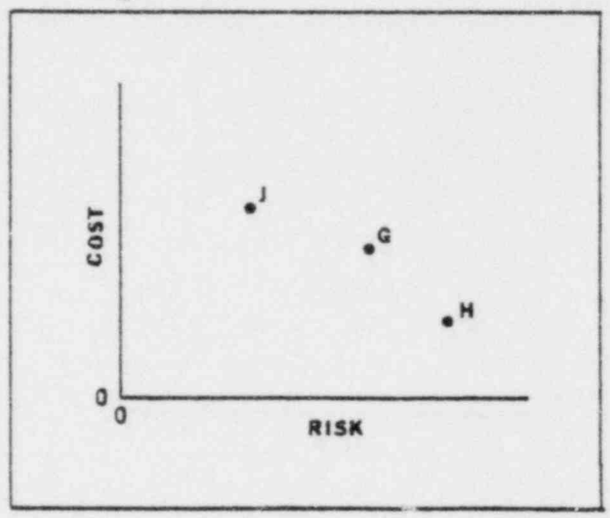


Figure 1.8



Figures 1.5 - 1.8. Exemplary choices between risky options, clarifying the pitfalls of some seemingly easy solutions. Figure 1.5 shows the implications of wanting no risk; Figure 1.6 shows the implications of deciding that the option adopted should be as safe as possible; Figure 1.7 considers the adoption of an absolute standard for maximum allowable risk; Figure 1.8 shows the implications of specifying fixed risk-benefit tradeoffs.

(in Figure 1.6) provides less risk than Option D, but at a large incremental cost. Most people would tolerate some small increase in risk for a large reduction in cost (at least if those bearing the risk also received the cost savings).

Another simplification calls for expressing the answer to "How safe is safe enough?" by a small number (like 10^{-7}), representing the maximum allowable probability of some important adverse consequence. Figure 1.7 illustrates one situation in which this solution would appear inappropriate. Suppose that alternatives E and F lie just on opposite sides of the designated standard, and that E costs substantially more than F. In practice, F might be preferred to E by most people, despite being above the safety standard.

A more sophisticated solution is to specify fixed tradeoffs between cost and risk. For example, one could adopt any safety measure costing less than one million dollars per expected life saved. Figure 1.8 suggests that this, too, could be an oversimplification. When risk is very high, one might be willing to incur great cost to reduce it. Thus, one might prefer G over H, even though the shift to G doubles the cost in order to reduce the risk by only one-fourth. At the same time, one might be more reluctant to pay for added safety when the risks are low. Thus one might not prefer J to G even though that shift buys more safety for less cost than the change from H to G. Such preferences are consistent if one feels that different value tradeoffs are appropriate at different levels of risk.

Overview

There are many candidates for the role of the approach to choosing among risky options. The present analysis is designed to focus the debate over the attractiveness of alternative approaches to resolving acceptable-risk problems by presenting each approach in a common conceptual and evaluative framework. It provides a critical guide clarifying (a) the political and epistemological assumptions made by each approach, (b) the manner in which each approach copes with the generic problems confronted in hazard decision making, and (c) the degree to which each fits into the real world within which hazards are managed, with its vested interests, fallible humans, and institutional stodginess.

The present chapter has offered a basic framework for conceptualizing acceptable-risk questions as decision problems. Chapter 2 analyzes the generic complexities of acceptable-risk problems with which any approach must contend; in doing so, it defines our universe of inquiry. Chapter 3 develops a set of criteria for evaluating approaches. It also presents a taxonomy of approaches based on the different notion of rationality underlying each approach. Each of Chapters 4, 5, and 6 first characterizes one family of approaches by how it addresses the generic complexities described in Chapter 2, and then applies to it the evaluative criteria of Chapter 3. Chapter 7 assesses the overall strengths and weaknesses of the approaches, as well as their relative ability to meet the challenges posed by particular kinds of acceptable-risk problems. Chapter 8 summarizes our findings, with recommendations for public policy being spelled out in Chapter 9. Finally, Chapter 10 offers an agenda for research needed most for improving society's decision-making capacity.

Defenders of government regulation often argue that one of its main benefits is "technology forcing," creating challenges for developers and encouraging them to produce technical innovations sooner rather than later. An analogous claim is that a hidden benefit of hazardous technologies is "society forcing," stimulating new institutional forms and managerial techniques. By giving society new capabilities, technologies may prompt it to be more sophisticated about where it is going.

Summary

Answering the question, "How safe is safe enough?" means making a decision between alternatives. The risk associated with the most acceptable alternative may be defined as an acceptable risk. However, decision makers using different decision rules, believing different information, or considering different alternatives could arrive at quite different notions of what options (and associated risks) to accept. As a result, there are no universally acceptable risks.

CHAPTER 2

Why Is It So Hard to Resolve Acceptable-Risk Problems?

Five Generic Complexities

Chapter 1 used a decision-making framework to conceptualize acceptable-risk problems. The specific examples given (in Figs.1.1 - 1.8) were, however, abstractions designed to illustrate basic principles rather than to represent actual problems of decision making. Chapter 2 attempts to characterize real acceptable-risk decisions by identifying five generic complexities that they present: (a) uncertainty about how to define the decision problem, (b) difficulties in assessing the facts of the matter, (c) difficulties in assessing the relevant values, (d) uncertainties about the human element in the decision-making process, and (e) difficulties in assessing the quality of the decisions that are produced.

The discussion of these problems indicates that even the most straightforward aspects of decision making (e.g., defining the problem or assessing the decision maker's values) are often fraught with difficulties or technically impossible. These complexities are "facts of life" facing any formal or informal attempt to resolve acceptable-risk decisions. Subsequent chapters will characterize various approaches to such decisions by reviewing how they address (or ignore) these five problems.

Uncertainty about Problem Definition

The problem definition establishes the universe of discourse for the decision-making process. It determines which options and consequences are valid considerations and what kinds of information and uncertainty are worthy of note. Despite its obviously central role, problem definition is often given but cursory attention in discussions of acceptable risk. A consideration of the issues arising in creating the definition suggests that in many cases the decision has effectively been made once the definition is set.

Where Is the Decision?

Decision-making methodologies often assume that decision problems have well-characterized definitions, and that they are resolved at fixed points in time by identifiable individuals. Case studies of actual decisions suggest that, more typically, decisions evolve over time as various actors make incremental changes in existing policies or create new options (e.g., Peters, 1979). Some observers would argue that such a decentralized trial-and-error approach is how decisions should be made. For example, by leaving the problem definition fluid, one is better able to incorporate the insights generated by thinking about the problem (Comar, 1979a). Vague definitions may also help opposing parties to reach compromises that would be impossible were they forced to be more explicit. On the other hand, without an explicit definition, it is hard to apply deliberative decision-making methods or to know just what (or whose) problem is being solved.

What Is the Hazard?

The decision to decide whether a risk is acceptable implies that, in the opinion of someone powerful, the technology in question may be too dangerous. Just putting a technology on the decision-making agenda can materially change its fate by attracting attention to it and encouraging the neglect of other hazards. For example, the act of worrying about CO_2-induced climatic change (Schneider & Mesirow, 1976) changes the status of fossil fuels vis-a-vis nuclear power.

After an issue is identified, the hazard in question must still be defined. Breadth of definition is particularly important. Are military and non-military nuclear wastes to be lumped together in one broad category or do they constitute separate hazards? Did the collision of two jumbo jets at Tenerife represent a unique miscommunication or a large class of pilot-controller impediments? Do all uses of asbestos comprise a single industry or are brake lining, insulation, etc., to be treated separately? Do "hazardous wastes" include residential sewage or only industrial solids (Chemical & Engineering News, 1980)? Regrouping may convert a set of minor hazards into a major societal problem or the reverse. Lead in the environment may seem worth worrying about, whereas lead solder in tuna fish cans may not. In recent years, isolated cases of child abuse have been aggregated, turning a persistent problem with a stable rate of occurrence into an apparent epidemic demanding action.

Often the breadth of a hazard category becomes apparent only after the decision has been made and its implications experienced in practice. Some categories are broadened, for example, when precedent-setting decisions are applied to previously unrelated hazards. Other categories are narrowed over time, as vested interests gain exceptions to the rules applying to the category in which their technology once belonged (Barber, 1979). In either case, different decisions might have been made had the hazard been better defined in advance.

Fixing category width does not, however, suffice to characterize a hazard. As shown in Figure 2.1, hazards begin with the human need they are designed to satisfy and develop over time. One could look at the whole process or just its conclusion. The more narrowly a hazard's movement in time is defined, the fewer decision options can be considered.

What Are the Consequences?

In the simple decisions of Chapter 1, the alternatives were evaluated on two dimensions of consequence, cost and risk, and assumed equal on all other dimensions, including benefits. The problematic, subjective aspect of the decision process appeared to be the task of determining what value tradeoffs to use.

Yet one might ask, just what do those terms mean? With a little imagination, any consequence can be interpreted as a cost, a benefit, or a risk. Before proceeding, the set of relevant consequences must be defined. Table 2.1 lists a few possible candidates for consequences. Each can readily be tied to a particular constituency; each is more compatible with some definitions of "hazard" than others; each can enhance or detract from the attractiveness of various decision options.

There are norms for selecting consequences. These reflect the balance of power at the time of their adoption and shift as the parties lobby to have their concerns better represented. The environmental move-

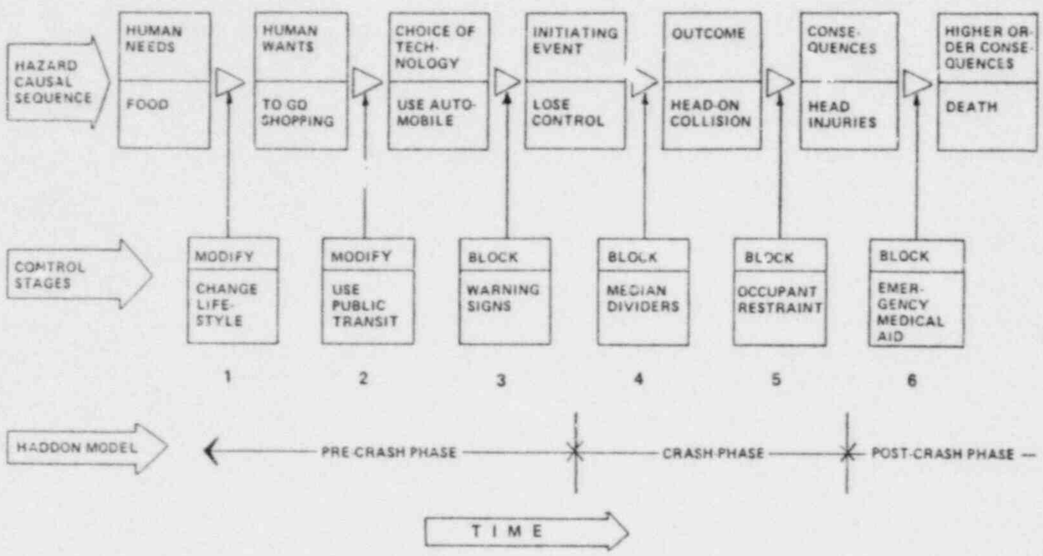


Figure 2.1. An illustration of the causal chain of hazard evolution. The top line indicates seven stages of hazard development, from the earliest (left) to the final stage (right). These stages are expressed generically in the top of each box and in terms of a sample motor vehicle accident in the bottom. The stages are linked by causal pathways denoted by triangles. Six control stages are linked to pathways between hazard states by vertical arrows. Each is described generically as well as by specific control actions. Thus, control stage 2 would read: "You can modify technology choice by substituting public transit for automobile use and thus block the further evolution of the motor vehicle accident sequence arising out of automobile use." The time dimension refers to the ordering of a specific hazard sequence; it does not necessarily indicate the time scale of managerial action. Thus, from a managerial point of view, the occurrence of certain hazard consequences may trigger control actions that affect events earlier in the hazard sequence. Source: Bick, Hohenemser & Kates (1979).

Table 2.1

Some Possible Dimensions of Consequences

for Characterizing the Attractiveness of Options

Economic
- Compliance costs
- Market efficiency (e.g., monopolization, capital formation)
- Innovation
- Growth rate
- Opportunity costs (i.e., how else could the money be used?)

Physical
- Death
- Genetic damage
- Injury
- Sickness

Ecological
- Species extinction
- Altered ecosystem balances
- Changed gene pools
- Habitat destruction

Political/Ethical
- Centralization
- Inter- and intragenerational equity
- Personal freedom
- International relations
- Societal resilience

Psychological
- Worry, anxiety
- Confidence in the future
- Alienation

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ment legitimated a few new dimensions; the current "regulatory reform" movement would like to reinterpret those dimensions or at least ensure that the traditional dimensions of corporate profit and loss are not forgotten. Some observers are worried about the neglect of consequences that are too general or far-reaching to enter the definition of any particular decision, like preservation of genetic diversity or societal resilience or the opportunity for experimentation (Dyson, 1975; Lepkowski, 1980; Svenson, 1978).

Removing a consequence from the official problem definition need not remove it from the agendas of the participants. Only self-confidence and self-awareness are needed to generate thoughts like "they won't let me talk about how this option affects my freedom of choice (or freedom of the chemical industry or my professional liability), so I'll do whatever I can to throw a wrench into the proceedings."

What Action Options Are Available?

If decisions involve choices between alternatives, much has already been decided when one defines the set of options to take seriously. In principle, one has, at the very least, a choice between adopting and rejecting a technology, remembering that rejection may effectively mean going with another technology. Promoters would often prefer an agenda including only alternative versions of "go," such as "go as planned," "go after encountering opposition," and "go after cosmetic changes." Gamble (1978) describes proponents of the MacKenzie Valley pipeline as acting as though "if enough studies were done, if enough documentation presented, somehow all would be well and the project could proceed as originally planned" (p. 951). Another dimension of options opens up when one considers the possibilities of making no choice, or many incremental trial-and-error choices, or deferring one's choice to a time when more options or information may be available (Corbin, 1980).

Further options are available if the hazard is defined in the broad temporal sense of Figure 2.1, allowing one to evaluate options directed at each stage of hazard evolution, including modifying wants, changing the technology, and preventing initiating events. Some of the consequences in Table 2.1 suggest that instead of making decisions about individual hazards, we should be setting fundamental social policy and deriving specific hazard decisions from those general principles.

In addition to becoming unavailable practically, excluded options tend to fade from view conceptually as facts relevant to them are not recruited to the decision-making process. Even options that are listed can be denied serious consideration by a number of standard ploys. One is to invoke noble alternatives beside which the option pales (e.g., we can feed the starving masses or balance the budget with the money saved by rejecting that option). Another way for effectively deleting relevant alternatives is not to research their properties, making them uncertain quantities from which many decision makers will shy away. A third strategy for downplaying an option is to invest in a competitor so heavily that the public cannot afford to let it go under; Fay (1975) calls this the "overcapitalization rip-off." Indeed, even modest investments in an option may be sufficient to exploit people's unwillingness to walk away from sunk costs (Teger, 1980). The fact that no major dam in the United States has been left unfinished once begun shows how far a little concrete can go in defining a problem (U.S. Government, 1978).

Implicit in any decision problem is a default option, one that will be adopted if the proceedings reach an impasse. When go and no-go are the only options considered, one common resolution seems to be assuming that the risks of an existing technology are acceptable until proven otherwise, while denying new technologies the benefit of the doubt (Dorfan, 1980).

How Should the Particulars Be Specified?

The need for definitions does not end once the broad outlines of the problem are laid down, nor does the power of definitions to determine decisions. For example, the stringency demanded by U.S. air quality laws hinges on how one operationalizes the "adverse health effects" they are designed to prevent (Feagens & Biller, 1979). The American Public Health Association (1980) accused the Occupational Safety and Health Improvement Act of 1980 (S.2153) of defining "'workplace' in a specious manner [allowing] employers . . . to exempt as many activities and workers from coverage as possible." Guidelines specifying that a safety option should be adopted as long as it costs less than $X per expected life saved seldom specify what year's dollars are to be used. Weinberg (1979) worries about the effects of measuring the safety of nuclear power plants in terms of the absolute number of Three-Mile-Island-magnitude accidents rather than their rate per reactor-year. New and old technologies may be subject to different standards, even though the legal definition of "newness" is often moot (Krass, 1980).

One can evaluate an option as it is defined by its proposers or as it is likely to emerge after being shaped by the vicissitudes of the implementation process. Since many things about actual hazards are hard to prove, whether one has to prove compliance or to prove non-compliance with the safety standard implicit in the proposed option may make a big difference in effective safety levels. Even such seemingly unambiguous terms as "dose" and "employed" (as in "workers employed in pollution abatement" or "unemployed due to the costs of compliance") are subject to shifting definitions and uncertain interpretations in practice (Brooks & Bailar, 1978; Walgate, 1980). In each of these cases, attention to detail is part of a winning strategy and capable of making an appreciable difference in the choices made and the risk levels eventually attained.

Summary

Before they can be resolved, decision problems must be shaped. The definitional process involves deciding whether a decision is to be made at all and, if so, what options and consequences are to be considered. Further specification is needed to elaborate the terms of the decision into operational form. Each of these pre-decision decisions can affect the choices that emerge, so much so that the outcome of the decision process may already be determined once its ground rules have been laid.

Difficulties in Assessing the Facts

One reason why decisions emerged so readily from the schematic figures of Chapter 1 is that all relevant facts were assumed to be known with precision. Our ability to assess what was happening allowed us to focus on evaluating the situation to decide what we want. Many acceptable-risk decisions involving familiar, recurrent hazards could be so characterized. For example, we may have quite accurate estimates of the costs involved and lives saved by adding a mobile trauma unit or fire station or by mandating airbags or motorcycle helmets. Often, however, critical facts are clouded by uncertainty (as in Figure 2.2). The points in the figure represent a best guess at the cost and risk of each option; however, the actual levels may lie anywhere in the respective rectangles. Option K might dominate Option L on both dimensions or on neither.

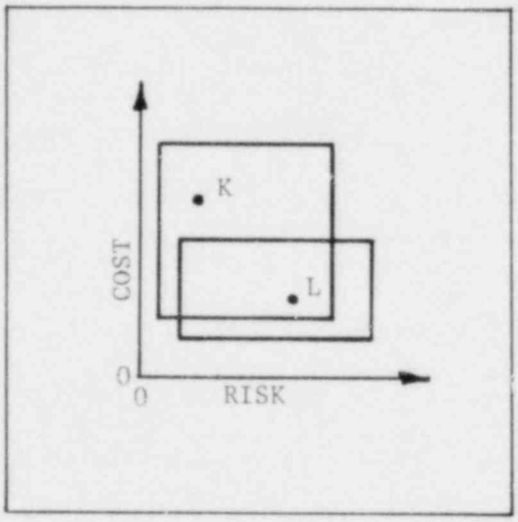

Figure 2.2. The effects of uncertainty in risk and cost estimates on the evaluation of decision options. Although the points indicate the best guess at the properties of Options K and L, each could be located anywhere in its respective rectangle. Different locations could lead to different decisions.

Uncertainty about the facts should come as no surprise to any scientist involved in providing the inputs to risk decisions. Learning the limits of data is the essence of scientific training. For the decision maker, an understanding of these sources of uncertainty is critical to assessing the confidence with which decisions can be made. An approach to acceptable-risk decisions can be characterized by how, if at all, it addresses, represents, and resolves such uncertainties. The full litany of relevant problems would require tutorials in the methodology of the physical, social, and biological sciences. The following is a sampling of common and critical problems.

Assessing Very Low Probabilities

One fortunate feature of our natural environment is that the most fearsome events happen quite infrequently. Major floods, disastrous plagues, and catastrophic tremors are all the exception rather than the rule among natural hazards. Social institutions attempt to constrain hazards of human origin to have a low probability of leading to disaster. Projects that kill large numbers of people frequently are unlikely to be developed, however great their promised benefit. The difficult cases are those in which the probability of a disaster is known to be low, but in which we need to know just how low. Unfortunately, quantitative assessment of very small probabilities is often very difficult (Fairley, 1977).

At times, one can identify an historical record that provides frequency estimates for an event related to the calamity of interest. The U.S. Geological Survey has perhaps seventy-five years of reliable data upon which to base assessments of the likelihood of large earthquakes (Burton, Kates & White, 1978). Iceland's copious observations of ice-pack movements over the last millenium provide a clue to the probability of an extremely cold year in the future (Ingram, Underhill & Wigley, 1978). The absence of a full-scale meltdown in 500-1,000 reactor-years of nuclear power plant operation sets some bounds on the probability of future meltdowns (Weinberg, 1979). Of course, extrapolation from any of these historical records is a matter of judgment. The great depth and volume of artificial reservoirs may enhance the probability of earthquakes in some areas. Increased CO_2 concentrations in the atmosphere may change climate in ways that amplify or dampen yearly temperature fluctuations. Changes in design, staffing, and regulation may render the next 1,000 reactor-years appreciably different from their predecessors. Indeed, any attempt to learn from experience and make a technology safer renders that experience less relevant for predicting future performance.

Even when experts agree on the interpretation of records, a sample of one thousand reactor- or calendar-years may be insufficient. If one believes the worst-case scenarios of some opponents of nuclear power, a 0.0001 chance of a meltdown (per reactor-year) might seem unconscionable. However, we will be into the next century before we will have enough on-line experience to know with reasonable confidence whether the historical probability is really that low.

Need for Modeling

To the extent that historical records (or the records of related systems) are unavailable, one must rely on conjecture. The more sophisticated conjectures are based upon models such as the fault-tree and event-tree analyses of a loss-of-coolant accident upon which the Reactor Safety Study was based (U.S. Nuclear Regulatory Commission, 1975). The fault tree involves a logical structuring of what would have to happen for a meltdown to occur. If sufficiently detailed, it will reach a level of specificity for which one has direct experience (e.g., the operation of individual valves). The overall probability of system failure is determined by combining the probabilities of the necessary component failures (Green & Bourne, 1972; Jennergren & Keeney, in press).

The trustworthiness of the analysis hinges on the experts' ability to enumerate all major pathways to disaster and the assumptions underlying the modeling effort. Unfortunately, a modicum of systematic data and many anecdotal reports suggest that experts may be prone to certain kinds of errors and omissions. Table 2.2 suggests some problems that might lie under the confident veneer of a formal model.

When the logical structure of a system cannot be described so as to allow computation of its failure probabilities (e.g., when there are large numbers of interacting systems), physical or computerized simulation models may be used. If one believes the inputs and the programmed interconnections, one should trust the results. What happens, however, when the results of a simulation are counterintuitive or politically awkward? There may be a strong temptation to try it again, adjusting the parameters or assumptions a bit, given that many of these are not

Table 2.2

Some Problems in Structuring Risk Assessments

• Failure to consider the ways in which human errors can affect technological systems. Example: Due to inadequate training and control room design, operators at Three Mile Island repeatedly misdiagnosed the problems of the reactor and took inappropriate actions (Sheridan, 1980; U.S. Government, 1979).

• Overconfidence in current scientific knowledge. Example: Use of DDT came into widespread and uncontrolled use before scientists had even considered the possibility of the side effects that today make it look like a mixed and irreversible blessing (Dunlap, 1978).

• Failure to appreciate how technological systems function as a whole. Example: The DC-10 failed in several early flights because its designers had not realized that decompression of the cargo compartment would destroy vital control systems (Hohenemser, 1975).

• Slowness in detecting chronic, cumulative effects. Example: Although accidents to coal miners have long been recognized as one cost of operating fossil-fueled plants, the effects of acid rains on ecosystems were slow to be discovered.

• Failure to anticipate human response to safety measures. Example: The partial protection afforded by dams and levees gives people a false sense of security and promotes development of the flood plain. Thus, although floods are rarer, damage per flood is so much greater that the average yearly dollar loss is larger than before the dams were built (Burton, Kates & White, 1978).

• Failure to anticipate "common-mode failures" which simultaneously afflict systems that are designed to be independent. Example: Because electrical cables controlling the multiple safety systems of the reactor at Browns Ferry, Alabama, were not spatially separated, all five emergency core cooling systems were damaged by a single fire (U.S. Government, 1975; Jennergren & Keeney, in press).

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known with certainty. Any persistent tendency to yield to this temptation could generate a systematic and subtle bias in modeling. At the extreme, models would be accepted only if they confirmed our expectations.

The lack of clear standards for the acceptability of models may have rendered inconclusive most debates arising out of Meadows, Meadows, Randers & Behrens' Limits to Growth (1972) and Forrester's World Dynamics (1973). Everyone agreed that these examples were somewhat wrong and somewhat oversimplified, but no one could tell quite what that meant.

The Need for Judgment

Once the system has been modeled to one's satisfaction, failure rates for the components must be assessed. Typically, some components are entirely novel or have never been used in this particular situation. Their performance parameters must be assessed by expert judgment. Thus even the components of the modeled system are not experienced directly, but are revealed through the filter of educated intuition.

Two methodological issues are worth bearing in mind when deciding how much credence to attach to such intuitions. One is that experts may not have their knowledge mentally organized in the form needed by the risk assessor. A mechanic or crisis counselor may have intimate experience with many breakdowns, but still not be able to summarize it in the needed univariate or bivariate frequency distributions. The second issue is that the technical details of how one asks for quantitative judgments can greatly affect the numbers that emerge (Poulton, 1977). Table 2.3 shows the results of asking lay people about the lethality of various potential causes of death using four formally equivalent formats.

Table 2.3

Lethality Judgments with Different Response Modes

Geometric Means

Malady	Death Rate per 100,000 Afflicted				
	Estimate Lethality Rate	Estimate Number Died	Estimate Survival Rate	Estimate Number Survived	Actual Lethality Rate
Influenza	393	6	26	511	1
Mumps	44	114	19	4	12
Asthma	155	12	14	599	33
Venereal Disease	91	63	8	111	50
High Blood Pressure	535	89	17	538	76
Bronchitis	162	19	43	2,111	85
Pregnancy	67	24	13	787	250
Diabetes	487	101	52	5,666	800
Tuberculosis	852	1,783	188	8,520	1,535
Automobile Accidents	6,195	3,272	31	6,813	2,500
Strokes	11,011	4,648	181	24,758	11,765
Heart Attacks	13,011	3,666	131	27,477	16,250
Cancer	10,889	10,475	160	21,749	37,500

Note: The four experimental groups were given the following instructions:
(a) Estimate lethality rate: for each 100,000 people afflicted, how many die?
(b) Estimate number died: X people were afflicted; how many died?
(c) Estimate survival rate: for each person who died, how many were afflicted but survived?
(d) Estimate number survived: Y people died; how many were afflicted but did not die?
Responses to questions (b), (c), and (d) were converted to deaths per 100,000 to facilitate comparisons.

Source: Fischhoff, Slovic & Lichtenstein, 1981.

Converting these judgments to a common unit revealed some dramatic differences in expressed risk perceptions. Whether expert judgments are similarly sensitive is a matter of speculation and concern (Fischhoff, Slovic & Lichtenstein, 1981).

The Need to Untangle Causes

Whereas some phenomena require long periods of time for an adequate sample to be accumulated, others simply take a long time to happen. For example, most carcinogens are presumed to take 15-30 years to exert demonstrable effects on human populations. When a substance is released into the environment, by the time we find out what we've done (or what's been done to us), it may be too late.

A concommitant of long periods of time is that other things happen to those exposed to the substance of interest. They face other carcinogens in their homes and jobs; they practice good or bad nutrition; they undergo medical tests and treatments. Epidemiological models are needed to tease out relationships. Yet there are a variety of such models, which make different simplifying assumptions and, at times, reach different conclusions. The impossibility of collecting adequate samples of reliable data may keep epidemiological studies from ever answering questions like: How do health effects vary with the distribution of exposure over time? Are smokers particularly susceptible? Do simple ameliorative devices, like staying indoors during smog alerts, make a difference? (Ames, 1979; Kozlowski, Herman & Frecker, 1980; Marx, 1979). As suggested by Figure 2.3, even the tragic instances in which people have been exposed to roughly measurable doses of hazardous substances

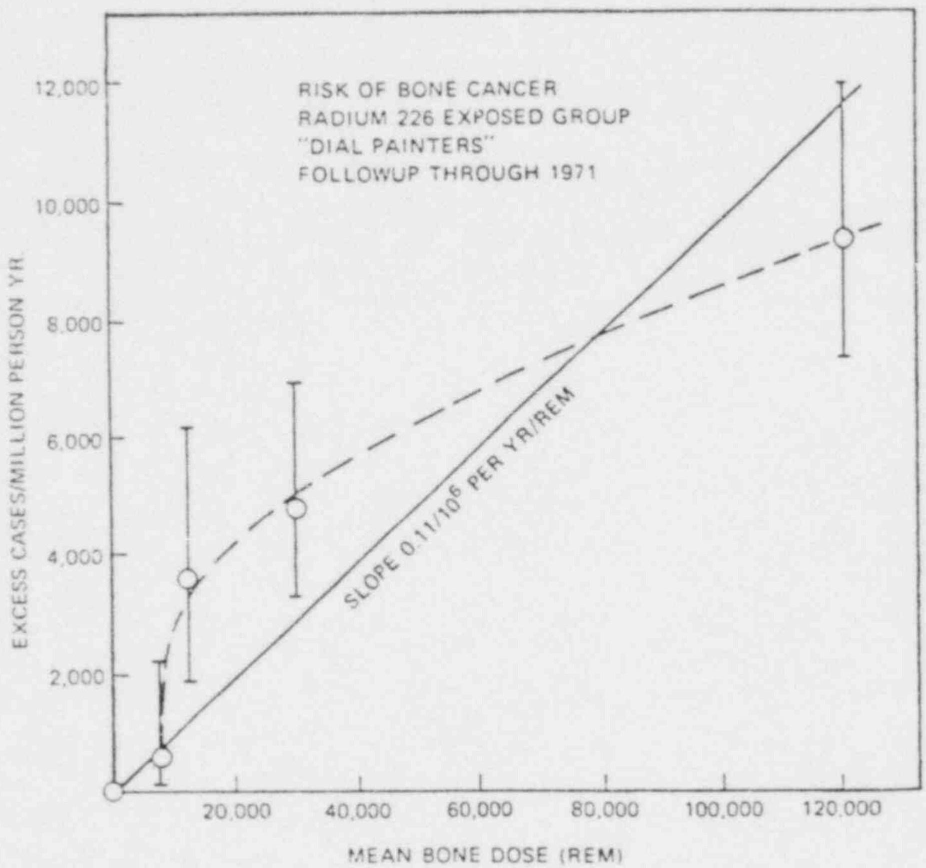


Figure 2.3 Excess cases of bone cancer observed for various levels of mean bone dose. The exposed individuals were workers who painted watches with radium during the years 1915-1935. The large error bars reflect uncertainty in the data. It is not clear whether a straight line without a threshold, or a curved line with a threshold, best fits the data. Most exposures of individuals today fall in the region below 10,000 REM mean bone dose. It is therefore critical whether the solid or dashed curve is correct. The former predicts harm at any level of exposure; the latter suggests no excess mortality below about 10,000 REM mean bone dose. By itself, the graph does not provide an answer. The assumption usually adopted is that the straight line is correct. The graph and its interpretation are reproduced from the Report of the Committee on the Biological Effects of Ionizing Radiation (National Academy of Sciences, 1972).

may not afford unambiguous answers.

The alternative to prolonged observations with humans is briefer studies of animals given large doses (relative to body weight) of suspected carcinogens. Interpretation of these results is often rendered arguable by the varying cancer rates obtained with different species, modes of administration, or numbers of animals per cage; by the fact that at times the overall rate of cancer remains the same, but the pattern of tumors changes; by the use of doses much greater than would ever be contemplated for a human population; by the presence of trace carcinogens in animal feed; by the problems of drawing inferences from animals to humans; and by incompetent laboratory practices (Ames, 1979; Carter, 1979; Holden, 1979; Knapka, 1980; Smith, 1979).

Elaborating the Consequences

Knowing some basic facts about the size of an effect may still leave one uncertain about the full meaning of its consequences. Assume that a millenial climate-modeling project demonstrates that the mean world temperature will change by 3-4°C in the next half century, with the greatest increases in polar regions. Reduction of the temperature gradient between different latitudes will, in turn, reduce atmospheric and oceanic circulation (U.S. Department of Energy, 1979; World Climate Conference, 1978). Although this is much better information than can reasonably be expected, it may not be good enough to allow us to express sensible opinions about the implications of this change. Living in the world is no guarantee of being able to understand the meaning of a shift in any of its parameters (such as an increase in the median age, or the percentage of handicapped persons, or the price of fuel). We may not realize that an older population could threaten the bankruptcy of the social security system, or that a warmer climate could eliminate the hard freezes that keep pests from destroying susceptible crops in some regions, or that a near-miss at a nuclear power plant with few immediate casualties could cause an erosion of confidence leading to an acute energy shortage. The fact that such secondary or tertiary effects seem obvious when drawn does not mean that they will be recognized spontaneously. A National Academy of Sciences study of the effects of thermonuclear war concluded that the expected reduction of the earth's ozone shield would not imperil the survivors' food supply because many crops could survive the increased ultraviolet radiation. Only external review, however, revealed that increased radiation would make it virtually impossible to work in the fields to raise those crops (Boffey, 1975).

Summary

The above is but a sample of the problems encountered in attempting to understand the facts of risk problems. A comprehensive approach to acceptable-risk decisions must first acknowledge and then contend with the realization that it is difficult to know what risks were, are, or will be. Subsequent chapters (4-6) characterize approaches by how they treat such uncertainties and how that treatment tends to prejudice their conclusions.

Difficulties in Assessing Values

Confronting Labile Values

Once we understand an effect, we must make an assessment of its desirability. Do we want this to happen? How badly? Such questions would seem to be the last redoubt of unaided intuition. Who knows better than an individual what he or she prefers? When one is considering simple, familiar events with which people have direct experience, it may be reasonable to assume that they have well-articulated opinions. Regarding the novel, global consequences potentially associated with CO_2-induced climatic change, nuclear meltdowns, or genetic engineering, that may not be the case. Our values may be incoherent, not thought through. In thinking about acceptable levels of risk, for example, we may be unfamiliar with the terms in which issues are formulated (e.g., social discount rates, miniscule probabilities, or megadeaths). We may have contradictory values (e.g., a strong aversion to catastrophic losses of life and a realization that we're no more moved by a plane crash with 500 fatalities than by one with 300). We may occupy different roles in life (parents, workers, children) that produce clear-cut, but inconsistent values. We may vacillate between incompatible, but strongly held positions (e.g., freedom of speech is inviolate, but should be denied to authoritarian movements). We may not even know how to begin thinking about some issues (e.g., the appropriate tradeoff between the benefits of dyeing one's hair and a vague, minute increase in the probability of cancer 20 years from now). Our view may undergo changes over time (say, as we near the hour of decision or of experiencing the consequence) and we may not know which view should form the basis of our decision.

Competent technical analyses may tell us what primary, secondary, and tertiary consequences to expect, but not what these consequences really mean. To some extent, we are all prisoners of our own experience, unable to imagine drastic changes in our world or health or relationships. What unspoken presumptions constrain our imaginations regarding, say, what it is like to be in a foreign culture or in prison? Such considerations move some foes of nuclear power to argue that our inability to grasp the time span during which some radioactive wastes must be stored means that we should avoid the whole business. Without basic comprehension, wise decision making is infeasible.

Manipulating Labile Values

When people do not know, or have difficulty appraising what they want, problem representations may become major forces in shaping the values expressed, or apparently expressed, in the responses they elicit. As a result, the way that issues are posed by nature, scientists, politicians , merchants, and the media may have great influence over which responses emerge as apparent expressions of people's values. Representations can induce random error (by confusing the respondent), systematic error (by hinting at what the "correct" response is), or unduly extreme judgments (by suggesting clarity and coherence of opinion that are not warranted). In such cases, the method becomes the message. If elicited values are used to guide policy, they may lead to decisions not in the decision maker's best interest, to action when caution is desirable (or the opposite), or to the obfuscation of poorly formulated views needing careful development and clarification.

An extreme, but not uncommon, situation is having no opinion and not realizing it. If we are asked a question when in that state, we may respond with the first thing that comes to mind and then commit ourselves to maintaining that first expression and to mustering support for it, while suppressing other views and uncertainties. As a result, we may be stuck with stereotypic or associative responses, generated without serious contemplation. The low rates of "no opinion" responses encountered by surveys addressing diverse and obscure topics suggests that most people are capable of providing some answer to whatever question is put to them. Such responses may reflect a desire to be counted rather than deeply held opinions (Payne, 1952; Schuman & Presser, 1977).

Many of the ways in which elicitation procedures can affect responses have been known since the beginnings of experimental psychology, over a century ago. Early psychologists discovered that different judgments may be attached to the same physical stimulus (e.g., how loud is this tone) as a function of whether it is presented in the context of increasingly intense or weak alternatives, whether the set of alternatives is homogeneous or diverse, and whether the respondent makes one or many judgments. Even when the same presentation is used, different judgments might be obtained with a numerical or a comparative (ordinal) response mode, with instructions stressing speed or accuracy, with a bounded or an unbounded response set, and with verbal or numerical response labels. Such effects seem to be as endemic to judgments of value as they are to judgments of loudness, heaviness or taste. Although the range of these effects may suggest that the study of judgment is not just difficult, but impossible, closer inspection reveals considerable underlying orderliness. Poulton (1968) discovered six "laws" of the "new psychophysics," showing how the judgmental value assigned to a physical stimulus varies systematically depending upon how it is elicited. There is no reason for judgments of internal states (regarding the desirability of consequences) to be immune to these effects.

Inferring Values

Judgments are sensitive to elicitation procedure because formulating a response always involves an inferential process. When confronted with an issue for which neither habit nor tradition dictates our answer, we must decide which of our basic values are relevant to that situation, how they are to be interpreted, and what weight each is to be given. Unless one has thought deeply about the issue, it is natural to turn to the questioner for hints as to what to say. Table 2.4 summarizes the elicitor's opportunities. They begin with deciding that there is something to question. In this fundamental way, the elicitor impinges on the respondent's values. By asking about the desirability of premarital sex, interracial dating, daily prayer, freedom of expression, or the fall of capitalism, the elicitor may legitimate events that were previously viewed as unacceptable or cast doubts on events that were previously unquestioned. Opinion polls help set our national agenda by the questions they do and do not ask (Marsh, 1979). Advertising helps set our personal agendas by the questions it induces us to ask ourselves (two door or four door?) and those it takes for granted (more is better).

Once the issue has been evoked, it must be given a label. In the

Table 2.4

Ways That an Elicitor May Affect

A Respondent's Judgments of Value

Defining the issue
Is there a problem?
What options and consequences are relevant?
How should options and consequences be labeled?
How should values be measured?
Should the problem be decomposed?
Changing the respondent's perspective
Altering the salience of perspectives
Altering the importance of perspectives
Choosing the time of inquiry
Changing confidence in expressed values
Changing the apparent degree of coherence
Changing the respondent
Destroying existing perspectives
Creating perspective
Deepening perspectives

Source: Fischhoff, Slovic & Lichtenstein, 1980, p. 123.

absence of hard evaluative standards, such symbolic interpretations may be very important (Marks, 1977). While the facts of abortion remain constant, individuals may vacillate in their attitude as they attach and detach the label of "murder." The use of economic, psychological, or anthropocentric terminology may invoke particular modes of thought and ethical standards (Ashcraft, 1977). When asked to choose between a gamble with a 0.25 chance of losing $200 (and a 0.75 chance of losing nothing) and a sure loss of $50, most people prefer the gamble; however, when the sure loss is called an "insurance premium," most people will forego the $50. When these two versions are presented to the same individuals, many will reverse their preferences for the two options. Table 2.5 shows a labeling effect that produced a reversal of preference with practicing physicians; most preferred Program A over Program B, and Program D over Program C, despite the formal equivalence of A and C and of B and D. The labels, saving lives and losing lives, afforded very different perspectives on the same problem.

People solve problems, including the determination of their own values, with what comes to mind. The more detailed, exacting, and creative their inferential process is, the more likely they are to think of all they know about a question. The briefer that process becomes, the more they will be controlled by the relative accessibility of various considerations. Accessibility may be related to importance, but it is also related to the associations that are evoked, the order in which questions are posed, imaginability, concreteness, and other factors only loosely related to importance. For example, Turner and Krauss (1978) observed that in two simultaneous national surveys, people

Table 2.5

Two Formulations of a Choice Problem

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the consequences of the programs are as follows:

If Program A is adopted, 200 people will be saved.

If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved.

Which of the two programs would you favor?

Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the consequences of the programs are as follows:

If Program C is adopted, 400 people will die.

If Program D is adopted, there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die.

Which of the two programs would you favor?

Source: Tversky & Kahneman, in press.

expressed less confidence in national institutions when asked after answering six items relating to "political alienation." Fischhoff, Slovic, Lichtenstein, Layman and Combs (1978) found that people judged the risks associated with various technologies to be more acceptable following a judgment task concerning the benefits of those technologies than following a task dwelling on their risks. According to Wildavsky (1966), the very act of asking people for their own personal values may suppress the availability of social values, as might asking them what their values are, rather than what they should be, according to whatever ethical principles seem relevant (Tribe, 1973). Even altering the time of questioning may affect the perspectives an individual considers. Consider people who regularly take stock of the world late at night and whose existential decisions are colored by their fatigue. Are those values to be trusted or should one rely on the way they value their lives at high noon on a bright spring day?

Evolving Values

It would be comforting to be able to say which way of phrasing value questions is the right one. Indeed, there are norms and procedures for spotting deliberately confusing or biased formulations(Payne, 1952; Zeiscl, 1980). However, no procedure can guarantee a polished product when respondents start with an incoherent opinion or none at all. Different perspectives may continue to evoke opinions that refuse to converge. Indeed, life is too short and too involved for anyone to have articulated preferences on every issue that might be posed by a pollster or decision-making specialist.

When the questioner must have an answer (say, because public input is statutorily required), there may be no substitute for an elicitation procedure that educates respondents about how they might look at the question and what are the practical implications and logical concommitants of various possible perspectives. The possibilities for manipulation in such interviews are obvious and, indeed, protracted interactions with respondents are anathema to many surveyers. However, one cannot claim to be serving respondents' best interests (letting them speak their minds) by asking a question that touches only one facet of a complex and incompletely formulated set of views.

Just as deliberative interaction and analysis may help to shape values, so may experience. To some extent, we come to know what we want on complex issues by making decisions as best we can and waiting to see how well we like their consequences. Changes in attitudes toward the environment over the last decade must reflect at least in part the results of the expensive and intensive period of learning-by-doing following World War II.

Summary

The existence of a value question is no guarantee that anyone has an articulated answer. In such situations, questions still must be posed in some way and the formulation chosen may shape the opinions that emerge. To capture the essence of acceptable-risk problems, an approach to decision making must acknowledge that values are inherently involved with the problem and that uncertainty may surround our values as well as our factual knowledge. An approach might, indeed, be designed to help us learn what we want.

Uncertainties about the Human Element

People create both technological hazards and the schemes for managing them. They generate and identify their own needs, accept technologies as addressing those needs, assess the risks and benefits these technologies incur, use them wisely or unwisely, see or miss the need for ameliorative action when things go wrong, and so on. As consumers, voters, legislators, regulators, operators, and promoters, people shape the world within which technologies operate and thus determine the effective degree of hazard that these technologies pose. Approaches to acceptable-risk decisions make assumptions about this behavior in (a) predicting lay people's perceptions of and responses to the risks they face, (b) assessing decision makers' confidence in the recommendations of the risk analysts, and (c) evaluating the quality of the technical judgments provided by experts forced to go beyond the available data.

Two contradictory assumptions can be found in discussions of human behavior: One is that people are extremely perceptive and rational (as defined by economic theory); such people make the best of the options offered to them by the marketplace, serve reliably as the operators of hazardous vehicles, and respond admirably to appeals and warnings. The contrasting assumption is that people are ignorant, unreasonable, and irrational; these people refuse to believe competent technical analyses, fight dirty in policy debates, and generally need to be replaced by more scientific individuals and methods. A popular hybrid assumes that people are perfect hedonists in their consumer decisions, but have no understanding of broader historical, political, or economic issues.

One reason for the survival of such simplistic and contradictory positions is political convenience. Some people want the lay public to participate actively in acceptable-risk deliberations and thus want to describe the public as competent; others need an incompetent public to justify an expert elite. A second reason is theoretical convenience; it is hard to build models of people who are sometimes good, sometimes stumbling. Perhaps the need for being disciplined by systematic observation is not always felt very strongly because one can so readily speculate about human nature and even produce a few bits of supporting anecdotal evidence. Good social theory may be so rare because poor social theory is so easy (Hexter, 1971). However, speculations about human behavior, like speculations about chemical reactions, must be based on evidence. Decisions and methods based on erroneous assumptions are likely to have unhappy outcomes. Moreover, since persistent repetition of such speculations can create myths about lay people and experts and their respective roles in the decision-making process, failure to validate them may mean arrogating to oneself considerable political power.

How Accurate Are Lay Perceptions?

At first blush, assessing the public's risk perceptions would seem to be very straightforward. Just ask questions like, "What is the probability of a nuclear core meltdown?" or "How many people die annually from asbestos-related diseases?" or "How does wearing a seat belt affect your probability of living through the year?" The responses can be compared with the best available technical estimates, with deviations interpreted as evidence of the respondents' ignorance.

Unfortunately, the elicitation effects that bedevil the study of people's values may be just as potent in affecting their judgments of risk. For example, Table 2.3 showed how choice of response mode could drastically affect lay assessments of lethality; by their choice of method, researchers could similarly affect the apparent wisdom of the respondents in observers' eyes. In addition, simply documenting gaps between the risk perceptions of experts and lay people may not produce the understanding most useful to improving societal decision making. A more insightful strategy might be to ask for each kind of risk information (a) What are its formal properties? (b) What are its observable signs? (c) How are those signs revealed to the individual? (d) Are they contradicted, supported, or hidden by immediate experience? (e) Do people have an intuitive grasp of such information? (f) If their intuitions are faulty, what is the nature of their misunderstanding and how severe are its consequences? (h) Does natural experience provide feedback highlighting misunderstandings and inducing improvement?

These questions ask, in essence, how adequate people's cognitive skills are for coping with the information they receive. Existing research suggests that these skills are often far from perfect. People seem to lack the intuitions and cognitive capacity for dealing with complex, probabilistic problems. As a result, they resort to judgmental heuristics, or rules of thumb, that allow them to reduce such problems to simpler and more familiar terms. On the bright side, these strategies are quite adaptive, in the sense that they always produce some answer and that answer is often moderately accurate. They are maladaptive in that they can produce erroneous judgments; furthermore, the ease with which they are applied inhibits the search for superior methods (Slovic, Fischhoff & Lichtenstein, 1977; Tversky & Kahneman, 1974).

Figure 2.4 shows the results of a study in which educated lay people estimated the absolute frequency of 41 causes of death in the U.S. These people had a pretty good idea of the relative frequency of most causes of death; moreover, quite similar orderings were revealed with different elicitation procedures, suggesting a consistent subjective scale of frequency. However, respondents underestimated the differences in the likelihoods of the most and least frequent causes of death: Subjective estimates differed over 3 to 4 orders of magnitude, while the actual number of deaths varies over 6. In addition, they persistently misjudged the relative likelihood of those causes of death that are unusually visible, sensational, and easy to imagine (e.g., homicides, accidents). In general, overestimated hazards tended to be those that are over-reported in the news media (Combs & Slovic, 1979). A similar pattern of results was found with estimates of the fatalities from various technological hazards (Slovic, Fischhoff & Lichtenstein, 1979).

Is this performance good or bad? One possible summary is that it may be about as good as can be expected, given that these people were neither specialists in the hazards considered nor exposed to a representative sample of information. Accurate perception of misleading samples of information might also be seen to underlie another apparent judgmental bias: People's predilection to view themselves as personally immune to hazards. The great majority of individuals believe themselves to be better than average drivers (Svenson, 1978), more likely than average to live past 80 (Weinstein, in press), less likely than average to

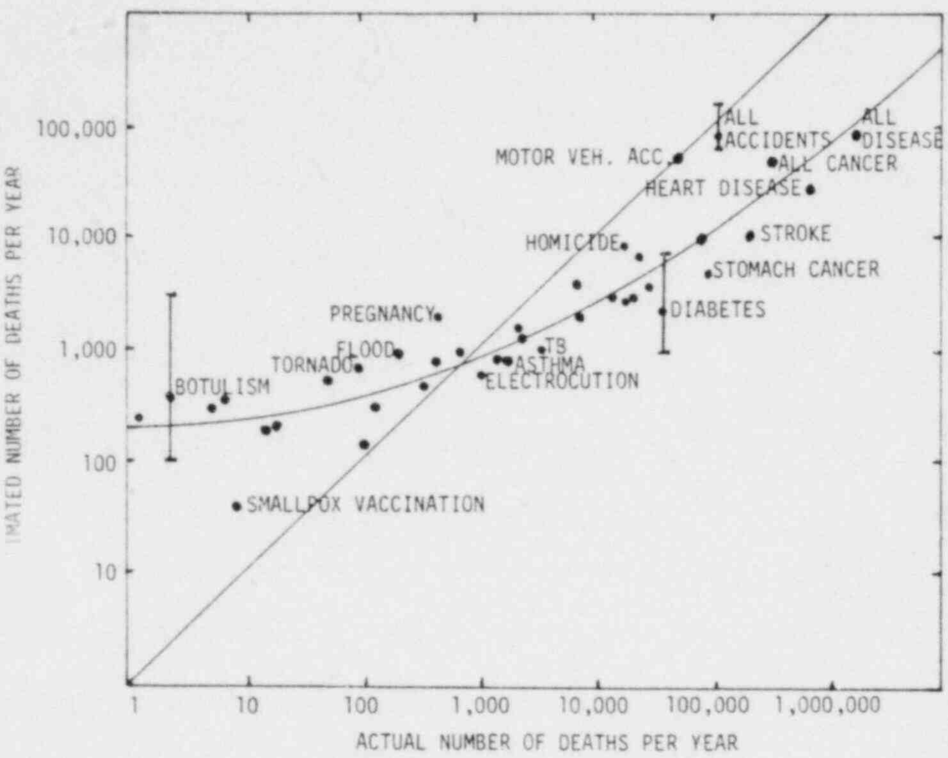


Figure 2.4. Relationship between judged frequency and the actual number of deaths per year for 41 causes of death. If judged and actual frequencies were equal, the data would fall on the straight line. The points, and the curved line fitted to them, represent the averaged responses of a large number of lay people. Although people were approximately accurate, their judgments were systematically distorted. To give an idea of the degree of agreement among subjects, vertical bars are drawn to depict the 25th and 75th percentile of individual judgment for botulism, diabetes, and all accidents. Fifty percent of all judgments fall between these limits. The range of responses for the other 37 causes of death was similar. Source: Slovic, Fischhoff & Lichtenstein (1979).

be injured by tools they operate (Rethans, 1979), and so on. Although such perceptions are obviously unrealistic, the risks look very small from the perspective of each individual's experience. Consider automobile driving: Despite driving too fast, tailgating, etc., poor drivers make trip after trip without mishap. This personal experience demonstrates to them their exceptional skill and safety. Moreover, their indirect experience via the news media shows them that when accidents happen, they happen to others. One could hope that people would see beyond the limits of their own minds and information, but inability to do so need not render them incompetent to make decisions in their own behalf (Slovic, Fischhoff & Lichtenstein, 1980).

Could the Public Be Better Informed?

If lay people have, in fact, done a good job of tracking unrepresentative data, then it would seem that their performance might have been better had the relevant information been presented to them more adequately. The source of much technical information is, of course, the technical community. There are a number of ways in which the experts may fail to inform the public. One is by not telling the whole story about the hazards they know best, because they fear that the information would make the public anxious, because dissemination is not their job, or because they have a vested interest in keeping things quiet (Hanley, 1980).

If listeners realize that the tale an expert tells is incomplete, they may discredit the expert and perhaps exaggerate the presentation's incompleteness ("If I caught that omission, how many others are there that I didn't catch?"). For that to happen, however, the omission must be discovered. Some evidence suggests that more typically what is out of sight is effectively out of mind. For example, Fischhoff, Slovic and Lichtenstein (1978) presented various versions of a fault tree describing ways in which a car might fail to start. These versions differed in how much of the full tree (shown in Figure 2.5) was left out. When asked to estimate degree of completeness, respondents were very insensitive to deletions; even omission of major, commonly-known components, like the ignition and fuel systems, led to only minor decreases in perceived completeness.

Experts may also exacerbate any tendency people have to deny uncertainty generated by gambles like those posed by hazardous but beneficial technologies (Borch, 1968; Kahneman & Tversky, 1979; Kates, 1962; Lichtenstein & Slovic, 1973). In order to reduce the attendant anxiety and confusion, people may insist on statements of fact, not probability. Thus, just before hearing a blue-ribbon panel of scientists report being 95 percent certain that cyclamates do not cause cancer, former Food and Drug Administration Commissioner Alexander Schmidt said, "I'm looking for a clean bill of health, not a wishy-washy, iffy answer on cyclamates" (<u>Eugene Register-Guard</u>, 1976). Likewise, Edmund Muskie has called for "one-armed" scientists who do not respond "on the one hand, the evidence is so, but on the other hand . . . " when asked about the health effects of pollutants (David, 1975). Lord Rothschild (1978) has noted that the BBC does not like to trouble its listeners with hearing about the confidence intervals surrounding technical estimates. In this atmosphere, unduly confident, one-fisted debators, ready

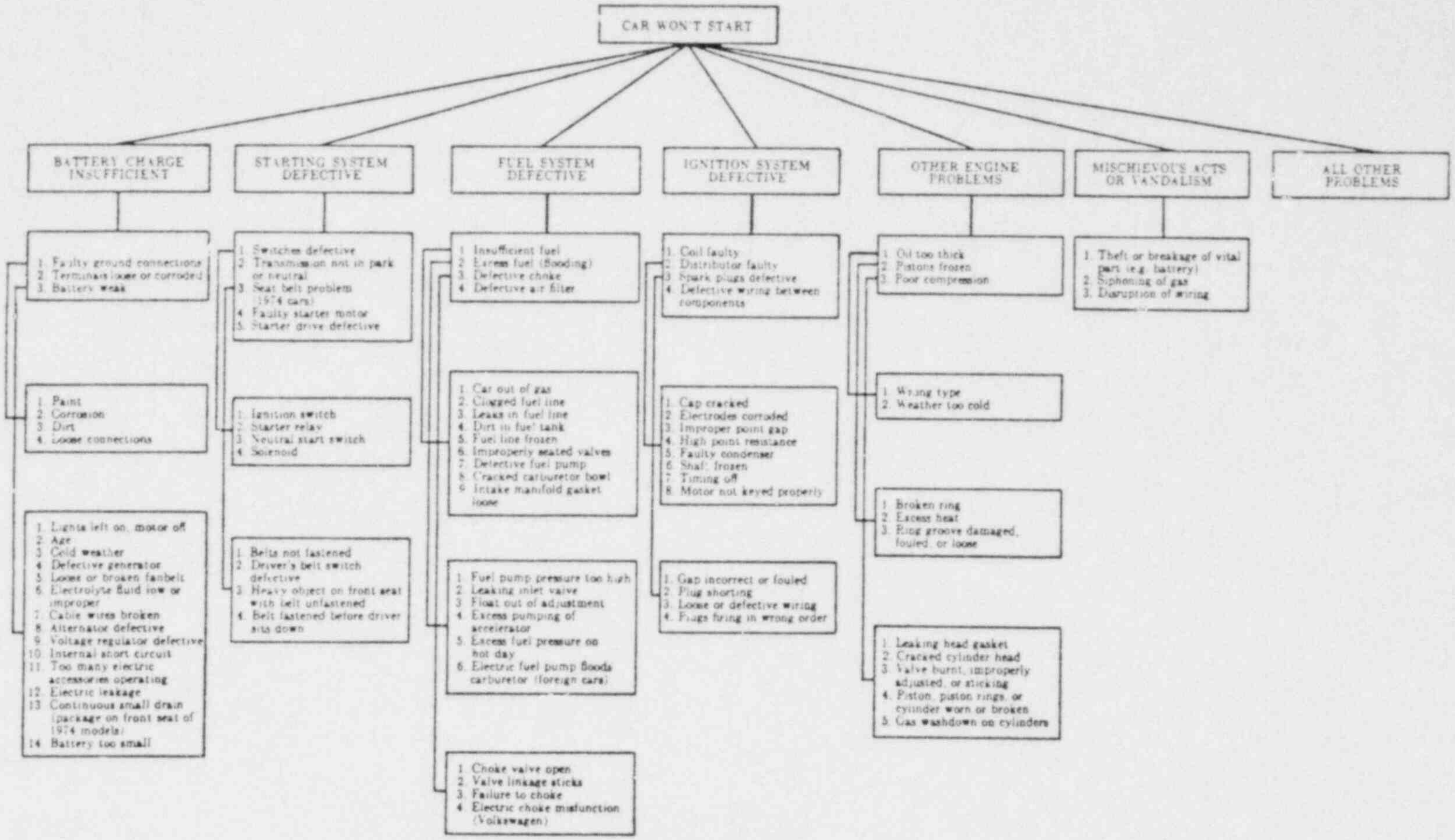


Figure 2.5. A fault tree presenting ways in which a car might not start.
Source: Fischhoff, Slovic & Lichtenstein (1978), p. 331.

to make definitive statements beyond the available data, may unjustifiably win the day from more even-handed scholars. The temptation may be very great to give people the simple answers they often seem to want.

Social as well as psychological processes help to make balanced presentations an endangered genre. The constraints of legal settings (Bazelon, 1980; Piehler, Twerski, Weinstein & Donaher, 1974), the exigencies of the political arena, and the provocations of the news media all encourage adversarial encounters that are inhospitable to properly qualified scientific evidence (Mazur, 1973). Lay people viewing such shouting matches may begin to wonder about these scientists or feel "since they can't agree, my guess may be as good as theirs" (Handler, 1980). One positive repercussion of Three Mile Island was that for a time the public was educated in plain English about the process of nuclear power generation and the sources of technical disputes, not just presented with conflicting assertions about overall safety.

Search for Rationality

In studying people's behavior, perhaps the most reasonable assumption is that there is some method in any apparent madness. For example, Zentner (1979) berates the public because its rate of concern about cancer is increasing faster than the cancer rate. One rational explanation would be that people believe that too little concern has been given to cancer in the past (e.g., our concern for acute hazards like traffic safety and infectious disease allowed cancer to creep up on us). A second is that people may realize that some forms of cancers are the only major cause of death whose rate is increasing. Just as it is counterproductive for lay people to view technology promoters as evil on the basis of insufficient or misinterpreted evidence, it is counterproductive for promoters to view lay people as misinformed and irresponsible on similar grounds.

Other apparently irrational behavior can be attributed to the rational pursuit of unreasonable objectives. This can happen when one rejects the problem definition deemed reasonable by the presenting body. Consider, for example, an individual who is opposed to increased energy consumption but is only asked about which energy source to adopt or where to site proposed facilities. The answers to these narrow questions provide a de facto answer to the broader question of growth. Such an individual may have little choice but to fight dirty, engaging in unconstructive criticism, poking holes in analyses supporting other positions, or ridiculing opponents who adhere to the more narrow definition.

Another source of apparent irrationality is opposition to reasonableness itself. The approaches to acceptable-risk decisions discussed in this report all make the political-ideological assumption that our society is sufficiently cohesive and common-goaled that its problems can be resolved by reason and without struggle. Although such a "get on with business" orientation will be pleasing to many, it will not satisfy those who believe that the decision-making process should mobilize public consciousness. Their response may be a calculated attack on narrowly defined rationality.

Experts are Fallible

Studies or anecdotes showing the fallibility of lay judgment are frequently cited as evidence for reducing the role of lay people in the risk assessment process (e.g., Bradley, 1980; Howard & Antilla, 1979; Sengar, 1980; Starr & Whipple, 1980). Implicit in this argument is often the presumption that experts are immune to judgmental biases. Certainly, their fund of substantive knowledge tells experts where to look for information and how to recognize possible solutions (deGroot, 1965; Larkin, McDermott, Simon & Simon, 1980). However, many risk problems force experts to go beyond the limits of the available data and convert their incomplete knowledge into judgments usable by risk assessors. In doing so, they may fall back on intuitive processes much like those of lay people. Some research evidence is presented below, mostly taken from studies in which scientists could have calculated the probabilities of events (had they been versed in statistical theory as well as their area of substantive expertise), but chose to rely on their intuitions.

Insensitivity to sample size. In an article entitled "Belief in the Law of Small Numbers," Tversky and Kahneman (1971) showed that statistically sophisticated individuals expect small samples to represent the populations from which they were drawn to a degree that can only be assumed with much larger samples. As a result, they gamble research hypotheses on underpowered small samples, place undue confidence in early data trends, and underestimate the role of sampling variability in causing results to deviate from expectations (offering, instead, causal explanations for discrepancies). In a survey of standard hematology texts, Berkson, Magath and Hurn (1939-40) found that the maximum allowable difference between two successive blood counts was so small that it would normally be exceeded by chance 66 to 85% of the time. They mused about why instructors often reported that their best students had the most trouble attaining the desired standard (see also Cohen, 1962, 1971).

Capitalization on chance. A crucial scientific intuition is the ability to detect valid signals in the presence of noise. Chapman and Chapman (1969; also Mahoney, 1977) have found that the expectations of scientists may be so strong that they see anticipated signals even in randomly generated data. A related tendency is to formulate such complicated theories that, with a little creative interpretation, any imaginable set of data can be viewed as being consistent with them (O'Leary, Coplin, Shapiro & Dean, 1974). Indeed, similar problems face attempts to validate even well-formulated theories like fault-tree analyses. Trees and events are so complicated that it may be hard to tell if an observed event actually fell into one of the categories considered in the analysis.

The converse occurs when scientists have no theory, but only a conviction that something interpretable must be happening in an observed set of important data. It is, of course, generally true that, given a set of events (e.g., environmental calamities) and a sufficiently large set of possible explanatory variables (antecedent conditions), one can always devise a theory for retrospectively predicting the events to any desired level of proficiency. The price one pays for such overfitting is shrinkage, failure of the theory to work on a new sample of cases. The frequency and vehemence of warnings against such "correlational overkill" suggests that this bias is quite resistant to even extended professional training (Armstrong, 1975; Campbell, 1975; Crask & Perreault, 1977; Kunce, Cook & Miller, 1975). Even when one is alert to such problems, it may be difficult to assess the degree to which one has capitalized on chance. For example, as a toxicologist, you are "certain" that exposure to Chemical X is bad for one's health. You compare workers who do and do not work with it in a particular plant for bladder cancer, but obtain no effect. So you try intestinal cancer, emphysema, dizziness, . . . , until you finally get a significant difference in skin cancer. Is that difference meaningful? Of course, the way to test these explanations or theories is by replication on new samples. That step, unfortunately, is seldom taken and is often not possible for technical or ethical reasons (Tukey, 1977).

Regression to the mean. When observing events drawn from a population with a constant mean and variance, extreme observations tend to be followed by less extreme ones. Such regression to the mean is statistically but not intuitively obvious (Kahneman & Tversky, 1973). One depressing failure by experts to appreciate it may be seen in Campbell and Erlebacher's (1970), "How regression artifacts in quasi-experimental evaluations can mistakenly make compensatory education look harmful." Upon retest, the performance of the initially better students tends to be lower. Similar misinterpretations may occur whenever one asks only limited questions, such as whether environmental management programs have weakened strong industries or reduced productivity in the healthiest sectors of the economy.

Judging the quality of evidence. The commission of judgmental errors may be less troublesome to effective decision making than is failure to realize the possibility of such errors. As discussed in the following section, a decision-making process may be able to get by with rather faulty inputs as long as it acknowledges the possibility of their fallibility. But when the top experts are generating the inputs, no one else may be knowledgeable enough to correct errors or uncover unwarranted assumptions. Thus the experts must judge the quality of their own judgments. An extensive body of research suggests that lay people are overconfident in assessing their own judgment, so much so that they will accept highly disadvantageous bets based on their confidence judgments. Furthermore, this bias seems to be impervious to instructions, familiarity with the task, question format, and various forms of exhoration toward modesty (Fischhoff, Slovic & Lichtenstein, 1977; Lichtenstein, Fischhoff & Phillips, 1977). A major culprit seems to be insensitivity to the tenuousness of the assumptions upon which beliefs are based. Table 2.2 offered some anecdotal evidence of similar insensitivity among experts. Figure 2.6 shows other examples of experts' overconfidence. The problem lies not in getting the wrong answer, but in failing to realize how great the possibility for error was. Summarizing its review of the Reactor Safety Study, the "Lewis" Commission noted that despite the great advances made in that study "we are certain that the error bands are understated. We cannot say by how much. Reasons for this include an inade-

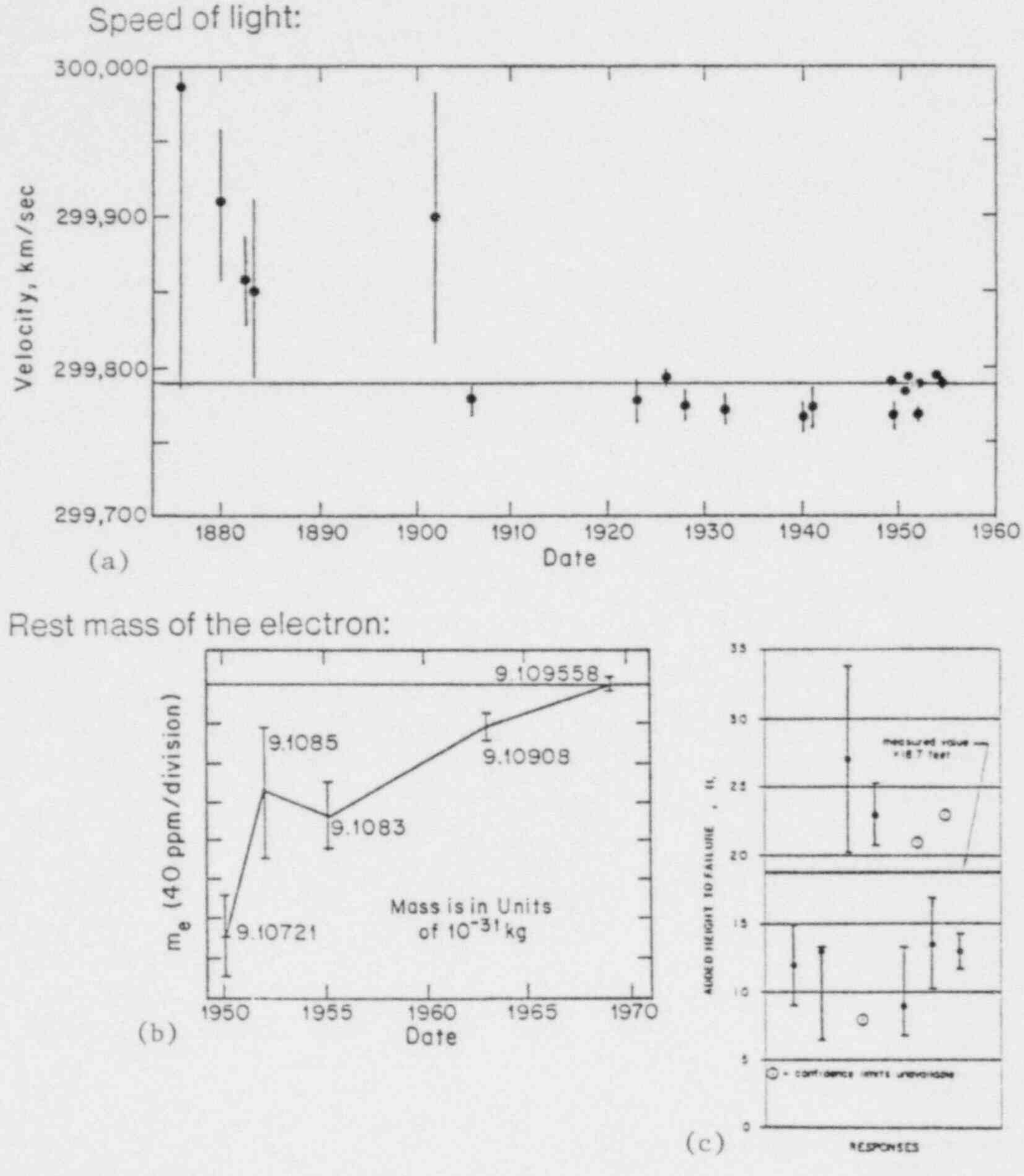


Figure 2.6. Three examples of overconfidence in expert judgment. Overconfidence is represented by the failure of error bars to contain the true value: (a) estimates of the speed of light (Rush, 1956); (b) estimates of the rest mass of the electron (Taylor, 1974); (c) estimates of the height at which an embankment would fail (Hynes & VanMarcke, 1976). Our thanks to Max Henrion for Figures a and b.

quate data base, a poor statistical treatment, [and] an inconsistent propagation of uncertainties throughout the calculation" (U.S. Government, 1978, p. vi).

Summary

However mathematical their format, approaches to acceptable risk are about people; for an approach to aid the decision-making process, it must make assumptions about the behavior and, in particular, the knowledge of experts, lay people, and decision makers. When these assumptions are unrecognized or in error, they can lead to bad decisions and distortions of the political process.

Difficulties in Assessing Decision Quality

The previous four sections have shown how uncertainty may surround acceptable-risk decisions: their definition, the facts they use, the values they evaluate, and the behavior of the individuals whom they describe and serve. A fifth kind of uncertainty concerns the overall quality of the decision reached by an approach. An appraisal of that quality tells consumers of an approach how much confidence they should place in its conclusions. An appraisal tells the purveyors of an approach whether they should try again before reaching any conclusions, by recruiting more information, assessing value issues more thoroughly, consulting additional individuals, changing the problem definition, or using an alternative method. In principle, an approach should be capable of reporting that it is not up to the task, either because the uncertainties are so great as to render its conclusions indeterminate or because crucial uncertainties lie in areas that the method does not address. When an approach fails to assess the robustness of its own conclusion, it implies that what it says goes, or at least is the best guess available.

The following are a number of generic ways to assess decision quality and their limitations.

Sensitivity Analysis

One general approach to assessing decision quality is sensitivity analysis, as developed by formal analysts (Ch. 6). Users first derive a best guess at the most acceptable option based on the best available estimates of the relevant facts and values; the decision-making process or computation is then repeated using alternative estimates for uncertain components. That is, one tests the sensitivity of the conclusions to possible errors in the estimates used, conferring more confidence on more robust conclusions. In informal decision making, sensitivity analysis might take the form of statements like "the climb may be riskier than our guide thinks, but even if it were, I'd still be willing to go."

To apply a sensitivity analysis, one must know where the uncertainty lies and what its extent might be. The possibility of uncertainty due to judgmental biases would, for example, be considered only if one were aware of the relevant psychological findings and took them seriously. The biases would threaten the sensitivity analysis itself if, as suggested in previous sections, they rendered the analyst insensitive to omissions and overconfident about current knowledge.

A further threat arises when sensitivity analyses treat possible problems in isolation; in such cases, the analyst may have a very limited feeling for how uncertainty from different sources of error compounds. As noted by the "Lewis" Commission, "errors and uncertainties must be made explicit and carried through succeeding stages of the calculation to see how they affect the final conclusion." (U.S. NRC, 1978, p. 9). Although varying more than one parameter at a time affords some protection, multi-valued sensitivity analyses are complex and costly. Too often, it is assumed that errors in different inputs will cancel one another out, rather than compound in some pernicious way (Tihansky, 1976). One situation in which this independence assumption seems doubtful is when a set of judgments is elicited with the same procedure, inducing the same perspective. For example, asking about preferences in a mode that uses a reference to dollar values might persistently deflate the expressed importance of environmental or other less tangible values. To take an example from the elicitation of judgments of fact, the Reactor Safety Study (U.S. NRC, 1975) called upon its experts to assess unknown failure rates by the "extreme fractiles" method, choosing one number so extreme that there was only a 5% chance of the true rate being lower and another such that there was only a 5% chance of the true rate being higher. Research conducted with a variety of other tasks and judges indicates that this technique produces particularly narrow confidence intervals, systematically exaggerating the precision of estimates (Lichtenstein, Fischhoff & Phillips, 1977).

Such correlated errors or recurrent biases represent a sort of analytical common-mode failure. From a technical standpoint, sensitivity analyses might be devised that could handle simultaneously the uncertainty from a variety of sources. Conceptually, however, it seems inappropriate to treat the persistent imposition of a particular perspective in the course of eliciting respondents' values as an error of measurement. Nor can the most sophisticated sensitivity analysis address the issue of inappropriate or incomplete problem definitions.

Error Theory

An alternative to case-by-case sensitivity analyses is to develop a theory offering some general insight into how seriously the limits or uncertainties of a decision-making process imperil its conclusions.

For example, Kastenberg, McKone and Okrent (1976) found that, as a rule, risk assessments are extremely sensitive to how outliers (unusual observations) are treated. Thus, whether one takes seriously or discounts unusual events may greatly influence the decisions one reaches. On the other hand, von Winterfeldt and Edwards (1973) showed that, under quite general conditions, modest inaccuracy in assessing probabilities or values should not have too great an effect on decisions with continuous options (e.g., invest $X or increase production by Y%). Furthermore, when one is assessing the same probability for each of several alternatives on the basis of a set of common attributes (e.g., the probability of 6 candidates succeeding in graduate school on the basis of the same test scores), it doesn't matter very much how one weights the different attributes (Dawes & Corrigan, 1974).

When the decision options, however, are discrete (e.g., operate/don't operate), poor probability assessment can be quite costly (Lichtenstein, Fischhoff & Phillips, 1977). This may be especially true when dealing with low-probability events. Modest underassessment may push the event below the threshold of concern, perhaps meaning not only that nothing is done, but that the topic is not even monitored for future signals. Overassessment may leapfrog the event over other low-probability/high-consequence events in our hierarchy of concerns and lead to the neglect of more important issues. Many advocates of nuclear power believe that its risks have been exaggerated to the detriment of concern over the effects of fossil fuels, such as CO_2-induced climatic changes or acid rain.

These fragments of an error theory allow one to make some general statements about which problems are likely to be most difficult and which conclusions are most likely to be suspect. An approach to acceptable-risk decisions could either generate its own error theory or translate its efforts to a form amenable to applying these quality-assessment techniques.

Convergent Validation

Trevelyan observed that "several imperfect readings of history are better than none at all." When a decision-making process and its implementers are known to be imperfect, we might use additional methods and experts hoping that they do not share common flaws. If they point to the same conclusion, our confidence in the quality of our decisions should increase; if they disagree, then at least we know something about the range of possibilities. Such convergent validation is akin to a sensitivity analysis in which the inputs remain the same, but the method for integrating them varies.

The reasonableness of this strategy hinges upon the existence of independent methods and opinions. A persistent threat to independence is the possibility that conceptions and misconceptions are widely shared within a decision-making or expert community. Studies of surprise attacks reveal that the experts, however great their number, shared the same essential incomplete perspective (Janis, 1972; Stech, 1979). In a sense, they were all reading the situation with the same limited perspective; the better they read, the quicker they met their demise (Lanir, 1978). Thus, when the experts or decision-making methods do agree, one still must make some determination of their absolute level of wisdom. Knowing the most about a topic is not an assurance of knowing a lot about it in an absolute sense. Figure 2.7 illustrates this point. Relative novices in automotive mechanics may understand as much about cars as "experts" understand about some sophisticated technologies. Creating a technology does not guarantee creation of a cadre of experts who comprehend it entirely.

In this light, agreement may not always be desirable or reassuring. Some issues may be so complex that no one method can hope to get the right answer. In such cases, agreement may indicate that, despite their exterior differences, the methods share underlying assumptions and prejudices. One might be better off adopting an interactive approach to knowledge, encouraging different disciplines and vested interests

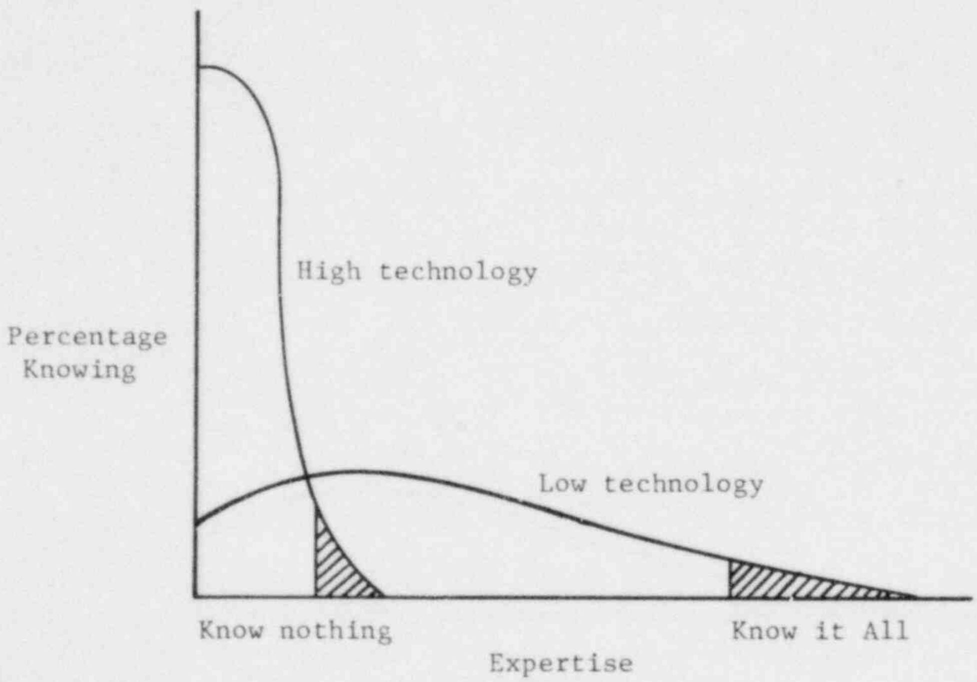


Figure 2.7. Possible distributions of expertise for simple and sophisticated technologies. The shaded area indicates the 5% of population who know most.

to criticize one another's arguments. Such disputations would emphasize identifying and correcting mistakes, rather than trying to produce the right answer from whole cloth. Accommodating critiques would require an iterative approach, continuing until correcting old problems stopped revealing new ones. Consensual positions emerging from this process would not be suspected of having been achieved the easy way.

The search for disagreement can produce disagreeable situations. At times, the estimates made by a sample of experts will reveal an orderly unimodal distribution of opinion, as represented in Figure 2.8a, a fictional distribution of expert assessments of a single parameter. At other times, one will find a majority and a minority opinion clustered around distinct means (Figure 2.8b). Views regarding the health effects of cigarettes (Burch, 1978), low-level ionizing radiation (Marx, 1979), or natural lead concentrations (Settle & Patterson, 1980) might reveal this latter pattern. Whereas a measure of central tendency might summarize opinions in the first case, aggregation seems more dubious in the second. The mean, for example, represents an opinion held by no one, whereas the mode or median would obscure the disagreement.

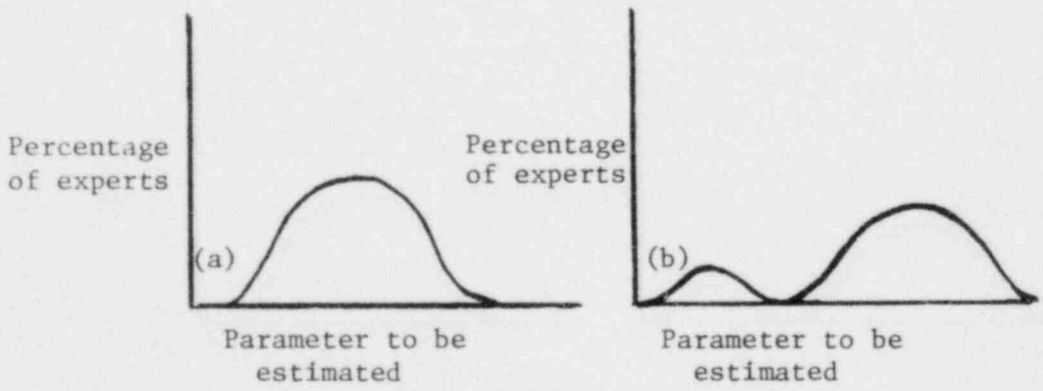


Figure 2.8. Distribution of expert opinion: (a) consensual issues; (b) split opinions.

Track Record

Approaches are adopted in part because they have the reputation of producing good decisions. Yet it is hard to find systematic field studies of the efficacy of any of the approaches to resolving acceptable-risk questions. The absence of studies may reflect the difficulty of establishing whether a society is better off for having adopted an approach.

For example, one need not endorse an approach simply because it is widely accepted. People may tout an approach because it embodies their world outlook, produces congenial recommendations, or provides their livelihood. Nor need one reject an approach because it has produced some notably bad outcomes. The muckraker in us is drawn to stories of welfare cheaters or "over-regulated" hazards. However, any fallible decision-making system produces errors of both kinds; for every hazard handled too harshly, there is one (or several or a fraction of a) hazard that is treated too lightly by the same imperfect system. In fact, the two error rates are tied in a somewhat unintuitive fashion that depends upon the quality of the decision-making process and available resources (Einhorn, 1978). Before criticizing the regulatory system for coming down too hard (or too easily) in a few cases, one should ask whether there are not too few horror stories of that type, given the ratio of errors of commission to errors of omission.

In other problems, apparently poor decisions may be the result of efficaciously solving the wrong problem. For example, the decision-making process that led Ford to reduce costs in manufacturing the Pinto's fuel system received much criticism, especially after the company had lost a $125 million dollar settlement. The validity of such criticism depends upon knowing the problem to which that decision-making process was applied. If it was purely a matter of profits, then a guaranteed saving of $11 on each of ten million Pintos makes the risk of a few large law suits seem like a more reasonable gamble. Since the judgment was reduced to $6 million upon appeal, the company may have come out ahead financially in the short run (although the impact of the adverse publicity might change that assessment). The decision looks different if Ford was trying to decide whether to invest safety dollars in design or whether to improve the fuel tank or pass the savings on to consumers who might be able to use it more efficaciously to reduce other risks in their lives.

These evaluations of Ford's approach to making acceptable-risk decisions were conditioned on knowing what problem Ford was trying to solve and on knowing how things turned out after the decision was made. Although such outcome knowledge is thought to confer the wisdom of hindsight on our judgments, its advantages may be oversold. In hindsight, people consistently exaggerate what could have been anticipated in foresight. They not only tend to view what has happened as having been inevitable, but also to view it as having appeared "relatively inevitable" before it happened. People believe that others should have been able to anticipate events much better than was actually the case. They even misremember their own predictions so as to exaggerate in hindsight what they knew in foresight (Fischhoff, 1975). Although it is flattering to believe that we would have known all along what we could only know in hindsight, that belief hardly affords us a fair appraisal of the extent to which surprises and failures are inevitable. It is both unfair and self-defeating to castigate decision makers who have erred in fallible systems, without admitting to that fallibility and doing something to improve the system. According to historian Roberta Wohlstetter (1962), the lesson to be learned from Pearl Harbor is not that American intelligence was incompetent, but that we must "accept the fact of uncertainty and learn to live with it. Since no magic will provide certainty, our plans must work without it." (p. 401).

A further obstacle to evaluating decision-making methods is identifying their areas of proficiency. For example, banks are usually viewed as adroit decison makers. Yet this reputation may come primarily from their success in making highly repetitive and very secure tactical decisions. Home mortgages are issued on the basis of conservative interpretations of statistical tables acquired and adjusted through massive trial-and-error experience. Bank ventures into more speculative realms (e.g., real estate investment trusts in the 1960's, loans to third world countries in the 1970's) suggest that the prowess of their methods may not carry over to innovative strategic decisions.

Table 2.6 lists further complications in the evaluation of decision-making methods. This list emerged from studying the attempts of another helping profession, psychotherapy, to assess its efficacy.

Summary

To guide social policy, an approach to determining acceptable risk must be able to assess its own limits and inform us of that assessment. Since the methodology needed for this task is in a rather primitive state, we must rely on our own intuitions. As elsewhere, these judgments can lead us astray, producing too much or too little confidence in the quality of decisions.

Table 2.6

Effects that Complicate Attempts to Evaluate the Efficacy of a Decision-Making Method

(a) The fact that practitioners have been trained in a method and claim to be carrying it out is no guarantee that they are. Assessing fidelity of implementation is crucial for knowing what is being evaluated.

(b) A well-designed method may fail because of unanticipated and uncontrollable changes in the world. Thus "good method" does not necessarily imply "good outcome."

(c) At times decision-making methods look good because they were fortunate enough to be used at times when one could not lose. Almost everybody and every method made money in the stock market of the 1950's and early 1960's. Thus "good outcome" does not necessarily imply "good method."

(d) In some cases, defining a "good outcome" is far from trivial, for example, when one must weigh short-term and long-term well-being.

(e) The apparent success of some methods may be less due to their substance than to the atmosphere they create. These "non-specific treatment effects" include reduced anxiety, increased self-confidence, and heightened attention to the problem.

(f) Anecdotal evaluations may be misled by tendencies to be influenced by professional folklore and to interpret random fluctuations as consistent patterns.

(g) An evaluation can be biased by looking only for the positive effects a method produces and ignoring possible detrimental effects, or by looking only for the negative effects.

Source: Fischhoff (1980b).

Can Facts and Values Be Separated?

Throughout this chapter, we have presumed a clear-cut distinction between facts and values. As argued by Hammond and Adelman (1976), Mazur, Marino and Becker (1979), and others, such a separation can have a powerful impact on clearing the air in debates about risk. Without a commitment to separation, debates about the facts may fill up with half-truths, loaded language, and character assassinations, as the sides try to get their points and experts heard. Even technical experts may fall prey to partisanship as they advance views on political topics beyond their fields of expertise, downplay facts that they believe will worry the public, or make statements that cannot be falsified.

Although a commitment to separate values and facts can minimize cases of values hiding in facts' clothing, it cannot assure that a complete separation will ever be possible (Bazelon, 1979; Callen, 1976). The "facts" of a matter are only those deemed relevant to a particular problem, whose definition forecloses some action options and effectively prejudges others. As discussed earlier, deciding what the problem is goes a long way to determining what the answer will be. Hence, the "objectivity" of the facts is always conditioned on the assumption that they are addressing the "right" problem, where "right" is defined in terms of "society's best interest," not the interest of a particular party. The remainder of this section elaborates on how our values determine what facts we produce and use, and how our facts shape our values.

Values Shape Facts

Without information, it may be hard to arouse or sustain concern about an issue, to allay inappropriate fears, or to achieve enough certainty to justify any action. However, information is, by and large, created only if someone has a use for it. That use may be pecuniary or scientific or political. Thus we may know something only if someone in a position to decide feels that it is worth knowing. Doern (1978) proposed that lack of interest in the fate of workers is responsible for the lack of research on the risks of uranium mining; Neyman (1979) wondered whether the special concern over radiation hazards has restricted the study of chemical carcinogens; Commoner (1979) accused oil interests of preventing the research that could establish solar power as a viable energy option. In some situations, knowledge is so specialized that all relevant experts may be in the employ of a technology's promoters, leaving no one competent to discover troublesome facts (Gamble, 1978). As noted in the discussion of decision quality, if one looks hard enough for, say, adverse effects of a chemical, chance alone is likely to produce an occasional positive finding. Although such spurious results are likely to vanish when the studies are replicated, replications are the exception rather than the rule in many areas. Moreover, the concern raised by a faulty study may not be as readily erased from people's consciousness as from the scientific literature (Holden, 1980; Kolata, 1980). A shadow of doubt is hard to remove.

Legal requirements are an expression of society's values that may strongly affect its view of reality. Highway-safety legislation affects accident reports in ways that are independent of its effects on accident rates (Willson, 1980); crime prevention programs may have similar effects, inflating the apparent problem by encouraging victims to report crimes (National Academy of Sciences, 1976). Although not always exploited for research purposes, an enormous record of medical tests has been created by the defensive medicine engendered by fear of malpractice. Legal concerns may lead to the suppression as well as the creation of information, as doctors destroy "old" records that implicate them in the administration of DES to pregnant women in the 1950's, employers fail to keep "unnecessary" records on occupational hazards, or innovators protect proprietary information (Lave, 1978; Pearce, 1979; Schneiderman, 1980).

Whereas individual scientists create data, it is the community of scientists and other interpreters who create facts, by explicating competing data and underlying assumptions (Levine, 1974). Survival in this adversarial context is determined in part by what is right (i.e., truth) and in part by the staying power of those who collect particular data or want to believe in them. By its scrutiny, each side in a dispute tries to eliminate erroneous material prejudicial to its position. Scrutiny from both sides is a valuable safeguard, likely to improve the quality of the analysis. If only one side scrutinizes, the resulting analyses will be unbalanced. Since resources are required to stay with a problem, the winners in the marketplace of ideas may tend to be the winners in the political and economic marketplace.

Facts Shape Values

Values are acquired by rote (e.g., in Sunday School), by imitation, and by experience (Rokeach, 1973). The world we observe tells us what issues are worth worrying about, what desires are capable of fruition, and who we are in relation to our fellows. Insofar as that world is revealed to us through the prism of science, the facts it creates shape our world outlook (Appelbaum, 1977; Henshel, 1975; Markovic, 1970; Menkes, 1978; Shroyer, 1970). The content of science's facts can make us feel like hedonistic consumers wrestling with our fellows, like passive servants of society's institutions, like beings at war with or at one with nature. The quantity of science's facts (and the coherence of their explication) may lower our self-esteem and enhance that of technical elites. The topics of science's inquiries may tell us that the important issues of life concern the mastery of others and of nature, or the building of humane relationships. Some argue that science can "anaesthetize moral feeling" (Tribe, 1972) by enticing us to think about the unthinkable. For example, although it may be true that we set an implicit value on human life in many of our policy decisions, making that value explicit may cost us more through eroding our social contract than it benefits us by clarifying our decision making.

Even flawed science may shape our values. According to Wortman (1975), Westinghouse's incompetent evaluation of the Head Start program in the mid-sixties had a major corrosive effect on faith in social programs and the liberal ideal. Weaver (1979) argued that whatever technical problems are found with Inhaber's (1979) comparison of the risks of different energy sources, he has succeeded in creating a new perspective that is dangerous to the opponents of nuclear power. Page (1978, 1980) has demonstrated how the low statistical power of many toxicological studies effectively represents a social policy that protects chemicals more than people. In designing such studies, one must make a tradeoff between avoiding false alarms (i.e., erroneously calling a chemical a non-carcinogen) and misses (i.e., not identifying a carcinogen as such). The decision to study many chemicals with relatively small samples means low power, which increases the miss rate and decreases the false-alarm rate. The value bias of such studies is compounded when scientific caution also becomes regulatory caution.

Summary

Separating issues of fact and of value is a fundamental aspect of intellectual hygiene. Failure to do so may lead scientists to play pundits and politicians to [illegible]pert. However, commitment to this principle must not blind us to the subtle ways in which facts and values are intertwined as we define our problems, choose topics for study, interpret data, show respect for divergent views, and give credence to non-scientific evidence. Science both reflects and forms social conditions.

Summary

Any approach to answering acceptable-risk questions must contend with a series of generic problems. These include (a) ambiguities in how to define the decision problem, (b) difficulties in ascertaining the facts of the matter, (c) uncertainty regarding whose values are to be represented and how they are to be elicited, (d) cognitive limitations in the people who apply the approach and deliberate its recommendations, and (e) questions about how to evaluate the quality of the decision process.

The bulk of this report analyzes several approaches in the light of these problems. How each attempts to contend with them affords a characterization of its underlying logic. How well each succeeds affords an assessment of its viability as a guide to social policy.

CHAPTER 3

Chocsing an Approach to Acceptable Risk: A Metadecision Problem

Unlike organized sports, hazard management has no "book" summarizing extensive trial-and-error experience in a set of rules for decision making. As a result, there may be as many approaches to acceptable-risk decisions as there are decision 'akers. Two people might agree on the risks to accept from one energy source and disagree on the risks to accept from another source, like opinionated fans watching (or playing) a game whose intricacies they have yet to understand. The sharp disputes between Lord Rothschild (1978) and the editors of Nature (1978) or between Herbert Inhaber (1979) and John Holdren (1979) about procedures for making acceptable-risk decisions suggest that we are a long way from a consensus among even society's better-informed citizens. Agreement is most likely to be found among individuals concerned with only a segment of acceptable-risk problems with which they have had hands-on experience. These include vested interests who have confidence in simple decision rules like "what is good for (General Motors, wilderness, etc.) is good for America" and specialists who "know" how to make components that are safe enough (e.g., valves, evacuation schedules). Without a procedure or conceptual framework for amalgamating these diverse perspectives, there is no way to pass from a narrow focus to more comprehensive wisdom. Even if one trusted the market or the corporations or the environmentalists or the engineers to make some decisions within their area of concern and expertise, one might not believe that this competence extended to more global decisions like coal versus nuclear power. Nor need one assume that expertise acquired through trial and error in the past confers any advantage in coping with complex, novel situations. Having developed effective rules of behavior need not guarantee mastery of rules of decision making.

Given the lack of consensus about methods, it is hard to say how acceptable-risk decisions are being made today. There seem to be a variety of approaches, often with poorly articulated rationales and idiosyncratic application reflecting transitory balances of intellectual, political, and economic power. Rather than trying to describe and criticize the specific approaches by which acceptable-risk decisions are being made, we have chosen to identify and analyze archetypal approaches by which decisions might be made. Although our focus is on the prescriptive appeal of these pure forms, the set of generic approaches we have created could be used to describe the hybrid forms encountered in practice. One might even design deliberate hybrids with compensating strengths.

The three categories of coordinated, deliberative decision-making approaches that we have identified appear in Table 3.1. They are described briefly here and in greater detail in Chapters 4-6. Those chapters characterize (or define) the approaches by how, if at all, they attempt to deal with the five generic complexities of risk problems described in Chapter 2. The potential of each approach to satisfy society's diverse demands is also evaluated, using a set of seven criteria developed later in this chapter; the first of these criteria is "does the approach adequately address the five complexities?" Others consider how an approach fits into the political and institutional reality within which acceptable-risk decisions are made.

Table 3.1

Three Archetypal Approaches to Acceptable-Risk Decisions

Approach	Decision Maker	Decision-Making Criterion	Locus of Wisdom	Description
Formal analysis	Government	Societal optimization	Formalized intellectual processes	Formal methods of decision theory specify decisions most consistent with accepted view of facts and values
Boot-strapping	Government	Preservation of historical balance	Societal processes	Implicit standards derived from description of past or present policies used as prescription for future action
Profes-sional Judgment	Technical experts	Professional judgment	Intuitive intellectual processes	Selected options emerge from decisions of qualified experts conforming to professional code which may be formulated in terms of practices, performance standards, or good judgment

Formal Analysis

Formal analysis assumes that intellectual technologies can help us manage the problems created by physical technologies. Cost-benefit analysis and decision analysis are the most prominent techniques for thinking our way out of whatever troublesome situations we have created for ourselves. Evolving from economic and management theory, these approaches share a number of common features:

(a) Conceptualization of acceptable-risk problems as decision problems, requiring a choice between alternative courses of action. For example, cost-benefit analysis attempts to identify the option with the greatest preponderance of benefits over costs.

(b) A divide-and-conquer methodology. Complex problems are decomposed into more manageable components which can be assessed individually and then combined to provide an overall assessment.

(c) A strongly prescriptive decision rule. The components are combined according to a formalized procedure; if one accepts the assumptions underlying the analysis and its implementation, then one should follow its recommendations.

(d) Explicit use of a common metric. Decisions are hard when one must make value tradeoffs between conflicting objectives. In order to compare different consequences, formal methods reduce them to a common unit (e.g., dollar value).

(e) Official neutrality regarding problem definition. These techniques are intended to be applicable to all problems with clearly delineated consequences, measurable options, and identifiable decision makers.

Purveyors of formal analysis tout its potential rigor, comprehensiveness, and scrutability. Skeptics wonder how often this potential is realized. Are analyses accessible to interested observers? Can all consequences and options of interest be accommodated? Don't actual applications have a more ad hoc flavor than the theory would suggest? Critics also worry about power being concentrated in an intellectual elite, analysts failing to appreciate the organizational impediments to implementing recommendations, and ideological biases lurking in the ostensibly neutral assumptions underlying the methods.

Bootstrapping Approaches

Whatever theoretical appeal formal analysis may have, the technical difficulties encountered in trying to conduct an analysis have led some observers to despair of ever devising a comprehensive formula for acceptable-risk decisions. An alternative approach, which produces a quantitative answer without recourse to a complicated formula, relies on first identifying and then continuing policies that have evolved over time. Proponents of this family of approaches argue that society achieves a reasonable balance between risks and benefits only through a protracted period of hands-on experience. The safety levels achieved with old risks provide the best guide to how to manage new risks. Assuming that one has identified such an equilibrium state, the balance between costs and benefits achieved there should be enshrined in future decisions, short-circuiting the learning and adjustment process and, in effect, lifting ourselves up by our own bootstraps.

One member of this family, the revealed-preferences approach, uses the cost-benefit tradeoffs effected by our market, social, and political institutions in the recent past as prescriptions for future balances. Another member, the natural-standards approach, looks to the geologic past; it argues that the ambient levels of pollution during the development of a species is the level to which that species is best suited and the level to be sought when setting future tolerances. In either case, a description of past policies is taken as a prescription for the future. The resultant policy should be consistent with existing decisions and be sensitive to complex tradeoffs that are hard to accommodate in formal computations. One conceptual limitation of bootstrapping is that for new hazards, which are often the most troublesome, there may be no relevant experience to which to refer. Another is that these methods pass judgment on the acceptability of individual options, without explicitly considering the alternatives. One possible political limitation is bootstrapping's strong bias toward the status quo; it assumes, in effect, that whatever is (or was), is right for the future.

Professional Judgment

Another response to the possibility that there is no one formula for determining "how safe is safe enough?" is to rely on the judgment of the technical experts most knowledgeable in a field. Professional judgment is exercised whenever a physician decides that a by-pass operation or immunization program is worth the risk, a civil engineer decides that soil porosity has been adequately handled in the design of a dam, or a boilermaker decides not to reinforce further a potentially leaky joint. In making their decisions, professionals might avail themselves of formal analyses, if such existed, but they are not bound by the conclusions of those analyses nor need they articulate the reasons for their decision. Their own "best judgment" is the final arbiter of whether to accept the risks associated with an option.

Although one might balk at even the suggestion of letting technical experts make decisions about value issues, technicians are trained to be servants responsive to their clients' needs. If society as a whole is defined as the client, professional judgment may be the best way to devise creative and balanced solutions, considering what is desirable, feasible, and practical. When professionals deliberate, they may not only summarize existing knowledge, but also create new knowledge in the form of new and better options. A physician may finesse the question of whether a drug is safe enough for a patient who is sloppy about taking pills by devising a therapeutic regime that circumvents the problem; similarly, a safety engineer may alter traffic patterns so as to increase the effective safety of an aging bridge with fixed load-bearing capacity.

Professionals may stumble in some areas where formal methods are strongest. An inarticulable rule frustrates critics and colleagues attempting to assess the professional's performance and spot errors. Under the cloak of professional wisdom may lie only a vague notion of what options are available or even a failure to consider more than one traditional solution. Finally, there is no necessary link between expertise in a substantive area and expertise in decision making.

Similarities and Contrasts

These three approaches are not as conceptually distinct as they might initially appear. Formal analyses require a large element of professional judgment, whereas professionals can (and at times do) base their judgments on formal analyses. Bootstrapping requires risk and benefit measurements resembling those in formal analysis; for their part, formal analyses often turn to the historical record for critical measures, making assumptions like those underlying bootstrapping. Professions are often tradition oriented, attempting to do what has been done in terms of policy making; the past studied by bootstrapping has largely been created by the actions of professionals.

The difficulties the approaches face also have similarities. Characterizing a proposed technology for comparison with a historically derived standard encounters many of the same technical problems as characterizing it for comparison with alternative courses of action in a formal analysis. Both bootstrapping and professional judgment may falter by failing to consider alternatives. Furthermore, the prescriptive validity of each is contingent upon their descriptive validity. Professionals should be allowed to make acceptable-risk decisions only if they do know more; the cumulative record of evolutionary processes should be consulted for guidance only if such processes properly accommodate social pressures and realities. These correlated weaknesses may decrease the possibilities for hybridizing approaches to compensate for one another's vulnerabilities.

In the analysis that follows, these approaches are treated as ideal types in two senses. First, each is discussed as though it were in itself a complete approach to making acceptable-risk decisions. Taking each very seriously, perhaps even more seriously than its strongest proponent, sheds the most light on inherent strengths and weaknesses.

Second, each approach is treated not only as it is done today, but as it might be done if applied as conscientiously and deliberately as possible. Considering the ideal implementation clarifies how much potential is latent in an approach, how far the state of the art lags behind the state of knowledge, and how things could be done better.

Other Approaches

Common to all of these approaches is the assumption of identifiable decision makers, applying a deliberative scheme. If that assumption is abandoned, one can identify two other families of approaches. These might be described as embodying market and procedural logic.

A pure market approach would eliminate all centralized acceptable-risk decision making, allowing risk levels to evolve through the action of unrestrained market forces. A pure procedural approach would involve sophisticated "muddling through," letting political, economic, and intellectual pressures shape decisions. Although the actors in either of these processes might refer to analytic, bootstrapping, or professional arguments, they would not be bound to them. Rather, these approaches rely upon the wisdom of the participants, their interaction with one another, and the feedback provided by their environment to produce relatively satisfactory results.

Although a detailed consideration of these approaches is beyond the scope of the present analysis, some mention is inevitable to the extent that the present approaches draw on them. For example, the conceptual adequacy of some bootstrapping and analytical approaches depends in part upon the efficacy of market processes, while questions of procedural logic emerge in assessing both professional and bootstrapping approaches.

Seven Criteria for Evaluating the Acceptability of Approaches to Acceptable Risk

Deciding which approach to use, like other decisions, involves a choice between alternatives. The options include the pure-form methods described above, deliberate hybrids, and the poorly articulated mixed methods by which decisions are being made today. The "do nothing" option in this context probably translates to "do as we've been doing."

This metadecision problem is difficult, in part, because the options are not directly comparable. Each embodies an alternative concept of how rational decisions should be made. If applied competently, each does best what it sets out to do. Rather than posing the metaphysical question, "What is the best form of rationality?," we have chosen to ask "Which technique serves our interests best in dealing with acceptable-risk problems?" To answer that question, we have developed a set of seven evaluative criteria, representing what a society might want out of an approach. These criteria appear in Figure 3.1 and are elaborated in the remainder of this chapter. They range from desiderata for theory and practice in a benign, cooperative, and responsive social environment to features needed when one considers the reality of highly charged controversies and institutions established in their ways.

Chapters 4-6 analyze the three approaches in terms of these criteria, looking at how well each could, in principle, satisfy them and how well each currently does in practice. Although such an analysis evaluates the decision options from various perspectives, it does not tell which to choose. Unless one option surpassed the others in all respects, society must decide which criteria are most important. Such judgments of impor-

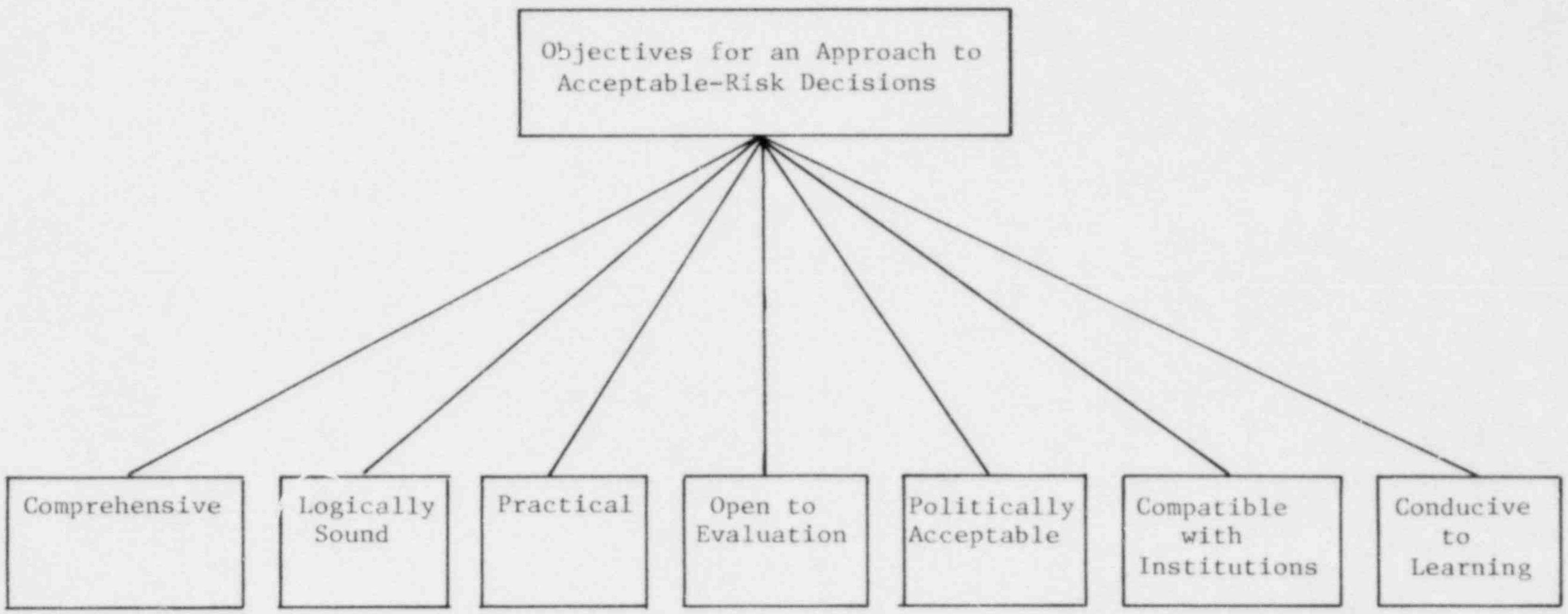


Figure 3.1 Qualities desired of an approach to making acceptable-risk decisions

tance might reflect personal values, legislative mandates, or the exigencies of particular situations. The approach preferred for one problem might be rejected in another situation for which its particular strengths (e.g., political acceptability) were not essential.

Comprehensive

Chapters 1 and 2 describe the basic elements of acceptable-risk problems and the complexities that they present to the decision maker. An approach should address these problems explicitly and persuasively. Failure to do so means that an approach is, at best, solving only part of the problem. Thus, an approach should accommodate a comprehensive problem definition, reflect the uncertainty surrounding technical issues, acknowledge the labile or conflicted nature of social values, realistically appraise the human failings confronting the decision-making and implementing processes, and assess the quality of its own conclusions. Moreover, it should be flexible enough to accommodate new information, particularly such insights as are generated by the analysis itself.

Logically Sound

Delineating the problem is not synonymous with providing guidance. Indeed, comprehensiveness alone can lead to confusion and frustration. For example, a 17-volume, 9,000-page Department of the Interior study of the environmental impacts of an Alaskan gas pipeline has been called "a monument to irrelevancy. Nowhere in it can one find a succinct analysis of the choice that must be made" (Carter, 1975, p. 363). To be useful, an approach must provide a timely and logically defensible summary of all that it encompasses. Without such summaries, "analyses" can unfairly discourage projects by inducing a feeling that "we shouldn't mess with anything that's so poorly understood," breed mistrust by making observers think that "they must be hiding something in that morass," or encourage capricious action by suggesting that "we might as well go ahead with this project since there's no convincing evidence against it."

Thus, a viable approach must produce some conclusion, if only "collect more data; we don't know enough to decide at the moment." Moreover, that conclusion must be derived via a defensible decision rule. Such a rule would be:

(a) sensitive to the various aspects of a decision problem; changes in available options, information, values, or degree of uncertainty should be capable of leading to different recommendations;

(b) reliable (or reproducible) in the sense that repeated application to the same problem should produce the same result;

(c) justifiable in terms of either theoretical arguments, demonstrating why it should lead to good decisions, or empirical evidence showing that it has worked in the past;

(d) suitable to societal risk problems and not imported unthinkingly from the other realms (e.g., corporate decision making or problems without potential loss of life); and

(e) unbiased in its recommendations, not giving undue weight to any interest or type of consideration.

Practical

Like the technologies they are meant to manage, decision-making methods must work in reality, as well as look good on the drawing board. It must be possible to implement the approach with real problems, real people, and real resource constraints.

Real problems. To apply an approach, one must establish a reasonable correspondence between its terms and equivalents in reality. Cost-benefit analysis, for example, would have limited usefulness if one had no operational definition of "cost." Any approach could fail if it used one statistical summary of risk (e.g., expected annual fatalities) when policy makers were interested in others (e.g., catastrophic potential), or if it were able to consider only a fixed set of alternatives in a reality that persisted in creating new ones. Like box cameras, an approach may only capture a situation by requiring the subject to be at a great distance, in the sun, and immobile (Zuniga, 1975).

Real people. Weighing strategies for the management of a technological hazard must be a labor-intensive enterprise that draws on a select pool of skilled individuals, including substantive experts (those who know most about a particular hazard) and experts specializing in the decision-making process itself. Can enough of these special people be recruited for a reasonable facsimile of the approach to be implemented? If experts can be found, does their task use them to best advantage? Is it too novel and complicated to be comprehended as posed? Do its questions fit the cognitive structure of their knowledge? Finally, one must ask if the experts can be trusted. In the contract-research age, problems breed putative experts. When the stakes are high enough, substantive experts are often employed by vested interests who may restrict their freedom to study certain questions and report certain answers. All of these questions become more acute as the scientific data base shrinks and experts are asked to create instant knowledge, in the form of educated intuitions, rather than draw upon the fund of knowledge that has undergone peer review (Fischhoff & Whipple, 1980).

Resource constraints. When decision makers admit to needing help, they typically want it immediately, to respond to a crisis in which their traditional decision-making procedures have obviously failed. In addition to time constraints, monetary constraints are also likely. Decision makers may be reluctant to spend hard cash for the probabilistic benefits of good advice, which at best increases one's chances of making the right choice. When the resources needed to implement an approach adequately are lacking, one must ask whether the result is close enough to the ideal to be worth the effort.

Open to Evaluation

As discussed in Chapter 2, assessing the quality of a decision or method is hard under the best of circumstances. An approach should not make matters worse by obscuring its internal functioning. All those whose fate it is deliberating have a right to ask: What are its underlying assumptions? What are its political and philosophical roots? What options does it foreclose or prejudge? Where are fact and value issues mixed? What inputs were used? What computational procedures were followed? How much uncertainty surrounds the entire enterprise?

Providing answers to these questions is essential to the validity of an approach. Many acceptable-risk questions are so complex and multi-disciplinary that no one can expect to get the right answer on the first try. At best, an approach might derive an approximate answer, for the sake of argument. The best form of that argument may be constructive criticism designed to spot omissions, errors, and hidden assumptions that can be treated in a subsequent iteration. Nonetheless, destructive criticism may be better than none at all, if it catches some problems and adds some new perspectives.

Evaluation is particularly frustrated by poorly defined procedures and lack of conceptual clarity. The unexamined approach is hardly worth using. An approach that fails to test its effectiveness and clarify its prejudices is not to be trusted.

Politically Acceptable

An approach can fail in the harsh, politicized world within which hazards are managed because it works too poorly, works too well, or works in a vacuum.

If an approach is palpably invalid (e.g., because it misdefines the problem or has no defensible integration rule), critics will readily impeach any displeasing recommendations. For example, the fuzzy logic of some environmental impact statements exposed them to interminable litigation by dissatisfied parties (Fairfax, 1979). At the other extreme, an approach may encounter little resistance because all interested parties see how they can manipulate it to their own purposes. In time, combatants may learn to conduct their debates in, say, the nomenclature of cost-benefit analysis, transforming the technique into a rhetorical device and voiding its impact.

Conceptual strength can also encourage political complications. If an approach produces a clear, persistent, and unwanted signal, the offended parties may choose to discredit it, rather than just fight one particular conclusion. An approach that redressed an existing imbalance of power between, say, producers and consumers, employers and employees, or laborers and the general public could similarly be attacked by the side whose advantage is jeopardized.

Finally, an approach can fail by disregarding means in its quest for the optimal end. In any participatory system, recommendations must be sold as well as generated. One aspect of that selling job is to insure that people's views have been accommodated. Usually that means asking them early and sincerely enough to affect even the problem definition. Attention to the process of decision making may also facilitate the creation of solutions, like negotiated settlements between opposing parties. Moreover, a good process may itself have positive consequences, like helping participants live and work together, reducing social alienation, and enabling participants to monitor a decision's implementation by educating them in its rationale and technical details. With a successful approach, process may be its most important product.

Compatible with Institutions

For better or worse, hazards are being managed today. To accommodate this management, a complex of social institutions has evolved. An approach's chances of survival drop as it departs from the standard operating procedures of the institutions. Even a method that satisfied the six other criteria might not get very far if no one is empowered or ordered to heed its recommendations, if legal precedents bind the hands of crucial actors, if it fails to produce the paperwork required for documentation, or if the personnel it requires are neither found nor wanted in the relevant halls of power.

On the other hand, an approach may fit too well. Institutions have their own agendas which need not coincide with those of the people they represent. Decision makers in institutions may like an approach that cloaks their decisions in ambiguity, reduces their accountability, establishes a position for them in hazard management, defers difficult value questions to external "experts," or studies hard issues forever. On the other hand, they may feel uncomfortable with many of the issues confronted by a good approach, such as extended time horizons, explicitly acknowledged uncertainty, or extensive outsider input.

Hence, it may be the institution rather than the approach that needs adapting. The ability to handle an acceptable approach to acceptable-risk decisions may be a valid test of an institution's fitness for the challenges of the late twentieth century.

Conducive to Learning

Attempting to satisfy these criteria encounters a fundamental conflict: the need to respect political and institutional realities without being overwhelmed by them. A final objective is to change those realities. An approach should educate its participants, eliminate opportunities for obstructionism, and build up its own record of precedents.

Somehow society should become better or wiser for its adoption. Achieving this objective might even lead one to sacrifice short-term benefits, like an efficient solution of a particular problem, for long-term goals, like developing generic standards.

Features that make an approach conducive to learning include: (a) leaving a clear record of deliberations and assumptions, to facilitate evaluation and the cumulation of knowledge; (b) affording two-way communication between scientists and decision makers, to improve understanding of one another's problems and uncertainties; (c) educating lay observers, to enhance their ability to follow the process and develop expertise in the substantive issue at hand and the subtleties of acceptable-risk questions; (d) having enough generality to be used on many problems, allowing users to acquire an in-depth understanding of one technique, rather than a superficial grasp of many problem-specific methods.

One more active role an approach might fulfill is recruiting talented scientists and lay people to a problem. Another is alerting users to recurrent oversights. A third is indicating generic categories of hazards that can be managed in a consistent fashion, drawing on the same decision-making effort. A fourth is increasing the credibility of society's decision-making bodies by offering them more trustworthy tools. Perhaps the most general criterion for judging the contribution of an approach to long-term effective management is whether it raises the level of debate.

Contrasts

Like the approaches they are designed to evaluate, these criteria are not entirely independent. Weakness in some respects may preclude strength in others. An approach is unlikely to be comprehensive if it does not elicit competent criticism from a variety of perspectives. Without openness to evaluation, there is little opportunity to learn from experience and increase understanding over the long term. An approach with obvious logical flaws is unlikely to fare well politically. As a result, an approach that stumbles in one respect is likely to encounter other difficulties as well.

On the other hand, some of these goals may be in conflict. It may be easier to find a logically sound integration rule if one leaves out certain awkward issues, thereby failing to address parts of the problem. Political acceptability may require involving so many parties in the decision-making process that the constraints of the responsible institutions are overwhelmed. Openness to evaluation may mean vulnerability to cheap shots and unfair criticism, thus impairing political acceptability.

If no approach does, or even can, satisfy all of these criteria and if their respective strengths and weaknesses lie in different realms, then we must decide what we really want. As a result, the choice of an approach is a value-laden and political act, reflecting our preferences for how society should look and function.

Summary

A review of how acceptable-risk decisions are currently made led us to identify three generic ways in which they might be made in structured settings: (a) formal analysis, which decomposes complex problems into simpler ones and then combines those component estimates into an overall recommendation; (b) bootstrapping, which looks for historical guidance in setting contemporary safety standards; and (c) professional judgment, which relies on the wisdom of the best available technical experts.

Since these methods have rather different sets of strengths and weaknesses, choosing between them requires some notion of what is important in an approach to acceptable risk. Seven evaluative criteria are described. An approach should be: (a) comprehensive, (b) logically sound (with a defensible decision rule), (c) practical (implementable), (d) open to evaluation, (e) politically acceptable, (f) compatible with institutions, and (g) conducive to learning. Determining the relative importance of these criteria is a political decision which underlies the choice of a method.

CHAPTER 4

Professional Judgment

Until they attract public attention, most hazards are managed by the technical experts most familiar with them. Engineers are responsible for designing dams, chemists for developing new solvents, and doctors for prescribing drugs. In balancing risks and benefits, these professionals rely on personal experience, accepted professional practice, and their clients' desires. The method for integrating this assortment of facts and values is professional judgment.

As a hazard gains notoriety, other actors enter the decision-making arena. These newcomers depend upon the professionals for guidance regarding the existence, practicality, and effectiveness of possible actions. These factors are often so ambiguous, esoteric, or complex that it is hard for a non-professional to maintain an independent perspective. Once decisions have been made, professionals guide their implementation and improvise solutions to problems that arise. Thus, even in politicized decisions, professional judgment plays a major role, making technical experts the arbiters of "how safe is safe enough?" for most hazards.

How Do Professionals Determine Acceptable Risk?

A variety of codes govern the behavior of professionals in their role of hazard managers. These codes may be characterized according to two dimensions: (a) their source and (b) their type.

Sources of Standards

Perhaps the most important codes are unstated; they represent the implied standards of professionalism inculcated during training and apprenticeship. One learns what a physician, engineer, or chemist does and does not do; what are the right and wrong ways to do things; what risks one does and does not take with others' lives; when to defer to higher authorities; when to admit defeat; when to call a colleague to task; what is "good enough for government work;" what short-cuts and cost-cuts are legitimate; when one's job is done and a problem can be entrusted to others. These implied standards are sufficiently general to give the professional a feel for what might be acceptable actions in all of the varied problems that arise. Since they are reality- and compromise-oriented, such codes may lead to different solutions to the same technical problem in different economic and political contexts.

Professionals produce explicit as well as implicit standards. For example, the American Society of Mechanical Engineers' (ASME) Boiler and Pressure Vessel Code gives technical specifics for that subsystem of nuclear power generating facilities. Such standards reflect a profession's collective trial-and-error experience in designing systems that work reasonably well. Explicit balancing of costs and benefits is the exception.

A third source of rules is governmental agencies. Although such rules are not issued by professional societies, their technical content ensures that they are developed with the help of professionals and hence reflect their philosophy. For example, the federal code known as 10CFR50 specifies the criteria for a minimally acceptable nuclear power generating reactor design. Some parts were created specifically for the code; in other instances, it defers to standards like those published by ASME.

Types of Standards

The most general rules might be called ethical standards. Typically adopted by professional organizations, they appeal to subscribers to adhere to some vaguely stated "principles of sound practice" and to consider the health and safety of those affected by their decisions. Although the sanctions a profession can impose on its members give these standards some teeth, they are probably too general to provide much guidance in specific situations. Since they rarely prescribe or proscribe particular behaviors, their primary function may be to legitimate fixing blame on professionals whose work has been proven to be inadequate by the occurrence of a mishap.

A fairly recent development is quality standards, which specify the kind and intensity of effort that should go into solving a particular problem. For example, the Canadian Standards Association (1978) recommends looking at the following factors: How difficult is the design to execute? How much of the design is proven or known? How many different processes are required? How complex is the product? What are the probability and consequences of failure? This analysis leads to classifying a project as requiring one of four increasingly stringent levels of quality. Each level is defined by requirements specifying the degree of detail required in the inspection, monitoring, development, design, and documentation of a project. Although loosely defined, these procedures constitute an important attempt to systematize a previously unarticulated aspect of professional judgment.

A third kind of rule, technical (or design) standards, specifies the nuts and bolts of how a system is to be designed. For example, 10CFR50 offers design parameters like "materials for bolting and other fasteners with nominal diameters exceeding 1 inch shall meet the minimum requirements of 20 mils lateral expansion and 45 ft. lbs. in terms of Charpy V-notch tests conducted at the preload temperature or at the lowest service temperature, whichever temperature is lower" (Appendix G, Part IV, para. A4). Less explicit technical standards can be found in terms like "best available technology" or "with allowances for all uncertainties."

Whereas technical standards specify hardware, performance standards specify immediate output. For example, an explication of the Clean Air Act might state that "emissions of 1.5 ppm are permissible and we don't care how you achieve that goal" (see Moreau, 1980). Vaguer expressions include "with an adequate margin of safety," "affording adequate protection" or "avoiding adverse health effects in sensitive groups." The use of performance standards is often attractive because it stimulates professional creativity, looking for the most efficient way to achieve a fixed goal. In this view, not only do technical standards overemphasize quality control, but they may be too inflexible to accommodate new designs.

Overview

The following discussion characterizes professional judgment by how it addresses the five generic problems facing any approach to acceptable risk. Like the analogous discussions in Chapters 5 and 6, it accentuates the negative. Looking at how professional judgment can or even must fall short seems like the best way to clarify how it should be bolstered and where it is good enough to be left alone. A critical look will also help identify the reasons for the apparently increasing mistrust of our scientific and technical elites. When as venerable and valuable an organization as the American Society of Civil Engineers feels pressed to launch an advertising campaign attesting to its social worth (Florman, 1979), something is happening that should be understood. Do the problems lie in the codes that guide professional judgment, in the minds of those who must implement the codes, or in the political-social-economic world within which professionals function? Unless professionals receive usable public or legislative guidance, it may be disingenuous to criticize too harshly the risk-benefit balances they strike.

Generic Problems

Technical experts are an invaluable social resoruce, displaying knowledge, integrity, and devotion to service. The critical question in the present context is to what extent their competence extends to resolving societal safety issues and to what extent the constraints of their jobs allow them to exercise such expertise. Professionals answer so many questions for us; can they also tell us "How safe is safe enough?" If they cannot provide a complete answer, how can we best exploit the pieces they can give us?

Defining the Problem

Professional socialization emphasizes service, satisfying a client's perceived needs within resource limitations. As a result, professionals depend upon their clients for defining the problem they are to solve. If their client's perspective is overly narrow or misconceived, whatever creativity and ingenuity they muster may be ill-used: in such cases, they may adroitly solve the wrong problem. For example, when the client asks for technical standards specifying the details of the official solution to a problem, alternative solutions may be ignored. When the nature of a product is specified but not who will use it, professionals may be trapped into designing systems that are prone to operator failure. Unless told about a project's social setting, professionals cannot even consider the possibility that "This is not an engineering, but a social, problem. Let's find out what aspects of current risks upset people before worrying about design issues." Or, "People want this project to be safer because they mistrust its promoters. Those feelings are so deep that no level of safety may be acceptable to them."

Tom Lehrer struck a responsive chord in many lay people's image of professionals with his caricature, "Once the rockets go up, who knows where they come down? That's not my department, says Werner von Braun." When professionals communicate only with technology promoters or regulators or environmentalists, they are unlikely to be responsive to the way other sectors of society would define a problem. On the other hand, balanced interaction may be easier to advocate than achieve. Often physical isolation, professional ethics, or conditions of employment constrain professionals to a technician's role. Narrow solutions are to be expected when professionals have a limited perspective on their own role and little influence on higher-level policy making.

To some professionals, these restrictions may not be so onerous. They may be more comfortable with solving problems than defining them; they may like working within constraints, rather than worrying about and assuming responsibility for delineating social goals; they may be content with their contribution to society from successfully managing a well-defined component problem (e.g., composing an unbiased patient package insert or designing a safety valve); they may fear the manipulative potential in helping to define one's client's problems.

In some senses, though, professionals shape the problem definition they receive by shaping the world within which they and their clients (and the rest of us) live. Their research activities establish what options can be considered. For example, feminist groups have claimed that male control of contraception research has led to a predominance of solutions whose risks are borne by women. In this light, the recent push for better warnings about oral contraceptive side effects is an attempt to ameliorate the consequences of an improper problem definition. Professionals' standard practices also determine which options become readily available alternatives. For example, the low status afforded to safety engineers in many work groups reduces the centrality of safety considerations and effectively forecloses consideration of safety options other than last-minute tack-ons and warning labels (Hammer, 1980).

Like other large and reasonably affluent social groups, professionals influence the diffuse debate that shapes a society's view of problems. For example, the central role of technology and technologists in American society has been linked to a deep-seated faith in technique, in engineered solutions to problems ranging from front-end collisions to shyness and loving (Ellul, 1969; Riesman, 1961). Professionals express their world outlook in the course of such daily activities as taling to neighbors, teaching in colleges, and serving on advisory boards. In addition, major professional organizations have lobbyists in Washington urging that certain issues be raised, certain alternatives be considered, and certain kinds of expertise be deemed important. Not only is this a legitimate activity in a democratic society, but elected representatives rely on these lobbyists for technical information needed in formulating political opinions. The incentive for candor in these briefings is that lobbyists caught lying lose their audiences. Nonetheless, it may be hard for all concerned to know when experts' assertions about the proper problem definition arise from pecuniary interest rather than technical expertise.

Knowing the Facts

By definition, professionals know more than anyone else about the substantive issues raised by technological hazards. But the facts do not always speak for themselves. Some interpretation is required and, in providing it, professionals are often caught in conflicting pressures.

Book-learning vs. experience. Every aspiring professional is taught a "book" of standard solutions, comprising the corpus of externally validated knowledge upon which the profession bases its claim to expertise. However, few professions allow full status to an individual who has merely been schooled. An apprenticeship is demanded in which the novice learns tricks of the trade that are not and perhaps cannot be expressed explicitly (Polanyi, 1962). These are not so much professional secrets as judgmental subtleties to which one is gradually socialized. One learns, for example, how to identify real-life problems with the recognized set of ideal types around which knowledge is organized, how much credence to give to various researchers' published work, and what deviations from approved research methods pose little threat to validity. To the extent that expertise begins where the "book" leaves off, questions of validity become matters of judgment; the definitive judgments are those of a field's most experienced members.

Experience may be particularly important when conflicting versions or interpretations of the facts must be reconciled. If the authorities tend to have outmoded information or undue commitment to their own pet interpretations, the profession may reach a biased view of the facts of the matter. If the authorities are intellectually active and situated at communications crossroads, the profession may have remarkable synthetic abilities.

Clinicians vs. scientists. As applied scientists, professionals are trapped between the norms of practitioners and of experimenters, between the desire to learn and innovate and the conformity pressures of apprenticeship and licensure. This conflict can produce both healthy intellectual tensions and unbalanced beliefs. For example, because of its need to have some response to every presenting problem, the medical profession has at times adopted clinical opinions and practices supported by little research. Once practices have been adopted, however, clinicians may be legally and ethically prohibited from withholding them in order to create the comparison groups necessary to test their validity (Bunker, Barnes & Mosteller, 1977). Fear of malpractice suits may also distort the evidence coming from the field, by encouraging unnecessary clinical tests that swamp clinicians with information, thereby obscuring signals. Another systematic bias in the information base of fields that acquire and test their theoretical knowledge by practical experience is that they are more likely to learn that a safety margin is inadequate (through observing a failure) than that it is more than adequate.

The interaction between theory and practice also shapes a clinical science's view of the facts by shaping the abstract models that professionals use to describe the world. Blueprints, disease models, and computerized simulations of nuclear reactors are all theoretical formulations whose relation to reality varies across situations. They represent some compromise between the scientist worried about abstracting the essential elements from complex realities and the practitioner concerned about what aspects of reality escape the model. The consummate professional understands both perspectives, being able both to model a situation and to improvise solutions to problems arising in its application. The ideal civil engineer, for example, can calculate structural tolerances by the book and anticipate mistakes in the pouring of cement.

The apparent success of civil aviation in managing hazards might be traced to exploiting the insights of both field and design personnel. Pilots and aeronautic engineers typically work together to develop systems and procedures (planes, navigational aids, etc.). Even here, however, practical and theoretical knowledge are not always integrated optimally. Some "classic" aviation tragedies can be traced to the earnest efforts of designers unfamiliar with how flight really works. For example, some World War II planes used identical handles on adjacent levers serving different functions; although the levers were easy to operate, they were also easy to confuse, particularly in emergency situations requiring quick responses and offering little opportunity to correct mistakes (Fitts & Posner, 1965).

Part vs. whole. Knowledge is also shaped by the breadth of the problem one chooses to or is allowed to address. Doctors may treat only physiological symptoms for problems that are rooted in marital stress, poverty, or working conditions. Some professions, such as architecture, have specialists whose job it is to know about the broader context within which a project is set (e.g., neighborhoods, traffic patterns) and about the interactions between the parts into which it is decomposed (e.g., construction, financing, materials supply). In other professions, scant credit accrues to individuals who leave their own discipline in order to understand such interrelationships (White, 1979). When isolated, professionals may naturally come to see their piece of the puzzle as its centerpiece and denigrate the knowledge held by other fields. In the ensuing conflict, disciplines that boast the hardest facts may gain undue importance when it comes to resolving conflicts or dividing resources. One symptom of this bias may be the preponderance of gadget-oriented solutions to safety problems versus "soft" solutions designed to change unsafe behavior (Knoll, 1979; Sheridan, 1980).

Determinism vs. uncertainty. Professionals typically manage hazards without directly expressing uncertainty about facts (Morgan, Rish, Morris & Meier, 1978). Professionals' problem-solving orientation leads to asking first "What could go wrong?" and then "How can we prevent it?" Thus, uncertainty about future traffic patterns can be disregarded if one builds a bridge strong enough to withstand any conceivable load; precise diagnoses become less important when physicians can prescribe all-purpose antibiotics, good for whatever ails one. "Over-design" and "large margins of safety" are other signs of coping with uncertainty without directly acknowledging it. A dam that is twice as safe as need be cannot fail, making the limits of knowledge less relevant.

One can only speculate whether professions tend to exaggerate or underestimate these unspoken risks. In either case, the lack of explicit expression may cause problems for science and society. Scientists lose respect for practitioners who seem to act without a word of uncertainty; practitioners lose respect for scientists who fail to produce the research they need. For non-scientists, plans that are presented without qualifications may assume the subjective status of unquestioned fact. The result may be reduced alertness to warning signs and attention to critics. The Teton Dam design and collapse revealed both of these consequences of failing to acknowledge uncertainty (U.S. Government, 1976).

Simply by virtue of its premise that even the best-designed technical system should not be assumed safe, the Reactor Safety Study (U.S. NRC, 1975) represented a significant step toward professional recognition of the need for treating uncertainty explicitly. The "Lewis" review (U.S. NRC, 1978) pushed professional consciousness forward by stressing that not only are there risks, but their magnitude is unknown, and perhaps unknowable to the desired degree of precision. Public acknowledgment of uncertainty in one industry may hasten similar perspectives in other realms (e.g., Elstein, 1979; Green & Bourne, 1972; Schneider, 1979; VanMarcke, 1977).

Assessing Values

In determining safety levels, professionals should represent the best interest of society as a whole. However, that interest is typically nebulous, conflicted, or expressed in imprecise legislative directives or legal opinions (Hoffman, 1976; Johnson, W. 1980). Its meaning for any particular problem must be defined, negotiated, and interpreted by the active participants, usually a mix of bureaucrats, promoters, professionals, and intervenors. To the extent that professionals must guess at society's values, they may tend to interpret ambiguities in ways that are consistent with their own values (Brown, 1965). Imputing a common set of values to any group is an exercise in stereotyping that cannot be correct in detail and is likely to be incorrect in the aggregate. The remainder of this section offers a cautious discussion of the values that might come into play when professionals consider acceptable-risk problems.

Professional values. Like other socializing agencies, professions inculcate values as well as substantive knowledge. This process is enhanced by individuals selecting like-valued professions and professions weeding out those who see things differently. One finds few campus radicals majoring in petroleum technology and even fewer surviving (values intact) to executive rank; a similar fate may befall libertarians in the welfare system.

Although the ambience of various professions differs, a common theme is confidence in professionals' competence to handle society's technical problems and perhaps a stout faith in technological progress in general. One resultant value is loyalty to colleagues, as seen in physicians' reluctance to testify against one another; a second is distrust of non-professional involvement, as seen in disparaging remarks about the public's ignorance and irrationality; a third is a preference for self-regulation over external supervision, as seen in battles to control state licensing. Belief that the system works may encourage deferrence to tradition and avoidance of radical solutions. Professionals try to improve through modest reforms, rather than sweeping changes. One example of the power of these values to shape work practices is the intelligence community's response to charges that the "like-mindedness" of analysts was hampering their decision-making ability. A call for "pluralism" was interpreted not as the need to bring in fresh perspectives, but as a call to convene duplicate groups of like-minded analysts (Lanir, 1978).

Pecuniary interests. In order to stay in business, professionals may be strongly motivated to err in the direction of affirmation when asked "Can you manage this hazard?" The current jockeying by professions to establish a position on risk must reflect desires both to help and to have a piece of the action. It may be hard for an engineer to believe or admit that money devoted to "tech-fix" research could be ill spent. One constraint on optimism is legal liability. Unlike bureaucrats and analysts, professionals are often monetarily responsible for their actions. Defensive medicine and over-engineering protect society's safety in order to protect professionals' finances, perhaps at the price of buying more safety than is needed.

If professionals are not to impose their own perspectives on ambiguous value issues, they need explicit guidance. Pecuniary interest would lead them to seek that guidance from those whose satisfaction is most important; if that client typically comes from one sector of the hazard-management community, that sector's values will naturally be overrepresented in the professionals' work. Since decisions must be interpreted in the context of all the little problems that arise in the course of a project, influence also accrues to those with the resources to hang around the professionals as they do their work.

Conflicting values. Whether professionals' values create conflicts of interest depends upon their ability to set aside their own values and act in the best interest of society's more poorly informed citizens. Measuring that ability is difficult because the imposition of any particular set of values is often hard to detect. Not only are society's "official" values rarely explicated, but professionals' implicit values are seldom communicated as such. In many cases only the resulting design decisions or safety margins are visible, making it hard for either professionals or their critics to tell just how risks and benefits were traded off against one another. Indeed, professionals, like other people, may not really know what motivated their decisions (Nisbett & Wilson, 1977). A further complication is the tendency for value conflicts to surface in the form of debates about facts (Sjöberg, 1980). Instead of arguing about how safe nuclear plants should be (about which everyone is entitled to their own opinion), people argue about how safe they are (focusing on those issues that are most moot). Thus professionals' values express themselves in terms that are diverse and hard to characterize.

Uncertainties about the Human Element

Problem solving is easiest when one deals with components that are well understood and joined by orderly cause-effect relationships. Realizing this, professionals are wont to concentrate on the known and knowable. Since human behavior is seldom as predictable as mechanical or chemical reactions, humans (operators, intervenors, sponsors) may be given little thought in the problem-solving process, except perhaps to recognize their nuisance value (Norman, 1980; Sheridan, 1980). Even physicians may worry most about physiology and ignore the "whole patient," with home and work pressures, poor nutritional habits, or lapses in taking medication.

Design. Knoll (1979) describes the consequences of focusing on "hard" components in engineering as follows:

> In construction, there is a tendency to forget . . . such humans as the owner or tenant who overloads or alters the structure or the executive of a utility company who decides to assign insufficient personnel to the checking of gas and water lines which may eventually cause accidents . . . [or] people who are only accidentally or indirectly interrelating with the structure, such as the truck driver ramming a column with his vehicle, or a Code Committee who leaves gaps or erroneous statements in the building regulations, or merely complains that a code cannot be used because it is too complicated or lacks clarity . . . [or] the owner or promoter with a tight budget or a schedule who forces designers and builders to deliver skimpy or shoddy work, with insufficient supervision or the

like. Although these individuals cannot always be reached by the legal system, structural safety is related to them and if the frequency of accidents ought to be controlled or reduced, their contribution must be dealt with, which means: designed for (p. 249-250).

According to Bøe (1979), overemphasizing technical issues in system design may eliminate the cues and feedback needed to give operators the "personal qualities of knowledge which are necessary to detect and control an unforeseen situation where the technical system has broken down, or more important, is about to break down" (p. 242). In the extreme, "an installation may have reached such huge dimensions and the technical and physical chain reactions may have become so fast that life-saving equipment and contingency plans no longer are in balance with the rest of the technology creating the risks" (p. 243).

One result of technical over-design and human under-design is holding humans responsible for failures over which they had no real control. Blaming children or cyclists for becoming casualties in traffic accidents occurring in a world designed for adult motorists falls into this category (P. Howard, 1978). Figure 4.1 details some design flaws likely to lead to a misattribution of "operator error" should anything go wrong.

The failure of flood-control projects to reduce flood damages appreciably has a similar interpretation (Burton, Kates & White, 1978). By eliminating frequent minor flooding, dams deny residents an appreciation of their own vulnerability and promote development of the flood plain. When a rare flood does exceed containment capacity, the damage is catastrophic. Thus, a failure of social engineering limits the value

HUMAN FACTORS INSPECTION REPORT

Examples of questionable design observed at a nuclear power plant

1.
A selection switch for boration (adding borated water, which moderates the fission reaction) has four positions: 0 to 550, 500 to 1,050, 1,550, and 2,050. The last two indications really mean "1,000 to 1,050" and "1,500 to 2,050." But that's not what they say.

2.
Two digital borating controllers are side by side and look exactly the same. But the left one is for concentrating and the right one is for diluting. The operator has to remember that the decimal point is one digit before the end on the left controller and after the last digit on the right controller.

3.
Water flows through seven feedwater heaters in succession. Each heater has numbered controls on the panel. The controls are numbered in inverse order to the direction of the water flow.

4.
After heater 3 (above) there are three pumps, A, B, C, and after heater 7 there are two pumps. The switches for these are arranged in two rows: 3A and 3B in one row and 7A, 7B, and 3C in the other row.

5.
Four meters on the left are for neutron flux, and four meters on the right are for the rate of change of neutron flux. The two on the far left correspond to the two on the far right, i.e. they are for intermediate range, and the two which are just left of center go with the two just to the right of center for source range.

6.
The auxiliary feedwater meters are labeled A (on left) and B (on right). The corresponding switches are also labeled A and B, but B is on the left and A on the right.

7.
There are four steam generators in this plant. There are four pen recorders to indicate temperature in the hot and cold legs of each steam generator. Each pen recorder has two pens, red and green. The first recorder on the left has red for hot 1, green for hot 2. The next one has red for cold 1, green for cold 2. The third recorder from the left has red for hot 3, green for hot 4. The right-hand recorder has red for cold 3, green for cold 4.

8.
General procedures during a loss-of-coolant accident call for the operator to check whether all of the lights are lit in a matrix of check-indicators. But some of the lights (which do not have lettering on them) are not supposed to be lit.

9.
The valves for safety injection of coolant are all nicely arranged in a cluster. The cluster is 60 identical switches arranged 3 high by 20 wide, with only small engraved alphanumeric tags underneath to indicate which valve is which. Mostly the alphanumerics are in order--except for one lost soul which is completely out of order and a long distance away from any other switches it corresponds to functionally.

Figure 4.1

Source: Sheridan, 1980, p. 29

of a civil engineering success. The National Flood Insurance Program (not without its own problems due to unsubstantiated assumptions about behavior) was designed to overcome these difficulties by mandating sound land-use planning (Kunreuther et al., 1978).

Lack of awareness about the human element may also prevent professionals from recognizing their own role as human operators. The feeling that substantive experts may not be experts in managing the risks they create has led to enhanced roles for health physicists, human subjects review panels, and pathogen advisory groups.

Public relations. The increasing intrusion of outsiders into the professionals' realm has evoked some strong opinions about the intruders' competence. Two conflicting themes seem to emerge from the professional community. When the discussion concerns the need for regulation, one hears about "consumer competence" and how people know enough about hazards to fend for themselves in the marketplace. When the topic is public participation in hazard management, charges of ignorance and emotionalism increase.

As discussed in Chapter 2, it is uncertainty about human capabilities that makes such politically motivated interpretations possible. One can find at least anecdotal evidence for almost any assertion one would like to make about people. To hold a responsible position regarding the source of apparent disagreements with lay people, the professional should ask: Is there systematic research to which I can refer? Are people acting strangely because they are solving a different problem? Has their experience been deceiving or inadequate and might better information have a salutary effect on our disagreements? Might they see something that I haven't noticed? Might my own experience be deceiving? What are the consequences of forcing people to accept solutions that they mistrust, however invalid the bases of that mistrust?

Professionals, like everyone else, are entitled to opinions about the behavior of society and its citizens. These opinions, like everybody else's, should be taken with a grain of salt. In explaining why physicists seem particularly prone to the guile of parapsychology charlatans, Hyman (1980) suggested that they fail to define the limits of their professional competence. Their training gives them an extraordinary ability to discern signals in certain kinds of random error, but not in the systematic error generated by masters of deception. Scientists' judgments about people and society may suffer a similar malady.

Assessing Decision Quality

When and how professionals evaluate the quality of their own decisions depends largely on how they resolve the various uncertainties discussed in the preceding sections. Because of these uncertainties, two major difficulties arise.

Characterizing solutions. If professionals did everything by the book, evaluation would be relatively easy. Not only would solutions be well characterized and well documented, but there would be some, even many, replicates whose consequences could be compared and aggregated. Often, though, professionals begin with a well-defined option and then adjust it to accommodate local conditions, producing a unique, hard-to-assess design. For example, calculated load factors only approximate those actually present in the dam that evolves in response to the porosity, seismicity, aesthetic, and construction constraints encountered on site. Similarly, a physician who knows the documented rate of side effects from a drug still does not know their likelihood for a particular patient, whose ailment may be misdiagnosed, who may be taking other drugs, or who may not follow the therapeutic regimen. Indeed, the physician may choose a second-best treatment program whose risks are more predictable because it is less vulnerable to these factors. Such real-life compromises, particularly those made at the last minute, may not be well documented.

The nature of the solution and its degree of safety are unclear, not only because conditions force changes in the standard solution, but because the safety of those solutions, even when adopted <u>in toto</u>, is context dependent. A familiar coefficient, resistor, or drug may perform differently under new conditions. If knowledge about performance is like other aspects of human knowledge, those who hold it may be only vaguely aware of the untested and unexplicated assumptions upon which it rests. Successful experience with a component in some contexts may confer unjustified confidence that its performance can be predicted in other domains. Summarizing attempts to assess the overall safety of existing or proposed systems, Knoll (1979) found that "no absolute calibration [of safety margins] has been found possible, based on rational scientific fact. The overall magnitude of the combined [safety margin] is still entirely a matter of the consolidated judgment of the code committee" (p. 254).

If every project is unique and hard to characterize and if the deliberations of professionals are hard to explicate, it is tempting to evaluate their work by the consequences of individual decisions. The complexity of many projects, however, makes it difficult to know just what has happened. When a living system responds to a treatment, one cannot always tell whether it would have recovered spontaneously. a physical system works, one cannot always tell whether cheaper alternatives would have worked as well or even which components were over-designed and which were being pushed to their limits. In the case of failure, this focus on concrete instances will encourage asking "What went wrong here?" rather than "Are we taking reasonable gambles (or ones with reasonable failure rates)?" The search for causes may become a search for a single cause (or culprit) as people try to minimize their cognitive load and to derive suggestions for future changes. Unfortunately, "to take one simple cause-effect relationship out of a complicated pattern may just as well serve to hide what actually happened as to tell the truth" (Bøe, 1979, p. 243).

Underlying such fault-finding is the assumption that there are identifiable and correctable problems. Seldom is the possibility raised that the system may be so complex as to be somewhat unknowable and unmanageable; i.e., at some point, complexity places an asymptote on reliability, with further safety measures as likely to introduce new problems as solve old ones. In this way, the assessment of decision quality may be biased by the assumption that posed problems are eventually solvable.

Characterizing evaluators. Among professionals' strongest values is the need for a powerful professional organization, responsible for both protecting its members' interests and assuring the quality of their work. As the theory goes, society's loss through this restraint of trade is more than compensated for by the stringent control of technical performance that lay people could not independently monitor. Professionals bear a sort of collective responsibility that makes meaningful self-evaluation less improbable. If they do not police and occasionally punish the worst of their members, all will suffer. If, for example, all physicians resolutely refused to testify against one another, society would take matters in its own hands, producing different, if not necessarily wiser, evaluations.

Striking a balance between protecting members and protecting society is perhaps the essential contradiction facing guilds. The financial incentives for denying past failures are so great that in structural engineering, "failures are most of the time not clearly reported, a fact which relates quite closely to the practicalities of restitution and the workings of the legal system which in most cases sets the incentives against comprehensive and public reporting" (Knoll, 1979, p. 253). When a failure is admitted, these same reasons lead to defining it as narrowly as possible (one bad actor, bad mistake, or bad beam), lest confidence in the profession as a whole be eroded. Defenses are often based upon the existence of standards that diffuse responsibility for acts with unfortunate consequences through a profession, industry, or government. The decomposition of complex projects may leave no one directly in charge of problems that arise from the interfaces between components.

These pecuniary pressures on the evaluation process may be compounded by psychological ones. Professionals often assume enormous responsibility for other people's lives and safety. Daily, they may be assuring others that "this pill won't kill you" or "that structural member will hold until the other ones are in place." Bearing this responsibility may require a special ability to deny or tolerate uncertainty. The multiple roles that professionals play by designing, approving, and implementing risky programs make them highly visible targets for criticism, some of it unfair (as when the hindsight bias of others works against them or when they have been left with responsibility for making decisions that others have shirked). In reassuring others about the quality of their decisions, they may also be reassuring themselves. Doctors' frequent claims that patients do not want to know the risks they face do not seem to be strongly supported by empirical evidence (Weinstein, in press); belief in the claim may help them cope with their own anxiety. In cost-plus enterprises, practices like over-design and defensive medicine partially finesse these conflicts by making the consumer pay for the professionals' protection.

How Adequate Is Professional Judgment for Resolving Acceptable-Risk Questions?

Comprehensive

Professionals' actions embody de facto answers to acceptable-risk questions. Yet providing answers is no guarantee of having addressed those questions in their full complexity (Schneider, 1979). Whether due to legal-ethical constraints or personal preference, professionals often accept a fairly narrow problem definition. Such happens whenever they restrict themselves to the consequences that interest their immediate client (perhaps ignoring broader societal concerns) or to solutions within their areas of professional competence (rather than pointing the client elsewhere) or to variations in the proposed technology (without considering seriously the "no go" option). Indeed, judicious choice of experts is one of the best indirect ways to control problem definition (and problem resolution).

Within this framework, the professional is likely to invoke a comprehensive view of the technical facts and their incumbent uncertainties. Indeed, the design process may create as well as utilize knowledge. On the other hand, professionals may have only a rough idea of some of the political and economic aspects of the problems they are resolving. Thus, professional judgment is likely to afford a very comprehensive view of a restrictively defined problem.

Logically Sound

It is difficult to assess the soundness of the procedures used by professionals to integrate those aspects of acceptable-risk problems that they have chosen to address. Many of their decisions are reached by judgmental processes that are inarticulate and perhaps inarticulable. In the absence of empirical studies, one can only speculate about whether these processes are prone to the same problems shown in studies of lay people's abilities to integrate diverse kinds of information. Do they, for example, give undue weight to considerations that are known with certainty (Tversky & Kahneman, 1979) or do their training and experience confer some special immunity from this bias?

Other decisions are reached through reliance on explicitly formulated public standards. Such standards also afford the promise of consistent decisions across the contexts in which they are applied. To the extent that standards have been evolved through trial-and-error experience with systems that provide useful feedback and an opportunity for the input of varied groups, they may reflect a balanced consideration of all relevant factors. To the extent that they represent just the application of judgment to general cases, the logic of general standards may be as unspecified as that of specific decisions.

Practical

Professional judgment works. Except when thwarted by intervenors, professionals produce answers, the best answers they can derive given their training and resource constraints. Professional judgment is also practical in that its decisions are formulated in sufficiently concrete terms to allow implementation. Moreover, when problems arise in implementation, professionals are often close enough and informed enough to improvise variations that preserve the spirit of the original decisions.

By minimizing outside involvement, professional judgment reduces operating costs. Costs are further reduced to the extent that professionals have access to the cumulative wisdom (and canned solutions) of their colleagues. The relatively low status of safety specialists in most professions, however, suggests that the decisions that are being made so practically and efficaciously may not always be primarily acceptable-risk decisions, that is, safety issues may not be raised very early, centrally, or explicitly.

Open to Evaluation

As described by Polanyi (1962), the ways of the professional can only be understood by another who has gone through the same extended apprenticeship, learning those subtle tricks of the trade which embellish the fundamentals that can be acquired from public sources like books and blueprints. As a result, professional decisions are made not only in non-public settings (e.g., on site, at the drafting table, by the patient's bedside), but also in a non-public manner. Since the processes and rationale of their decisions are inaccessible, professionals, from Hammurabi to current liability suits, have been judged on the outcomes of their decisions. If a bridge fails or patient dies, claims about the soundness of the logic underlying the decision may pale in the light of hindsight. Experts' intolerance for lay criticism may reflect both a feeling that they know more than their critics (and that substantive knowledge is the best guarantee of wisdom), and a realization that professional judgment is in some senses indefensible. The defense of having adhered to "accepted practice" only transfers the responsibility to others' judgments.

Politically Acceptable

The increasing encroachment of regulators, lawyers, and intervenors on the set of decisions previously left to the professionals' unfettered management suggests external dissatisfaction with their acceptable-risk decisions. Some of this unease reflects scapegoating of professionals for unfortunate outcomes of decisions left to them by default. Other criticism is politically motivated. One way to influence acceptable-risk decisions is to wrest power from the professionals. Still other critics view professionals as pawns in a larger struggle. Professionals' work merits comment only insofar as it produces decisions that one dislikes. Much environmental politics can be interpreted as an attempt to control the context that most immediately influences professionals' decisions.

Finally, some people view professionalism as the enemy itself. Agreeing with G. B. Shaw that professions are conspiracies against the laity, they see any concession of power to professionals as creating a technocracy, giving undue deference to professionals' social and pecuniary values. In this view, reliance on professional judgment not only surrenders control but legitimates it.

Compatible with Institutions

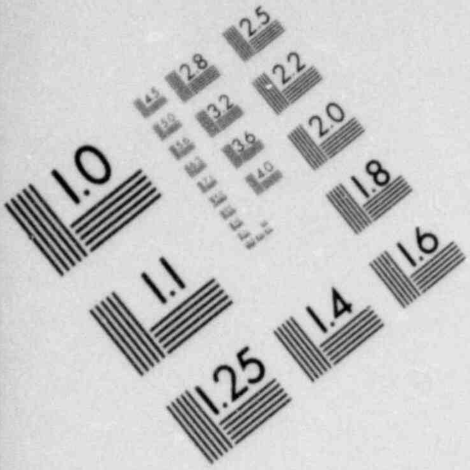
Professional judgment fits current institutional arrangements well because in many situations, it is the institution. Unless someone intervenes, professionals manage by default (within the constraints provided by their clients or employers). Even when alternative decision-making methods are tried, professionals' judgment may be relied on because of their knowledge and experience.

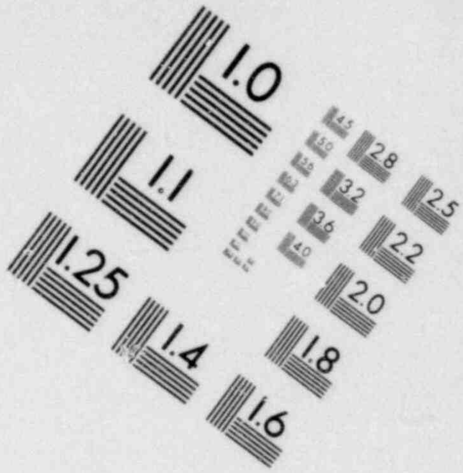
For their part, professionals accommodate themselves to the bureaucracies within which many decisions are made. They are team players, accustomed to interacting with varied clients. Unlike scientists whose cautionary norms may keep them from making sufficiently definitive statements to allow the bureaucrats to do their jobs, professionals are willing to venture a best guess at most topics. It is unclear how professionals would fit into innovative decision-making forums that emphasize more public participation.

Conducive to Learning

Professions are organized for long-term effectiveness. Indeed, they exist to ensure the orderly accumulation and transmission of knowledge. Unlike parts of the public, they are not fickle in their commitment to particular substantive problems. Unlike many elective and administrative officials, they do not come and go in 2, 4, or 6 year cycles. Their connections with corporate, government, and university research laboratories allow them to stimulate intensive study of the problems that confound them in the field. Just as their research and training create general solutions to technical problems, so do their standard-setting efforts create general solutions to social problems.

The internal focus of these activities may mean, however, that the professions are strengthened at the expense of other sectors of society. Some of their activities may be interpreted as erecting bigger





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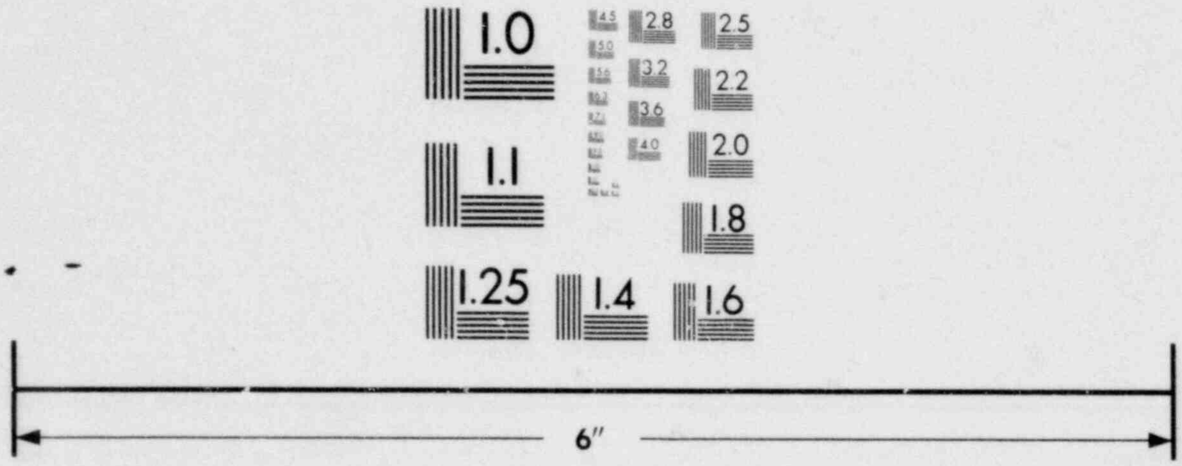

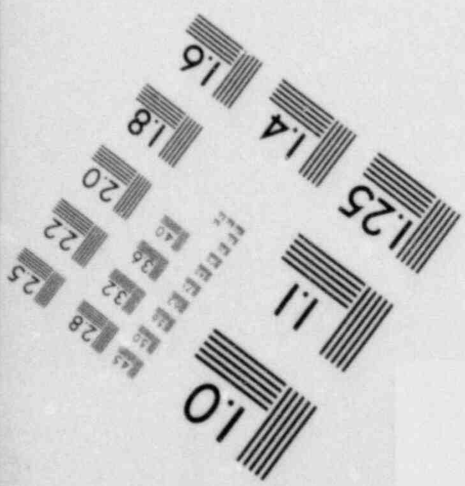

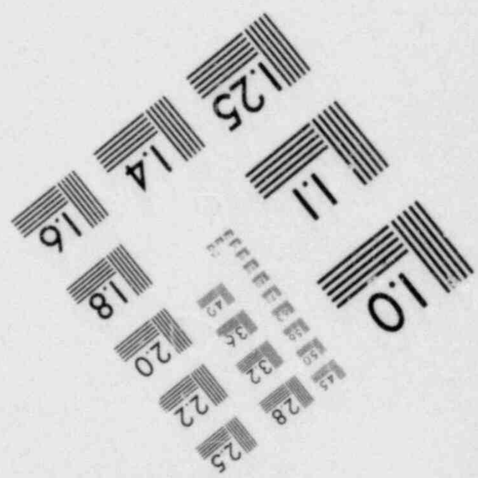

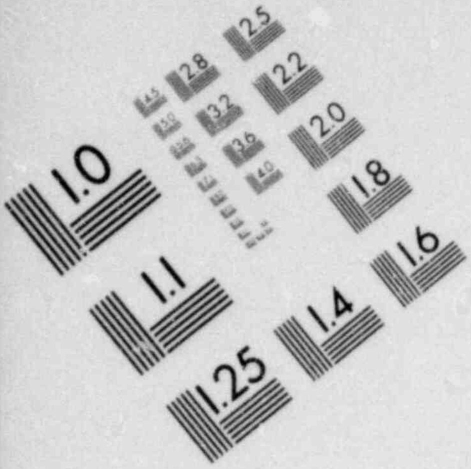

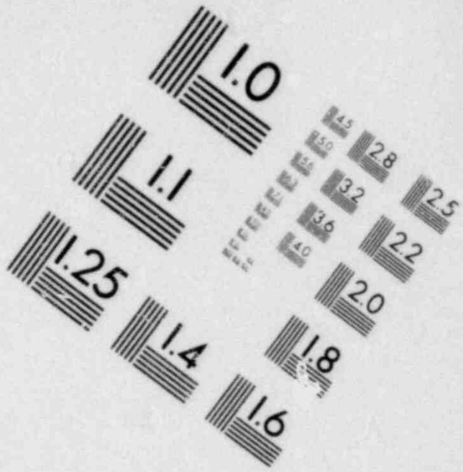

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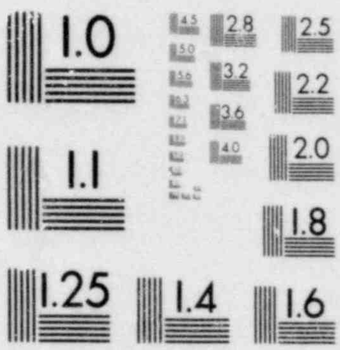

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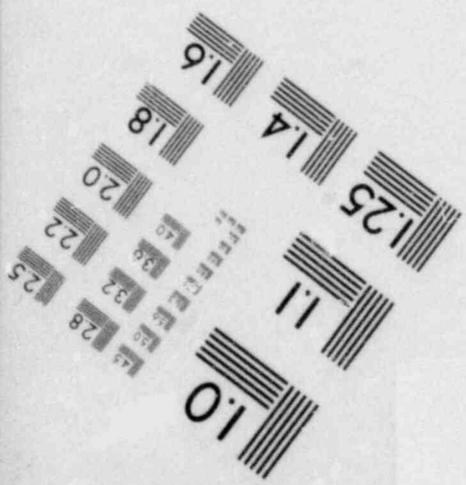
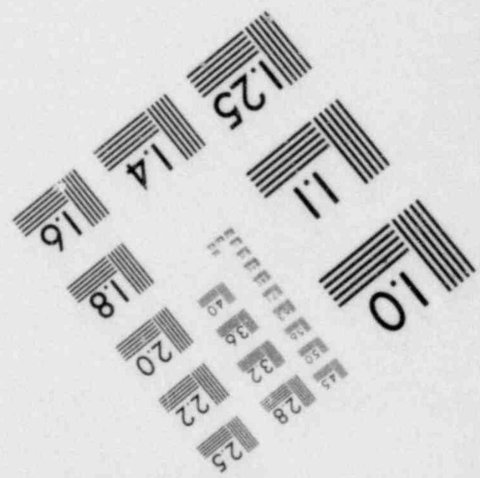




and better barriers to lay involvement and to the development of an informed and effective citizenry. Others may represent the careful, cumulative imposition of professionals' values and standards on society. Any persistent contentment with narrow problem definitions may be interpreted as a long-term contribution toward digging society into a hole.

Summary

By definition, professionals do their job better than anyone else could. That job may not, however, include the elements of a viable approach to acceptable-risk decisions. Professionals' training, personal values, work practices, and relations with various client groups may leave them without the rich and balanced view that one would want before conferring sole responsibility for such decisions.

CHAPTER 5

Bootstrapping

Both the professional judgment and formal analysis approaches assume that we can think our way to sensible acceptable-risk decisions. With a little computational help, one can accommodate all relevant points of view and achieve a balance that acknowledges political and technical realities. Proponents of bootstrapping approaches reject this assumption, arguing that risks cannot be analyzed adequately in any short period of time. Rather, society achieves an acceptable tradeoff between risks and benefits only through a protracted period of hands-on experience, allowing for trial-and-error learning.

If this is true, the critical question becomes: what are decision makers to do when they cannot wait for these evolutionary, adjustive processes, but must immediately make lasting decisions about acceptable-risk issues? Bootstrapping approaches propose using the level of risk that has been tolerated in the past as a basis for evaluating the acceptability of proposed risks. For example, if one believes that our market, social, and political institutions have been able to effect a nearly optimal balance of risks and benefits for familiar technologies, that experience can be codified into historic standards which could then be applied to future decisions. Short-circuiting history's cumbersome balancing process, we could move immediately to that nearly ideal balance. In effect, we would lift ourselves up by our own bootstraps, adopting standards that are consistent with current social policy and sensitive to the realities that frustrate the implementation of utopian solutions.

Although bootstrapping approaches resemble formal analysis by having explicit calculations and an articulated decision rule, their logic is very different. Formal approaches assume that policies that have evolved without the benefit of careful quantitative analysis may be inappropriate; hence, most existing policies have no prescriptive weight. On the other hand, bootstrapping approaches' reliance on adjustive processes leads their proponents to believe that descriptions of past policies may afford prescriptive guidelines. Four such bootstrapping methods are discussed below. They differ in the past they describe and in the biological, cybernetic, or economic mechanisms they invoke to argue that an acceptable equilibrium was achieved in that past.

Risk Compendia

Believing that many people have a poor grasp of the risks of modern life, some bootstrappers have tried to quantify the risks of many hazards in common terms. These estimates are aggregated into compendia designed to enhance decisions makers' intuitions and eventually produce more consistent standards for different hazards. For example, Wilson (1980) argued that we should "try to measure our risks quantitatively . . . . Then we could compare risks and decide which to accept or reject" (p. 43). Likewise, Sowby (1965) observed that we need to pay more attention to "some of the other risks of life" when deciding whether or not we are regulating radiation hazards properly, and Lord Rothschild (1978) added, "There is no point in getting into a panic about the risks of life until you have compared the risks which worry you with those that don't, but perhaps should" (emphasis in original).

Typically, such exhortations are followed by elaborate tables, or even "catalogs of risks" (Cohen & Lee, 1979), in which diverse indices of death or disability are displayed for a broad spectrum of life's hazards. Thus Sowby (1965) provided extensive data on risks per hour of exposure, showing, for example, that an hour riding a motorcycle is as risky as an hour of being 75 years old. Wilson (1979) developed Table 5.1, which displays a set of varied activities, each of which he estimated to increase one's chances of death in any year by 1 in one million. Wilson explained that ". . . these comparisons help me evaluate risks and I imagine that they may help others to do so, as well. But the most important use of these comparisons must be to help the decisions we make, as a nation, to improve our health and reduce our accident rate" (p. 45). In similar fashion, Cohen and Lee (1979) ordered a large set of hazards in terms of expected reduction in life expectancy (Table 5.2) on the assumption that "to some approximation, the ordering in [this table] should be society's order of priorities. However, we see several very major problems that have received very little attention . . . whereas some other items near the bottom of the list, especially those involving radiation, receive a great deal of attention" (p. 720). Since current risk levels are viewed as a valid basis for comparison, such risk compendia imply bootstrapping on the present. A proponent might paraphrase Stephen Spender, and claim that "I have seen the present and it works" or, at least, that it works well enough to single out the few outliers that are receiving too much or too little attention.

Table 5.1

Risks that Are Estimated to Increase Chance

of Death in Any Year by 0.000001*

Activity	Cause of Death
Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lunk disease
Spending 3 hours in a coal mine	Accident
Living 2 days in New York or Boston	Air pollution
Travelling 6 minutes by canoe	Accident
Travelling 10 miles by bicycle	Accident
Travelling 150 miles by car	Accident
Flying 1,000 miles by jet	Accident
Flying 6,000 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 1,000 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 benzopyrene
Risk of accident by living within 5 miles of a nuclear reactor for 50 years	Cancer caused by radiation

* 1 part in 1 million
Source: Wilson, R. (1979)

Table 5.2

Estimated Loss of Life Expectancy

Due to Various Causes

Cause	Days
Being unmarried--male	3,500
Cigarette smoking--male	2,250
Heart disease	2,100
Being unmarried--female	1,600
Being 30% overweight	1,300
Being a coal miner	1,100
Cancer	980
20% Overweight	900
<8th grade education	850
Cigarette smoking--female	800
Low socioeconomic status	700
Stroke	520
Living in unfavorable state	500
Army in Vietnam	400
Cigar smoking	330
Dangerous job--accidents	300
Pipe smoking	220
Increasing food intake 100 cal/day	210
Motor vehicle accidents	207
Pneumonia--influenza	141
Alcohol (U.S. average)	130
Accidents in home	95
Suicide	95
Diabetes	95
Being murdered (homicide)	90
Legal drug misuse	90
Average job--accidents	74
Drowning	41
Job with radiation exposure	40
Falls	39
Accidents to pedestrians	37
Safest jobs--accidents	30
Fire--burns	27
Generation of energy	24
Illicit drugs (U.S. average)	18
Poison (solid, liquid)	17
Suffocation	13
Firearms accidents	11
Natural radiation (BEIR)	8
Medical X rays	6
Poisonous gases	7
Coffee	6
Oral contraceptives	5
Accidents to pedalcycles	5
All catastrophes combined	3.5
Diet drinks	2
Reactor accidents (UCS)	2*
Reactor accidents--Rasmussen	0.02*
Radiation from nuclear industry	0.02*
PAP test	-4
Smoke alarm in home	-10
Air bags in car	-50
Mobile coronary care units	-125
Safety improvements 1066-76	-110

* These items assume that all U.S. power is nuclear.
UCS is Union of Concerned Scientists, the most prominent group of nuclear critics.
Source: Cohen and Lee (1979).

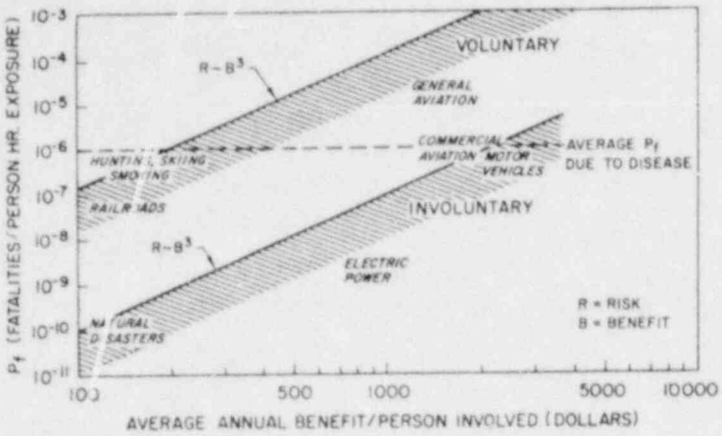
Properly speaking, however, comparing existing hazards is not a decision-making procedure, but merely an aid to intuition. The logic of such calculations does not require any particular conclusion to be drawn, say, from the contrast between the risks of motorcycling and advanced age.

Revealed Preferences

The revealed-preferences approach (Starr, 1969, 1972) improves upon simple comparisons of risk both by considering benefits and by providing a decision rule. It assumes that our society has already reached an "essentially optimum" balance between the risks and benefits of any existing technology and that this preferred balance is revealed in contemporary benefit and risk data. A new technology's risks are deemed acceptable if they do not exceed the level of risk associated with ongoing technologies having similar benefit to society.

Starr tried to demonstate the usefulness of revealed preferences by examining the relationship between risk of death and economic benefit for a number of common technologies (see Figure 5.1a). From these analyses, he derived several hypotheses about the nature of acceptable risk:

- The acceptable level of risk is roughly proportional to the third power (cube) of the benefits.
- The public is willing to accept risks from voluntary activities, such as skiing, that are roughly a thousand times greater than those it will tolerate from involuntary activities providing the same level of benefit.
- The acceptable level of risk decreases as the number of persons exposed to a hazard increases.



REGRESSION LINES FOR VOLUNTARY AND INVOLUNTARY EXPOSURE

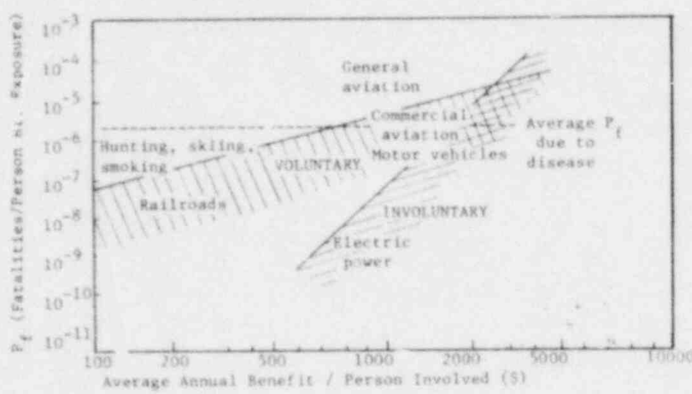


Figure 5.1. Relationship between statistically measured risk of death and economic benefit. (a) as studied by Starr (1972) and (b) as reanalyzed by Otway and Cohen (1975). In both figures, risk is measured by fatalities per person per hour of exposure. Benefit reflects either the average amount of money spent on an activity by an individual participant or the average contribution an activity makes to a participant's annual income. In Figure 5.1a, the best-fitting lines were drawn by eye with error bands to indicate their approximate nature. In Figure 5.1b, regression procedures were used after deleting natural disasters from the category of involuntary risks.

Although its logic has some intuitive appeal, the revealed-preferences method has several drawbacks. For example, it is hard to produce convincing measures of the risks and benefits of such diverse technologies. Otway and Cohen (1975) reanalyzed Starr's data and reached somewhat different conclusions (Figure 5.1b), as did Fischhoff, Slovic and Lichtenstein (1979), who performed an alternative analysis with the same underlying logic (Figure 5.2). These technical problems pale before the political difficulties raised by the basic assumption that current risk-benefit tradeoffs are satisfactory.

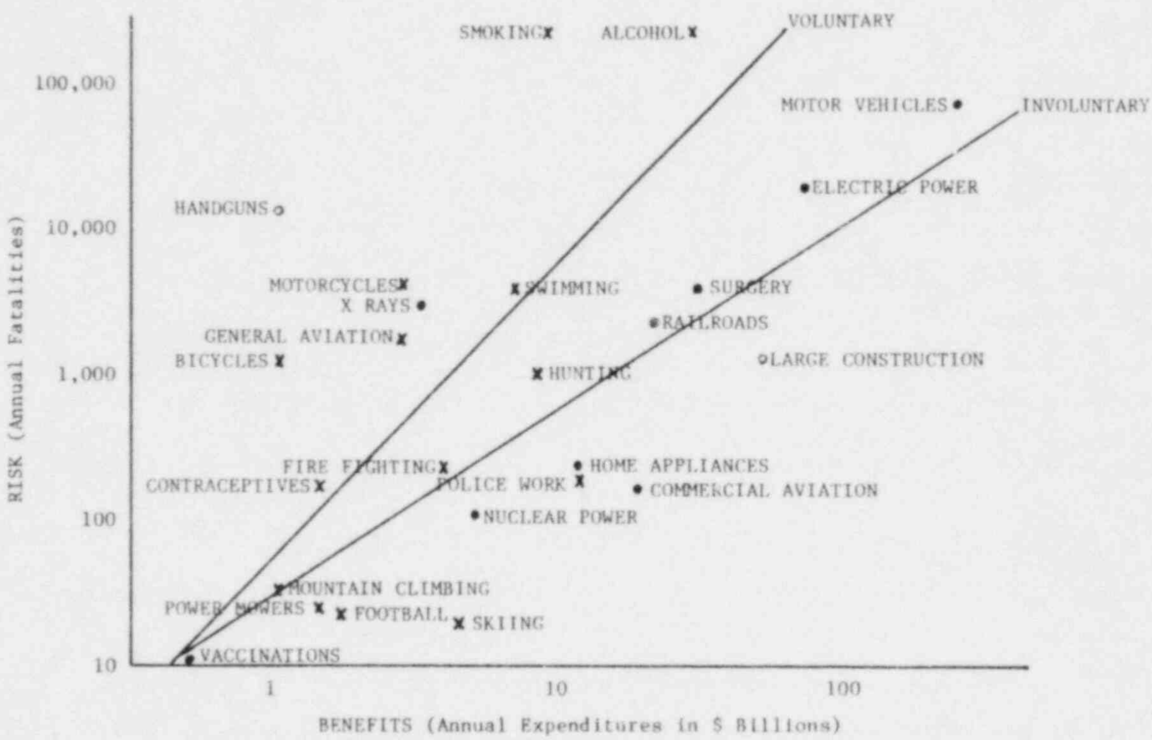


Figure 5.2. One possible assessment of current risks and benefits from 25 activities and technologies. Items are marked with an X, if voluntary; with a closed circle, if involuntary. Handguns and large construction could not be classified as primarily voluntary or involuntary. They are marked here with open circles and are not included in the calculation of the two regression lines shown in the figure. (Source: Fischhoff, Slovic & Lichtenstein, 1979, p. 20)

A variant of revealed-preferences analysis has been used to answer the question, "What is a life worth?" by rephrasing it as "What is the value placed on a particular change in survival probability?" Thaler and Rosen (1976) observed the "market behavior" of people trading occupational risks for economic benefits and found that a premium of about $200 per year was required to induce workers in risky occupations (e.g., coal mining) to accept an increase of .001 in their annual probability of accidental death. Assuming that this tradeoff was acceptable to all concerned, they inferred that society should be willing to pay about $200,000 to prevent a death. Here, too, technical difficulties may be substantial; a replication by Rappoport (1977), using somewhat different data and procedures, derived a value of $2,000,000.

Implied Preferences

Belief in society's ability to manage hazards might lead one to examine its legal records rather than its statistical traces. The legacy of laws, tort precedents, and regulatory actions can be interpreted as reflecting the compromise between what people want and what current economic and political arrangements allow them to have. One could attempt to shorten these sometimes tortuous processes by identifying their implicit risk-benefit tradeoff and applying it as a standard for the acceptability of other hazards.

The logic of implied preferences can be seen in the following proposal by the Atomic Industrial Forum (1976) to adopt the risk levels then tolerated in nuclear power plants as a guide to setting tolerable levels in the future.

> The Nuclear Regulatory Commission has recognized an acceptable level of risk, at least for regulatory purposes, in granting permits and licenses. While this level of risk has not been specifically quantified, the Reactor Safety Study now provides a benchmark for comparison. With this background, new issues can be assessed by judging whether these issues impact significantly on the plant risk envelope as determined in the Reactor Safety Study. If an issue can be shown not to affect significantly this risk, then design alterations additional to the vintage plant design analyzed in the Reactor Safety Study could not be justified.
>
> The Reactor Safety Study [has shown] the probability of exceeding 10CFR100 guidelines to be approximately 1×10^{-5} per reactor per year. In this regard, an event with a probability of 1×10^{-6} per reactor per year of exceeding 10 CFR 100 guidelines would not significantly affect the plant risk characterized in the Reactor Safety Study (p. 6).

Proponents of implied preferences, like proponents of the democratic process (Lindblom, 1965), make no claims that existing rulings are perfect. Rather, such rulings are thought to represent society's best attempt so far to accommodate people's desires and the facts of life in a hazardous world. Their weaknesses are the weaknesses of democracy itself: laws are sometimes hastily conceived and poorly written; they often are extended to cover situations undreamed of when they were written; their precise formulation may reflect fleeting political coalitions and public concerns.

As a result, despite the respect it gives to precedence, this legal legacy may lack coherence. Simultaneous actions at federal, state, and local levels may defy coordination. The varied forms these actions take may defy comparison and consistency checks; they include laws (and their rhetorical preambles), regulations (expressed in performance, technical, or vague standards), court cases (and appeals), federally subsidized risk reduction programs, etc. In addition, this record is incomplete. Successfully managed hazards may be absent because their risks were acceptable without legal intervention; unsuccessfully managed ones may be absent because their promoters were strong, their victims weak, or their risks underrated. To the best of our knowledge, there has been no comprehensive attempt to determine what, if any, consistent policy underlies legal actions (Johnson, B., 1980).

Natural Standards

A flaw shared by the above versions of bootstrapping is that all are subject to the limitations of the society whose decisions they describe, with its myths, mistakes, and inequities. Perhaps safety standards should be independent of a particular society, especially for risks having collective, cumulative, or irreversible effects. Rather than examining historical time for guideline periods that reveal social wisdom, one might want to look to geological time to reveal biological wisdom. Tolerable exposure levels would be those characteristic of the conditions in which a species evolved. Such "natural" standards need not constitute outright bans, as traces of many chemicals are needed for survival and some level of radiation- or chemical-induced mutation may be good for a species (if not for individual members). Since exposure has varied from epoch to epoch and from place to place, one could establish ranges of tolerable exposure.

An early natural standard was Agricola's (1556) philosophy of non-degradation of the environment in De Re Metallica. He advocated prohibiting human activities that would impose risks greater than those experienced in some "pre-existing natural state." In this spirit, Settle and Patterson (1980) suggest restricting lead levels in food to those found in archaeological remains; the National Resources Defense Council has proposed that the risk to future generations from the entire nuclear fuel cycle be limited to the risk presented by the ore bodies utilized in these operations prior to being mined (Rotow, Cochran & Tamplin, 1979). A related approach, analogous to the Atomic Industrial Forum's proposal to ignore risks that are small relative to those already accepted by society, would deem as acceptable events that contribute only a small increment over natural exposures (ICRP, 1973; Maxey, 1979). Figure 5.3 shows how the U.S. Atomic Energy Commission standards compared with natural background levels of radiation in 1976. It also compares then-current levels of SO_2 and NO_2 with background levels, suggesting the implications of invoking natural standards in these contexts.

A proposal by Adler (described in Weinberg, 1979) shifts the focus of natural standards from the average level of background radiation to the (apparently harmless) variations in that level to which the species may be accustomed:

> . . . rather than trying to determine the actual damage caused

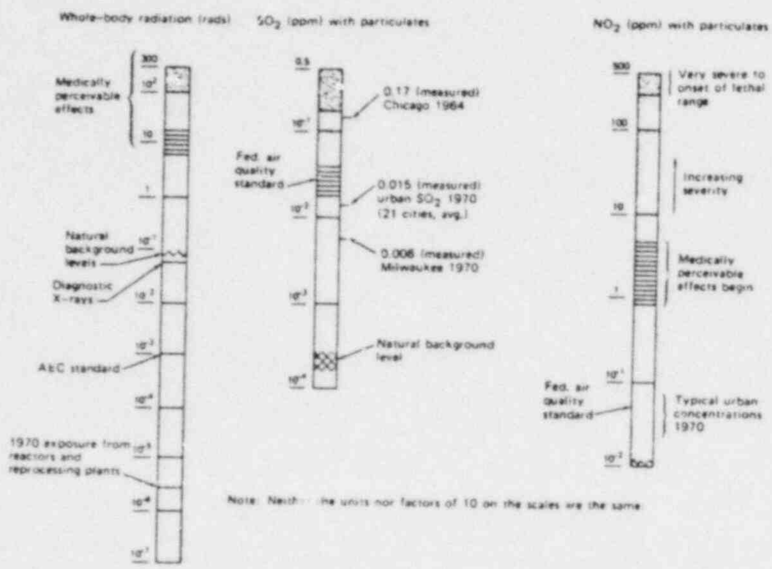


Figure 5.3. Comparison of pollutant standards, background levels, exposures of human origin, and health effects for radiation, SO_2 and NO_2. Source: WASH-1224, U.S. Atomic Energy Commission.

by very low radiation insult, and then setting an allowable dose, one instead compares the man-made standard with the background. Since man has evolved in the midst of a pervasive radiation background, the presumption is that an increment of radiation 'small' compared to that background is tolerable and ought to be set as the standard. [Adler] suggests that small, in the case of gamma radiation, be taken as the standard deviation of the natural background--about 20 millirads per year (Weinberg, 1979, p. 10).

One attractive feature of natural standards is that they can be set without knowing precise dose-response relationships; another is that they avoid the problems of converting consequences into a common unit (like dollars per life lost). Nonetheless, as a guide to policy, natural standards have several logical flaws without obvious remedies:

(a) Unless natural exposures have diminished, any new exposure adds to nature's dose and thereby constitutes excess and "unnatural" exposure (although conceivably within the range of toleration).

(b) Some technologies, such as steel-making, produce many pollutants. In principle, each effluent may constitute a small, hence acceptable, increment over background exposure. Natural standards provide no criterion for deciding when singly tolerable pollutants are cumulatively intolerable.

(c) Technologies may increase some exposures and reduce others (e.g., by replacing "dirtier" technologies). Although it seems sensible to make tradeoffs between such gains and losses, natural standards pass judgment only on individual increases.

(d) For completely new substances (e.g., saccharin) there is no historical tolerance. In such cases, a natural-standards policy would tolerate none of the substance at all, unless it involved no risk. The Delaney Amendment, which outlaws the addition of any known carcinogen to food, reflects this philosophy and encounters its limitations.

Generic Problems

Defining the Problem

The first question that arises in using bootstrapping is deciding which past constitutes the lode of wisdom. Are the nearly optimal tradeoffs to be sought in the present (risk compendia), the recent past (revealed and implied preferences), or the distant past (natural standards)? When these tradeoffs fluctuate over time, one must choose the most representative (or optimal) values. Should we rely on final (or most recent) values, on those from particularly stable periods, or on extreme values? These might be interpreted as representing, respectively, the results of the balancing process, some local equilibrium, or stress limits.

Except with natural standards, one must then decide which hazards to look at in that ideal past. One reasonable criterion for including a hazard is that riskiness should be a limiting factor. That is, it should be possible either to save money by making the activity riskier (e.g., by skimping on design, production, or regulation) or to save lives by spending money on safety measures. The revealed-preferences analyses in Figures 5.1 and 5.2 adhered to this criterion yet produced somewhat different conclusions, suggesting that the method needs more careful specification before it can be expected to produce robust results.

The next problem is defining the contemporary hazard that is to be compared with this historic set, in particular, the breadth of the category that it represents. Making general reference to the magnitude of risks currently "tolerated," Comar (1979b) argued for ignoring any hazard bearing less than 10^{-5} per year risk of death (unless it provides no benefit or can be easily reduced). Okrent and Whipple (1977) advocated a similar threshold for beneficial technologies (like manufactured goods). Implementing either of these bootstrapping schemes means deciding what a technology is. Are asbestos brake linings and asbestos-lined hair dryers to be treated as one or two technologies? Aggregation or disaggregation could mean the difference between having two technologies under the threshold or one above it. Kletz's (1977) rule of removing any activity that causes more than one fatal accident per 2500 workers spending their careers in the chemical industry encounters a similar problem, as do proposals to ignore events whose risks are only slightly above natural or implied standards. Without clear guidelines to the contrary, a consequential event could be redefined as a set of inconsequential events, each posing a small, hence negligible, threat.

Once the hazards have been selected, one must decide which of their consequences to measure (deaths, accidents, etc.). An important lacuna in the natural standards approach and in risk compendia is that benefits are not included among the consequences. For those consequences that are considered, a unit of observation is needed (per capita, per mile traveled, per vehicle). Starr chose to look at deaths and measure them per hour of exposure, both because of the availability of statistics and a personal speculation regarding how people think about hazards. Implementation of this scheme founders when an hour of exposure is hard to define (e.g., with handguns, vaccinations, or smoking), just as other indices (e.g., deaths per mile traveled) fail because they cannot be applied to all relevant hazards. The choice of index is important because different indices may cast the acceptable-risk problem in different perspectives. For example, reducing the risk per ton of coal mined may increase the risk per miner's hour of work; a project that extracted a certain quantity of coal at minimal cost in lives might be unacceptable to miners unless their hourly risk or work week was also reduced (Crouch & Wilson, 1979).

The final step in defining a problem for bootstrapping is choosing moderator variables, such as voluntariness, which are allowed to establish double standards for risk acceptability. The importance of moderators emerges clearly when one notes the weak overall correlation between risk and benefit in Figure 5.1. The hypothesis (or assumption) that society manages hazards so as to get more benefit from more risky ones was only supported when voluntariness was introduced as a moderator. A skeptic might ask "How many other moderators were tried before one was found that created a double standard?" If many were tried, the "historic" risk-benefit tradeoff may be a statistical artifact.

To take an analogous example from revealed-preferences studies of the value of a life, the riskiest jobs are generally the most poorly paid in some industries (e.g., logging). That is, the regression equation predicting wages from risk has a negative coefficient. The bootstrapper's response may be "let's control, statistically, for experience or agility or job security or . . . whatever it will take to produce a (multiple) regression equation with a positive coefficient on the risk variable." Although that equation will show workers being reimbursed, rather than charged, for taking risks, one must wonder whether the agile analyst can always find some moderators showing that risk taking is rewarded. What if a different set of moderators were needed for every profession? What does it mean that the workers who are ostensibly being reimbursed for the risks they take are but statistical constructions, living in that nonexistent world where the relevant moderators are partialled out (Meehl, 1970)?

Logical criteria for selecting moderators might require them to (a) be readily assessable for all hazards, (b) make some sense as a basis for social policy, and (c) not represent surrogates for other considerations. For example, involuntariness is often invoked as a sufficient condition for society to demand more stringent standards. Yet, it is poorly defined for some hazards (e.g., handguns, motor vehicles). Empirically, it seems important only when associated with catastrophic potential (i.e., when many people are threatened by a hazard they could not avoid), suggesting that voluntariness may not be the key variable (Slovic, Fischhoff & Lichtenstein, 1980).

In summary, bootstrapping analyses offer an incomplete problem definition. Although they consider some fact and value issues in great detail, they ignore the question of what options are available. Judgments are rendered on the absolute acceptability of individual options, regardless of the superiority, inferiority, or nonexistence of the alternatives. Indeed, bootstrapping provides guidance in choosing between two options only when one passes its threshold of tolerance and the other does not.

Knowing the Facts

Although bootstrapping approaches are all strongly data based, they have rather different attitudes toward what the facts of the matter are. Risk compendia can take whatever statistics are available; no ordering is made in terms of relevance; no input is considered indispensable.

Revealed preferences make similarly minimal demands; if suitable risk and benefit statistics are not available, a hazard is dropped from the analysis.

Implied preferences occupy a middle position; the corpus of law is moderately well defined, but it is unclear how broadly or deeply it must be worked. Although these attitudes toward sampling render the procedures somewhat indeterminate, the effect of sampling bias on the validity of their conclusions is seldom discussed.

Natural standards lie at the opposite extreme, specifying exactly what quantities to look for. This demand creates somewhat different problems. Although one may hope to assess natural exposure to chemicals that leave traces in bones or rock, appraising the natural incidence of accidents and infectious disease is probably impossible. Furthermore, should such an analysis be completed, it would likely show that the ecology of hazards in which humans live has changed drastically over the eons--mostly for the better, as in the case of the reduced incidence of infectious disease. The biological wisdom (or importance) of restoring one component of the mix to its prehistoric values would demand careful examination.

The bootstrapping analyses cited above all relied on average death rates to characterize risk. However, society may be more concerned with setting standards on the catastrophic potential of activities (Rowe, 1977a; Ferreira & Slesin, 1976; Slovic, Fischhoff & Lichtenstein, 1980). Although it is considerably more difficult to assess the small (or minute) probability of catastrophic events than annual fatality rates, Farmer (1967) and others have described recent experience with some hazards in a two-dimensional space defined by probability of occurrence and magnitude of consequence (see Figure 5.4). Assuming that one had confidence in all the assessments in this figure and accepted the time period in question as representing a relevant optimum, the risks of nuclear power would be acceptable by virtue of lying below the envelope circumscribing the risks of the other hazards. The fate of a technology whose curve crossed those of the other curves would be somewhat moot (e.g., dams). In deciding which part of the curve is most relevant, one would be judging, in effect, whether a society adapts primarily to the average or to the variance of its yearly accident experience.

Another popular index that might be applied to varied hazards is loss of life expectancy (see Table 5.2). However, it, too, has problems. Although some people feel enlightened upon learning that a single takeoff or landing in a commercial airliner takes an average of 16 minutes off one's life expectancy, others find themselves completely bewildered by such information. On taking off in an airplane, one will either die prematurely (almost certainly by more than 16 minutes) or one will not, and such averages seem to many to capt e the essence of the risks very poorly. Indeed, McNeil, Weichselbaum and Pauker (1978) found that patients facing the prospect of surgery for lung cancer were as concerned about its threat of immediate death as with its contribution to their life expectancy.

Assessing Values

Relying on descriptions of the past to provide guidance for the future presumes that "whatever was, was right." With natural standards, one might be able to derive a scientific rationale for this claim, for

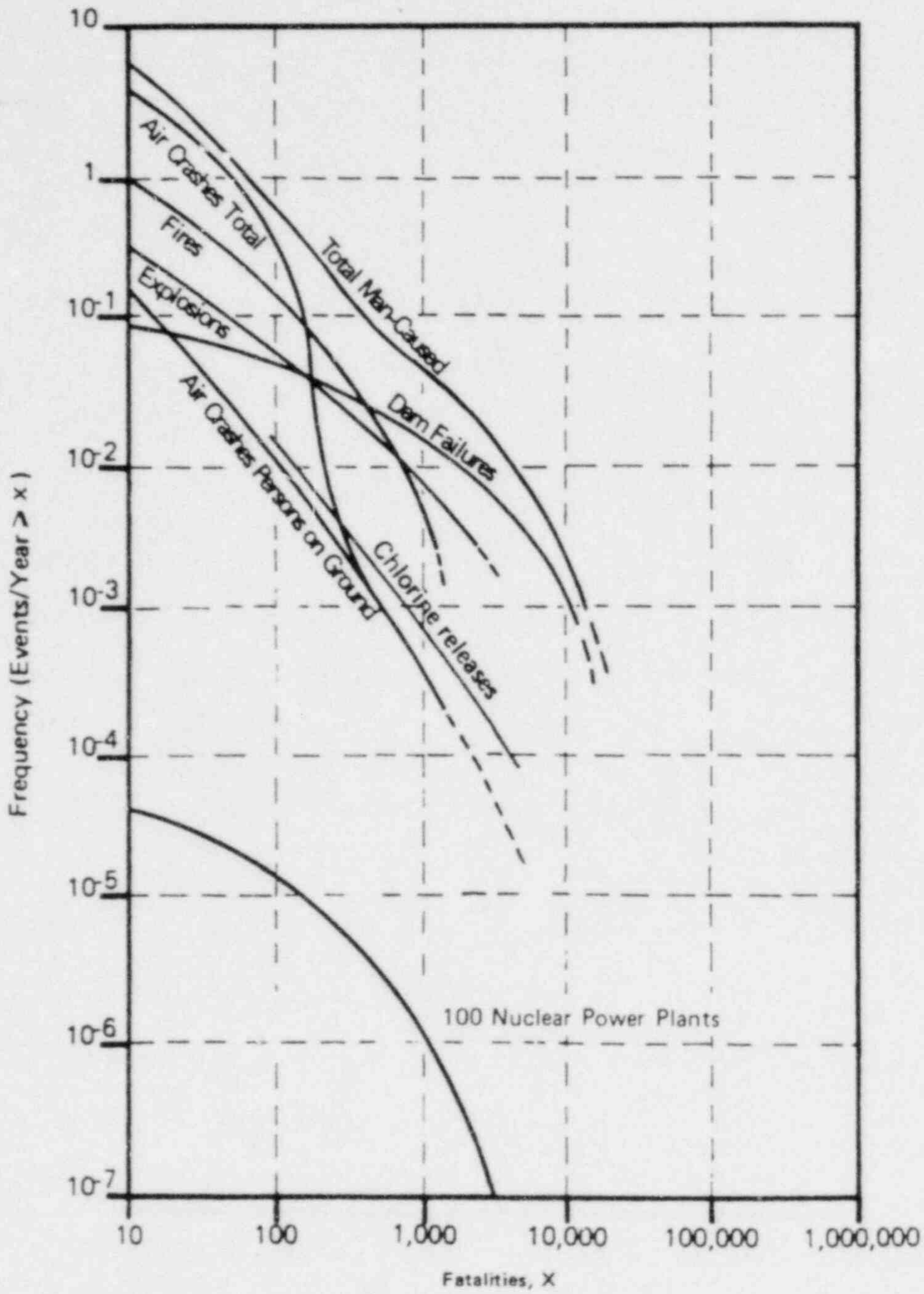


Figure 5.4. Frequency of Events Involving Different Numbers of Fatalities. Source: U.S. Nuclear Regulatory Commission, 1975.

example, by arguing on the basis of evolutionary theory that there is an optimal level of environmental stress. Substantiating this empirical claim would not absolve one of justifying the value-laden claim that stresses imposed on individuals are to be tolerated for the good of the species and the robustness of future generations.

With revealed and implied preferences, one is clearly enshrining those economic, social, and political relations that have generated the tradeoffs described by the analysis. Thus, one asserts not only that society has reached an equilibrium, but also that it has reached an acceptable one. Neither environmentalists nor their opponents in the "regulatory reform" movement are likely to accept this latter claim. If either group has its way, our current situation would prove to represent a very local equilibrium.

Aggregate revealed-preferences analyses, like those shown in Figures 5.1 and 5.2, invite further charges of bias. Like cost-benefit analysis (Chapter 6), such analyses fail to consider who is bearing the costs and benefits. By neglecting equity issues, these approaches offer no guide to selecting between options with different distributional effects; they may perpetuate current inequities or inadvertently endorse radical changes.

As always, technical aspects of implementing an approach prejudge certain value issues. For example, using a measure of benefits like total expenditures or total output, as did Starr, means taking several controversial positions. Since such measures include "bads" as well as goods, money spent on reducing the pollution that an industry causes is positively weighted as heavily as the value of the product it manufactures. In addition, one ignores any ways in which market prices fail to reflect the full social costs of an activity. One assumes, for example, that cigarette prices take account of the smoker's higher probability of heart disease or cancer and that pesticide prices fully reflect both their deleterious side effects and the increased yield of foodstuffs. Depending upon one's perspective, the benefits of pesticides may be under-valued or over-valued by "total expenditures." The revealed-preferences approach is most prone to these criticisms because it makes the most conspicuous effort to quantify benefits.

To conclude where we began, even if an approach could capture the preferences of the period it chose to study, these would indicate only what risks are accepted, not what risks are acceptable. In line with Hume's dictum that no "ought" can ever follow from an "is," Tribe (1973) and others have argued that prescriptive guidelines must reflect not just what a society does want, but what it should want. Using a community conflict about whether to build a dam as an example, Tribe notes that bootstrapping analysis could help the community infer how much its inhabitants do in fact value the birds and other wildlife that would be lost if the dam were built, as compared with the boating and other activities that the dam would provide. However, it could not shed light on "what those values ought to be--about the extent to which theirs should be a wildlife-valuing community, with all that this might entail for how its members view and value both nature and one another" (p. 656, emphasis in original).

Coping with the Human Element

Except perhaps for natural standards, all these bootstrapping approaches make strong behavioral assumptions. It is only by validating these assumptions empirically that bootstrappers can confer prescriptive weight to their descriptive results. One such assumption is that the state described by an analysis was the final stage in a balancing process, not just an intermediate point. The validity of the recent past as a guide would be vitiated if one believed that social and market institutions were just beginning to achieve reasonable compromises with the myriad of new technologies that have emerged in recent years. One symptom of disequilibrium might be rapidly increasing risks (reflecting, say, a cancer time bomb that has yet to be recognized and managed); equally symptomatic might be rapidly decreasing risks (reflecting, say, the gradual impact of recently enacted regulations).

Once the existence of an equilibrium was established, one would want evidence attributing it to some underlying optimizing process. The natural-standards advocate would want to show that there is some ideal level of environmental stress (or insult) for human evolution or survival. Belief in revealed preferences or risk compendia would be strengthened by evidence that people make sufficiently informed and "rational" decisions for their behavior to reflect their own best interests (Viscusi, 1979). The research cited in Chapter 2 makes this last assumption dubious. Consumers not only do not know all that could and should be known about risky alternatives, but they are often denied that information by advertising and marketing practices. For example, unless automobile buyers know from a design standpoint what safety is possible and at what price, and unless the industry provides varied alternatives from which to choose, market behavior may not reflect the personal cost-benefit tradeoffs an individual might elect after thoughtful inquiry.

One doubtful assumption of any approach that relies on market mechanisms to achieve an acceptable equilibrium is that those mechanisms are sufficiently responsive when a long time gap separates exposure and consequence (e.g., carcinogens). Technologies whose carcinogenic potential is unknown when they are first introduced may be unduly dangerous, particularly when subsequent control is difficult (either because no other options exist or because their industry is heavily capitalized). Consumers and workers could not negotiate fair deals for such hazards. Even with known hazards, our societal institutions free many polluters from paying for long-term effects, if only by allowing them to go bankrupt.

An option open to bootstrappers who look to contemporary social institutions to produce nearly optimal balances is to improve the functioning of those institutions. Bootstrappers could press for more research on the properties of new technologies, better programs for informing consumers about risks, and innovative legal institutions for fairly distributing the costs and benefits of risky technologies. If they are successful, we would have a society that managed hazards so that our experience in the near future would create a balance that could be exploited by the bootstrappers of more distant futures.

Finally, the behavioral assumptions of some bootstrapping approaches seem to contain internal contradictions. For example, reliance on risk compendia assumes both that people are sufficiently informed and astute to manage most hazards consistently and effectively and that they are incapable of getting along without simplistic decision aids. All approaches except natural standards assume that society manages hazards well; yet some hazards are so mismanaged that they must be taken out of the political-social-economic arena and have "consistent" standards forced on them. With new technologies, this segregation may be justified as a way to shortcut time-consuming processes. But when bootstrapping is applied to "veteran" hazards, the analyst has some explaining to do: How is it that society manages so well in general, but not here? Finally, if society does adjust hazards by trial and error, is it fair to subject a new hazard as proposed on the drawing board to the standards achieved by old hazards? A new technology may be judged too harshly if it is not given the opportunity to reduce costs through economies of scale, increase productivity as experience is gained by its work force, or evolve superior configurations by responding to competitive pressures.

Assessing Decision Quality

A striking feature of Tables 5.1 and 5.2 is the absence of any qualification of the estimates provided. A defense for this omission might be that, given the weak logical underpinnings of risk compendia as a decision rule, further specification (e.g., through the use of confidence intervals) might represent misplaced imprecision. A rough list provides all the information that such analyses can supply. However, this argument belies the contention that risk compendia are aids to intuition. Those who need such aids most would also be most poorly equipped to guess what qualifications should accompany these risk estimates or to understand how qualification would weaken whatever conclusions that such lists suggest.

The hashmarks in Starr's revealed-preferences analysis (Figure 5.1a) acknowledge imprecision in at least one aspect of the analysis, the fact that he roughed in the best-fit lines in the figure. However, when one compares the divergent pictures created by Otway and Cohen's (Figure 5.1b) reanalysis of Starr's data and the comparable analysis of Figure 5.2, the tidy hashmarks in Figure 5.1a seem to generate too much confidence in the quality of the conclusions drawn from it. These figures might become indecipherable blurs if one added vertical and horizontal error bars to the points, along with confidence intervals around the best-fit lines. The order-of-magnitude disagreement between the value-of-a-life estimates produced by the conceptually similar efforts of Thaler and Rosen and of Rappoport affords a quantitative assessment of the robustness of revealed-preferences procedures. Some theory is needed for deciding how much analysis-to-analysis variation renders the results too unstable to provide a base for public policy.

Although these examples refer to revealed preferences, all bootstrapping approaches seem to be quite sensitive to the precise way the problem and its components are defined. In the absence of reasoned guidelines to resolving definitional issues, the procedures become ill-defined, hardly an assurance of producing a quality decision.

An additional layer of uncertainty is added to these analyses by the uncertain status of their underlying behavioral assumptions. For example, we know that people are not the "compleat" decision makers postulated by revealed-preferences and that completely unrestrained markets are unachievable, particularly with technologies that have only a few producers or are vital to national defense. What we do not know, and what is critical to assessing the quality of the conclusions generated by these analyses, is the extent to which these failings negate the claim that they "reveal people's preferences." A final source of ambiguity is that revealed-preference theory was originally generated by economists to handle private goods with monetary consequences; it is unclear to what extent it can be extended to decisions about public goods with life-and-death consequences (McNown, 1978).

How Adequate Are Bootstrapping Approaches for Resolving Acceptable-Risk Questions?

Comprehensive

The omissions and inclusions of three of these bootstrapping approaches are quite straightforward. Risk compendia and natural standards consider risks in great detail, but ignore entirely the benefits accruing from technologies. Revealed preferences accommodate one expression of benefits, but include no consideration of how those benefits (and the risks) are distributed. At the other extreme, analysis of implied preferences reflects whatever factors happened to influence the political processes it chooses to describe; its comprehensiveness cannot be assessed.

All of the approaches ignore the question of what alternatives are available. Indeed, since they pass judgment on the acceptability of particular technologies, none of them provide guidance for choosing between two alternatives when they both pass or both fail the acceptability test. In that way, they fail to address the decision makers' problem of choosing between options.

Logically Sound

The strength of bootstrapping approaches is their breadth. More than other methods, they attempt to look at a full spectrum of hazards so as to impose consistent safety standards. The summary measures they use are interpreted, with some justification, as reflecting society's or nature's empirical (i.e., non-analytic) integration of a wide range of processes (e.g., economic pressures, political negotiations, public preferences, engineering ingenuity).

The weakness of bootstrapping approaches is their lack of depth. The logic of exactly how these societal or natural processes perform their integrative magic is neither made very explicit nor subjected to empirical validation. Equally inexplicit are the details of how such analyses are to be conducted. Conclusions are highly sensitive to problem definition, yet there seems to be no theoretical basis for choosing between alternative definitions.

One purpose of revealed preferences is to avoid the logical thickets encountered when one tries to reduce risks and benefits to a common unit. The analyst finesses this issue by comparing the risks and benefits of a test case with the pattern of risk-benefit tradeoffs currently accepted. One purpose of the analysis in Figure 5.4 was to avoid the analogous thickets of reducing probability and magnitude of risk statistics to a common measure. Each of these strategies works only if a clear pattern emerges and the standing of the test case vis-a-vis that pattern is unambiguous. Such clarity becomes increasingly unlikely as the number of relevant dimensions increases, e.g., one wants to consider benefits, probability of fatal accidents, magnitude of fatal accidents, expected number of cases of disability, etc. When clarity is absent, bootstrapping approaches offer no decision rule.

<u>Practical</u>

The weakly specified conditions for an adequate bootstrapping analysis make most of these techniques eminently implementable. At times, any set of data expressible in a common unit will do. When more rigorous requirements are imposed. these techniques can quickly become quite impractical. For example, with natural standards, there is no cheap way to assess ambient levels of many chemicals in geological time; there is no feasible way to derive rates of disease or accident; there is no conceivable way of looking for geologic effluents of newly created chemicals. With revealed preferences or risk compendia, there might be no way of expressing the set of relevant hazards in a common unit. Even if a common unit exists in theory, that might not be the unit in terms of which the hazards were managed; within a set, various hazards may be thought of in terms of risk per hour of exposure, risk per unit of production, total annual casualties, or consequences of their maximum credible accident. Finally, it may be hard to define some of the terms needed for such an analysis; e.g., what constitutes an hour of exposure to handguns; how voluntary are risks from prescription antibiotics or motor vehicles; are traffic accidents on the way to the airport (or experienced by non-flyers due to congestion near airports) part of the risks of aviation?

Open to Evaluation

Like other computational approaches, bootstrapping analyses are, in principle, highly scrutable. As with those other approaches, this potential is somewhat frustrated by problems in both theory and practice. Problems of practice arise whenever inadequate attention is given to making the substance, assumptions, and limitations of analyses comprehensible to the recipients whose intuitions they are intended to educate. For example, the pioneering analyses of Tables 5.1 and 5.2

gave little attention to how lay people interpret very small probabilities, what degree of precision they impute to point estimates like those presented, or whether they think to question the scientific validity of the statistics. Statements such as "the risk from nuclear power is equal to the risk of riding an extra three miles in an automobile" may confuse rather than enlighten many readers. Without a better understanding of cognitive processes, attempts to aid intuition may only confound it, or even deliberately exploit its weaknesses for the sake of rhetorical aims.

In the original presentation of his results, Starr (1969) carefully detailed the limitations he saw in his analysis. Although his list included several points not mentioned here, it still omitted many of the conceptual or political limitations of the revealed-preferences approach that are discussed above. We are just beginning to develop a full understanding of these limits. Were a full set of qualifications to accompany any of these analyses, the recipient would probably still be hard pressed to know how to deal with it. Whenever an approach has such fundamental problems, it is hard to determine whether even the best of all possible applications is good enough to guide societal decision making.

Politically Acceptable

At the heart of bootstrapping analyses lie two strong political presumptions. One is that the past "worked," in the sense that its denizens were able to achieve their legitimate goals. The second is that the future should work in the same way; that is, the goals of the past should be our goals. If made explicit, these presumptions would not sit very well with many people, particularly those who feel that society has not done right by them or those who feel that the notion of a smooth, efficient, responsive society is a myth promulgated by those interested in preserving the status quo.

Other ethical presumptions emerge in the implementation of these approaches. The lack of distributional or equity considerations is one. The precise way that benefits are measured is another. Natural standards, for example, ignore immediate benefits (e.g., income, innovation, employment) in favor of vaguely specified long-term goals, such as survival of the species or the integrity of ecological systems. For better or worse, such abstract and absolute standards are likely to fare poorly in political battles. On the other hand, without such standards, there is often no one around to negotiate for future generations (or "minor" animal species or vegatation without recognized economic value). In choosing a relevant past and the set of relevant hazards, the analyst may prejudge other value questions and invite trouble from knowledgeable observers.

Compatible with Institutions

Although widely invoked in recent risk discussions, bootstrapping analyses have little legal standing in existing institutions. The Delaney Amendment imposed natural standards on the Food and Drug Administration; the fact that it is rarely invoked and even more rarely upheld suggests that it was a misfit even there. Perhaps the bootstrappers' greatest success is with the International Committee on Radiation Protection, a collegial body which has constantly referred to background exposures in its deliberations (e.g., Morgan, 1969). Moreover, its recommendations have been adopted for many purposes. Otherwise, bootstrapping analyses are more likely to be found on the pages of Science or Technology Review than on those of the Federal Register or the Code of Federal Regulations.

Since it offers specific directives, requires no involvement with the public, and adopts a simple, narrow problem definition (by ignoring alternatives), bootstrapping should lend itself well to the procedures of bureaucratic regulatory agencies. Since it mandates performance standards, bootstrapping should also find a home in professional organizations, whose members can search for creative solutions to problems, unshackled by the constraints of design standards. Although poorly developed, the implied-preferences approach would seem to fit easily into existing institutions, since it assumes that those institutions are doing such a good job that they need help only in doing faster what they do naturally. In a sense, implied preferences may fit too well, reinforcing current bad practices as well as good ones.

We suspect, though, that ambiguities in problem definition will render bootstrapped rulings vulnerable to court (or other) challenges. In any specific application, the details make all the difference and the choice of details may be hard to defend. For example, the problems of implementing the Delaney Amendment largely reflect the unresolved debate over what "zero risk" means, a debate arising from the vast improvement in science's ability to detect deleterious effects of chemicals over the last twenty years (Bradley, 1980).

Conducive to Learning

By aggregating over time, bootstrapping analyses are built on a long-term perspective. By providing a systematic way to accommodate new scientific information, they allow for the ready aggregation of knowledge about diverse hazards. By looking to the past, they promise consistent standards, codifying existing wisdom.

They may be somewhat less successful in providing for the future. Although the standards adopted for other hazards in the past are considered, the cumulative impact of the decisions that result from bootstrapping is not. Accepting many tolerable hazards may lead to an overall risk burden that is intolerable. In addition, bootstrapping is most likely to be applied to decisions about the acceptability of new technologies. Those new hazards are all required to pass a test that many familiar technologies have failed. This double standard may be seen as an obstacle to innovation or as a response to society's overall risk burden. From the public's perspective, one way to reduce a currently intolerable risk level is to forbid any new hazards, unless they reduce dependence on more harmful existing ones.

Summary

Bootstrapping approaches assume that an adjustive process has produced a nearly optimal balance of risks and benefits in our social or natural environment; hence descriptions of past or present policies provide reasonable prescriptive guides. If our society has managed hazards well, that experience may be codified and applied to future decisions. By circumventing the need for costly trial and error, we can, in effect, lift ourselves up by our own bootstraps.

What seems at first glance to be a simple and compelling approach looks less viable under careful examination. Risk compendia are superficial and misleading when they ignore benefits, equity, catastrophic potential, and uncertainty. Revealed preferences take benefits into account, but rely on strong and unsubstantiated assumptions about human behavior and the validity of market data. Although implied standards may be the most inclusive, this approach makes less sense if one considers the tumultuous way in which government often makes decisions. Even if these approaches could capture what people have wanted in some ideal past, they fail to consider what people should want. Natural standards avoid the flaws of society, but their insensitivity to economic issues is politically unrealistic.

Finally, all four approaches leave critical details of their implementation unspecified, making them poorly defined as decision rules. Bootstrapping analyses appear at first glance to be a natural way to educate our intuitions. Yet the facts do not speak for themselves, except for listeners who already know what they want to hear. When the facts must be interpreted, the weakness of the logic underlying bootstrapping analyses renders their conclusions ambiguous.

CHAPTER 6

Formal Analysis

Formal analyses attempt to clarify the issues in acceptable-risk decisions by the application of analytical schemes based upon formally defined principles of rationality. Cost-benefit analysis and decision analysis are the two most prominent representatives of this genre and the ones that will receive the greatest attention here. Common to all versions of formal analysis is an attempt to evaluate and compare the advantages and disadvantages of proposed actions. Each involves four stages:

(1) The decision problem is defined by listing alternative courses of action and the set of all possible consequences. The scope of these lists is a critical determinant of the adequacy and acceptability of the analysis.

(2) The relationships between these alternatives and their consequences are described. Sophisticated mathematical or structural models may be used in this stage. These reflect a divide-and-conquer strategy, decomposing complex problems into more manageable parts; they include models of physical processes, market behavior, dose-response relationships, and so forth. Probabilistic aspects of the alternative-consequence relationships are quantitatively expressed in most decision analyses and in some cost-benefit analyses.

(3) All consequences are evaluated in a common unit. In cost-benefit analysis, money is the measure of value; decision analysis uses subjective judgments of worth or utility.

(4) The components of the analysis are integrated to produce a "bottom-line" number evaluating each alternative. In cost-benefit analysis, this number represents the difference between the benefits and costs to be expected if that alternative is selected; in decision analysis, it represents the option's expected utility. Often, review procedures (e.g., sensitivity analysis) are applied to assess the robustness of these numbers.

If these analytic tools are interpreted as constituting *methods* for acceptable-risk decisions, then the alternative faring best on the bottom line should be adopted. Anyone who accepts a technique's underlying assumptions and its implementation should follow its recommendations. A more moderate view holds that the simplifying assumptions and deficiencies of even the best analyses render them only an *aid* to decision making. In this view, the goal of analysis is to clarify a problem's facts, values, and uncertainties, making it easier for decision makers to rely on their own intuitions in choosing an alternative.

Cost-Benefit Analysis

"Cost-benefit analysis" goes by many different names, including "benefit-cost analysis," "risk-benefit analysis," and other permutations. Techniques whose label includes the word "risk" always focus on threats to life and limb, but so do some cost-benefit analyses. For convenience, the term cost-benefit analysis is used here. In addition, many different techniques go by the name "cost-benefit analysis." The label has been used for almost any explicit consideration of the monetary advantages and disadvantages of one or more decision options. Here, it refers to those analyses most firmly grounded in economic theory.

Conceptual Basis

Cost-benefit analysis first gained prominence in the 1930's when the U.S. Army Corps of Engineers adopted it for evaluating water resource projects. Its origins lie in economic theory, particularly in social welfare economics and resource allocation. Somewhat in the spirit of accounting, it attempts to add up the values of all of the good and bad consequences of a project. These values are defined as individuals' preferences (or subjective valuations). The tools of economic theory are used to assess these preferences, particularly as they are revealed in market behavior, in order to study the economic efficiency of proposed projects. A utilitarian criterion leads to selection of a project that produces the greatest good for the greatest number (i.e., has the greatest preponderance of costs over benefits summed over all affected individuals). Elementary expositions may be found in Layard (1974) and Stokey and Zeckhauser (1978), with a more complete discussion in Mishan

(1976).

Simply adding costs and benefits ignores who gets what. The Pareto optimality criterion is designed to accommodate equity concerns: An action is considered acceptable (indeed, preferable) if it improves the subjective economic status of at least one member of society, without making any other member worse off. Many social policies benefit some people and harm others, thereby violating Pareto optimality. In such cases, the Pareto criterion could be met only by having those who gain compensate those who would otherwise lose, either directly (e.g., through negotiated payments) or indirectly (e.g., through tax relief to the losers). The difficulties of creating viable compensation schemes has led to development of a less stringent criterion, potential Pareto improvement (also called the Kaldor-Hicks criterion). According to this criterion, an action is acceptable if the gainers could compensate the losers; the requirement that they actually do so is dropped. This criterion legitimates choosing the alternative that maximizes the difference between total benefits and total costs, regardless of their distribution.

In its pursuit of economic efficiency, cost-benefit analysis intends to include all consequences amenable to economic valuation and exclude all others (Parish, 1976). "Amenable to economic valuation" is subject to different interpretations, particularly when deciding whether to include "soft" values, such as "scenic beauty" or "national honor." Many practitioners evaluate only those commodities and services with readily measurable market values (e.g., construction costs, sales, and wages). Indirect economic evaluation methods using demand principles, shadow prices, and the like may extend the range of considerations to which a dollar value may be attached. There is, however, some disagreement about how far these methods should be pushed to allow inclusion of social and political consequences. Some analysts argue that the introduction of non-economic consequences would confuse the analysis, obscure the purely economic facts, and prevent a "clear interpretation and social rationale" (Mishan, 1974, p. 91). According to Parish (1976), "we should render unto Caesar those things that are Caesar's; our primary expertise and responsibility lies in explicating the workings of Mammon. And we certainly should not attempt to play God" (p. 3.4, emphasis in original).

Although the idea of listing, calculating, and summing monetary consequences is straightforward, its execution may be very difficult. Some economic effects must be ignored for want of credible assessment techniques. Other problems ha generated enough conflicting techniques to fill the professional literature with critiques and rebuttals. With some problems, such as establishing the monetary value of a life, those conflicts seem far from resolution.

Variants of Cost-Benefit Analysis

Cost-effectiveness analysis. In some problems, all alternatives have the same benefits. For example, a chemical firm may have several ways to reduce workers' inhalation of a toxic substance by a fixed amount. Since the benefits of the methods are equal, cost becomes the only issue. In other problems, all alternatives have the same cost. For example, the chemical plant may allocate a fixed sum of money for protecting workers. The problem then becomes choosing the alternative that achieves the greatest reduction in toxic inhalation for that amount of money.

In neither case is there any need to reduce costs and benefits to a common metric. Cost-effectiveness analysis is designed to reveal which alternative produces the greatest effect for the amount of money one has to spend or which produces the desired effect with the smallest expenditure. As a result, it avoids the sticky task of directly assessing the economic value of a given reduction in exposure. Of course, the value placed on workers' health enters the analysis indirectly, through the decision about how much to reduce exposure or how much to spend.

One danger of cost-effectiveness analysis is that the opportunity to avoid comparing costs and benefits may tempt one to oversimplify the problem. For example, one may fail to ask (a) whether the budgeted amount is too large or too small, given the severity of the problem; (b) whether the firm might use those funds better in other ways (e.g., on alternative safety options whose benefits might be difficult to compare or on increased compensation to workers); or (c) whether there are subtle differences in the options that vitiate the equivalence of their costs or benefits (e.g., a filter that costs more may also remove other pollutants). Although all techniques may define problems too narrowly or omit subtle costs and benefits, the temptation to do so may be particularly great with cost effectiveness.

<u>Value-impact analysis</u>. Since January, 1976, the Nuclear Regulatory Commission has used an analytic technique called value-impact analysis, whose formal properties have not been well defined. This

technique has been described at times as if it were similar to either cost-benefit analysis or cost-effectiveness analysis, with some preference for the latter interpretation. When possible, using cost-effectiveness analysis would avoid the problems of monetizing possible consequences such as cancers, genetic damage, and trans-generational waste storage.

Some value-impact analyses are, however, neither cost-benefit nor cost-effectiveness analyses. For example, a recent NRC-sponsored study of international shipments of nuclear materials (Fraley, Chockie, Levy & Kofoed, 1979) appears to be a partial decision analysis, with little consideration of uncertainty and with verbal descriptions, rather than numerical expressions, of values.

Using Cost-Benefit Analysis to Set Acceptable Risks

As with other formal decision-making tools, cost-benefit analysis may be regarded as either a method or an aid. That is, one can choose whichever option is found to have the greatest preponderance of benefits over risks or use the analysis as a guide to be supplemented by other considerations. Rowe (1977) offered a four-stage process for accommodating such considerations. Stage 1 analyzes direct economic benefits and costs. If the former are greater than the latter, indirect and non-quantitative effects are analyzed (Stage 2), followed by examination of the cost of additional reductions in risk (Stage 3). Rowe notes that "the central question in this risk-reduction analysis is determining the point at which risk has been sufficiently reduced" (p. 962), and acknowledges the difficulty of specifying what "sufficiently" means. Stage 4 reconciles inequities, using society's current practices as a reference point. Thus, this final stage uses bootstrapping to elaborate a formal analysis.

Rowe's proposal does mor raise questions omitted in cost-benefit analysis than to resolve them. For example, it leaves unanswered: How are the non-quantitative consequences of Stage 2 integrated with the formal analysis? What is the criterion for deciding how much risk reduction to buy? What bootstrapping approach risk inequities avoids the problems discussed in Chapter 5?

Decision Analysis

Decision analysis has its origins in the theory of individual decision making developed by von Neumann and Morgenstern (1947) and Savage (1954). Decision theory is an axiomatized theory for making choices in uncertain conditions. It is also a prescriptive theory; if you accept the axioms and their interpretation in practice, you ought to make the recommended choices. Decision analysis implements decision theory with the aid of techniques drawn from economics, operations research, and management science. The details of this marriage of axiomatic theory and applied methodology may be found in Howard (1968), Howard, Matheson and Miller (1976), Keeney and Raiffa (1976), Raiffa (1968), and Schlaifer (1969).

A thorough decision analysis has five main steps:

(1) Structuring the problem. The analyst defines the decision problem by identifying the relevant alternatives, the set of possible consequences, and the sources of uncertainty. Structural models are used to express the interrelationships among these elements; the construction and application of such models requires both technical expertise and good judgment.

(2) Assessing probabilities. Uncertainties about the present and future state of the world are quantified as probabilities. Decision analysts view probabilities as expressions of individuals' beliefs, not characteristics of things. As a result, probabilities are elicited as judgments from the decision maker or from experts (Spetzler & Staël von Holstein, 1975).

(3) Assessing preferences. Unlike cost-benefit analysis, which

quantifies preferences by analysis of market data, decision analysis uses subjective value judgments, that is, utilities. Thus, decision analysis can, in principle, accommodate any consideration that the decision maker deems appropriate. Values for such "soft" considerations as aesthetics or "satisfying Senator X" can be judged and included as easily as for "hard" considerations like monetary cost.

In this process, attitudes toward risk are also accommodated. For example, an analysis could reflect the decision maker's feeling that a safety device having a .5 chance of saving 100 lives is less desirable than one that will surely save 50 lives. Such an attitude, called risk aversion, is defined as the feeling that the desirability of an alternative with uncertain outcomes (or consequences) is less than the desirability of its expected outcome (i.e., its outcomes weighted by their probability of occurrence). Risk proneness is the reverse, representing a preference for a gamble with uncertain outcomes over the expected outcome of that gamble.

When a particular outcome has several kinds of values associated with it (e.g., a successful operation can lead to both reduced pain and prolonged life), cost-benefit analysis simply adds together the various costs and benefits. In decision analysis, other combination rules are also available (e.g., a multiplicative rule when the utility of one aspect of value depends on the level of another; Keeney & Raiffa, 1976).

(4) Evaluating alternatives. The attractiveness of each alternative is summarized by its expected utility, which is equal to the sum of the utilities of each possible outcome, weighted by their probabilities of occurrence. The alternative with the greatest expected utility is the

indicated choice.

(5) Sensitivity analysis and value of information. The analysis is reexamined from two perspectives.

(a) Can it be simplified by omitting components that do not affect the final decision? For example, an alternative that was inferior to another in all aspects could be dropped.

(b) Are there places where a reasonable change in the structure, a utility, or a probability could lead to the selection of a different alternative? Two tools are used for this reexamination. In sensitivity analysis, the calculations are repeated, each time dropping or adding one or more components or using a different assessment of one or more utility or probability. When a critical component is found, value-of-information analysis is used to assess the value of gathering further information that might change the recommended decision. For example, calculating the value of receiving perfect information sets an upper bound on how much one should pay for partial information.

Using Decision Analysis to Set Acceptable Risks

Since the key elements in a decision analysis (probabilities, utilities, problem structure) are subjective, they must come from someone. However, in societal decisions, there is rarely one entity (i.e., individual, organization) that is the final arbiter of these questions. When more than one set of utility or probability judgments must be considered, decision analysis may be used in one of several ways to guide acceptable-risk decisions.

For a start, the analyst can prepare several complete analyses, each reflecting the perspective of one party. Gardiner and Edwards (1975) found that when two opposing groups, realtors and conservationists, used only their own intuitions for ranking alternative solutions to a coastal zoning problem, they were in strong disagreement. However, when their rankings were generated by a simplified form of decision analysis, much of the disagreement disappeared.

Another approach is to try to generate agreement on the judgments needed to produce a consensual analysis. Such agreement could reflect compromises (I'll give up here if you give up there; put it to a vote; let's take an average) or genuine consensus. That consensus could be seen as representing the views of a hypothetical Supra-Decision Maker (Keeney & Raiffa, 1976).

Keeney and Raiffa (1976) recommend using a Supra-Decision Maker even when the various parties cannot agree. That entity could incorporate the probabilistic judgments of various experts into its own beliefs using theoretically justified techniques (e.g., Morris, 1974). Integrating different values would require the assumption, often made by public policy makers, that they can accurately reflect an entire society's values. A less presumptuous technique would be to elicit the values of various stakeholders (environmentalists, politicians, manufacturers, impactees, etc.) and then have the Supra-Decision Maker determine the relative importance of each (von Winterfeldt, 1978).

Although formal analysis can help generate agreement, it may also lead to polarization of views. The act of publicly specifying one's views may harden one's commitment to them and discourage compromise.

Leaders may assume extreme positions to ensure followers' allegiance. Finally, as constituent groups gain experience with formal analysis, they may exaggerate their positions in order to bias the analysis in their favor. Where the parties cannot agree on the relative attractiveness of the alternatives, other procedures are needed to augment decision analysis.

Generic Problems

Defining the Problem

Competent formal analyses begin with a careful problem definition. Uncertainties and values are then addressed within that framework. Having such an open and explicit problem statement can both reduce the possibility of omitting key issues and increase the opportunities for incorporating new concerns, options, and information as they arise. In a problem definition, cost-benefit analysis can accommodate any economic consequences; decision analysis can accommodate any consequences that the decision maker can judge. Although both can incorporate any options, they may treat the set of available options somewhat differently. Decision analysis considers the entire set simultaneously, whereas cost-benefit analysis often focuses on one proposal; other options only arise in the analysis of opportunity costs, other ways that money invested in the focal option could be spent.

A corollary of having no bounds on problem definition is providing no guidance. A model can include everything (if the resources are provided), but need not include anything. Because of resource constraints, a formal model cannot include everything. It must simplify and omit. It may start small, as a "back-of-an-envelope" sketch, and be elaborated with more details, components, and sub-models in successive iterations. Cost-benefit analysis offers no guideline as to when the model is complete. Decision analysts stop when they believe that further changes in the model would not alter the selection of the best alternative. To the extent that they are generalists, formal analysts are not able to provide an independent perspective for a client who is satisfied with an impoverished problem definition. By contrast, the professional making acceptable-risk decisions (Chapter 4) has substantive knowledge with which to challenge clients. To reduce this problem, the analyst must either specialize in a particular topic or possess the personal skills to induce clients and experts to think more broadly. Another antidote to narrowness is to involve parties capable of providing a variety of perspectives (although this step could complicate the problems of producing a single, convergent, consensual analysis).

Although critics have typically complained about overly narrow analyses, breadth may also hold dangers. An analysis may become so large as to be unwieldy and unworkable, its structure so complex as to obscure the interrelationships of its parts, the needed inputs too numerous to measure carefully. Indeed, some analysts might argue that the power of their tool comes from fast, limited analyses designed to afford some systematic understanding of a narrowly defined problem. In some situations, full-blown analyses may promise more definitiveness than they can hope to deliver. In others, time pressures may justify deliberate omissions. For example, a flurry of complaints about severe side effects from a recently licensed drug might lead a regulatory agency to do a quick analysis that ignores considerations that would be important in more leisurely circumstances (e.g., the effect of a recall on pharmaceutical innovation). Of course, persistent narrowing of focus, as might happen in an agency that always functions under crisis conditions, will leave larger issues perpetually unaddressed.

Knowing the Facts

One promise of formal analyses is to organize the facts of a matter effectively and explicitly. Analyses can, in principle, accommodate any fact or estimate compatible with their problem definition. The uncertainties surrounding these facts are commonly addressed in decision analysis, but less frequently in cost-benefit analysis. Uncertainties may be reflected in sensitivity analyses. Once the best-guess analysis has been completed using the most likely version of each component, it is repeated using alternative versions of what those components might be. Uncertainties may also be incorporated directly into an analysis in the form of pr bilities used to calculate the utilities of options.

Although both cost-benefit analysis and decision analysis use probabilities, they give them different interpretations. Decision analysts hold the subjectivist view, according to which probabilities represent an individual's degree of belief in the state of the world, not a property of the world (Kyburg & Smokler, 1964; Savage, 1954). Hence, they feel free to elicit probabilities of unique events (e.g., a major international conflict in the next six months, an untested new drug being teratogenetic) as well as probabilities for recurrent events for which frequency information is available (e.g., a valve failing in the course of 10,000 operations). Indeed, they wo d hold that extrapolating from frequency counts to predictions requires the exercise of judgment, hence is inherently subjective (e.g., to rely on past failure rates, one must believe that the valve will be subject to essentially identical conditions in the future).

Although there is no conceptual requirement that they do so, most cost-benefit analysts who address probabilities appear to hold a frequentistic view, seeing them as characteristics of events or processes. This view makes it difficult to combine frequentistic data with subjective judgments or to deal with uncertainties for which there are no relative frequencies.

Reliance on judgment allows decision analysts to expand the range of factual issues that can be given representation in their work. It also makes them particularly dependent upon the quality of those judgments. The vagaries of judgment discussed in Chapter 2 and particularly the difficulties in assessing uncertainty are cause for concern. Although some analysts have devoted considerable thought and care to the problems of probability elicitation (e.g., Staël von Holstein & Matheson, 1978), one may still wonder how much judgmental skill can be taught to the decision maker or expert in the midst of an analysis.

Assessing Values

A strength of formal analysis is that many value issues are given explicit quantitative expression, as befits their central role in societal decision making. Doing so helps bring disagreements into the open and establish which ones are most critical to the final decision. This attention has led to increasing awareness of a number of troublesome value issues.

Unstable values. One feature of people's preferences is that they may change over time. By inferring preferences from historic market data, cost-benefit analysis assumes unchanging values. Decision analysis can, in principle, ask people what they want today and what they expect to want in the future (in which the consequences of today's decision will be experienced). Moreover, values may not be well articulated at any point in time. Neither cost-benefit nor decision analysis is very well suited to situations in which people do not really know what they want. Indeed, decision analysts often ask unfamiliar questions like: "How many days of uncomfortable hospitalization would you endure to lower your probability of dying this year by 10%?" Even with far more familiar topics, subtle changes in elicitation techniques may produce quite different answers (see Chapter 2). Reliance on economic data confers no immunity here to cost-benefit analysis; the essence of marketing is to manipulate people's uncertain values, altering their preferences and creating desires that they never had.

Non-monetary consequences. Since it evaluates consequences relative to one another, not by translation to dollar terms, decision analysis is relatively free to address non-economic consequences (e.g., local pride, beauty, species preservation). On the other hand, cost-benefit analysis can treat only economic consequences and typically does treat only those that are readily quantified in dollar terms. For example, Walker and Bayley (1977-8) tentatively proposed evaluating the yearly "environmental" costs of building a highway across a marsh as: (a) educational value: $5 for each of 50,000 student visitors and (b) recreational value: $24 for each of 500 fishing trips, $24 for each of 100 boating trips, and $55 for each of 50 bird-watching trips. Such a procedure ignores any intrinsic value that preserving the marsh and its wildlife might have or any value that people attribute to the marsh that is not captured in what they spend to visit it. One implication would be that those who live close by value it less than those who travel from afar to visit it.

Value of a life. In placing a value on the loss of human life, as elsewhere, cost-benefit analysis must find a monetary equivalent. Unfortunately, "there is no universal agreement on how to value lives; indeed, more suprisingly, no one has even claimed to have found an unequivocal procedure for life evaluation" (Zeckhauser, 1976, p. 419; see also Jones-Lee, 1976; Linnerooth, 1976; Schelling, 1968).

According to one traditional economic approach, the value of a person's lost life equals the amount of money one would need to invest today to earn the income that he or she would have earned. By this view, those in society who are underpaid are also undervalued. Those who have no income (e.g., homemakers) have no value and those who "take from society" (e.g., retirees) have a negative value. This approach also ignores the effect on society's fabric of accepting various potentially lethal gambles and the non-economic effects of a death on loved ones or dependents (Schelling, 1968). A second economic approach, equating the value of life with court awards, may recognize pain and suffering, but is hardly more satisfactory on other counts (Holmes, 1970). A third economic approach looks at the financial compensation needed to induce workers to accept increased occupational risks. As discussed in Chapter 5, this revealed-preferences approach founders on technical difficulties and overly strong behavioral assumptions regarding how much workers know about the risks to which they are exposed and how free they are to bargain effectively with their employers.

Frustration with the limits of these market-based approaches has led some cost-benefit analysts to advocate a method in the decision-analysis tradition: asking people directly what they would be willing to pay for some marginal change in their probability of survival (Acton, 1973; Linnerooth, 1975). In these efforts, an important theoretical distinction is the difference between how much people will pay to avoid a risk and how much they demand as compensation when a risk is imposed upon them. The latter value is appropriate for hazard problems that involve involuntary risks. Since it is also likely to be larger, confusing the two would underestimate the value of a life.

Within the context of decision analysis, R. Howard (1978) has argued that the appropriate concern is one's value to oneself, not one's value to others or to the economy. He further notes that it is not irrational to place an infinite value on one's life when the chances of dying are large (e.g., refusing a gamble involving a .8 chance of death for any amount of money), but to accept a finite amount of money in return for a small increase in the risk of death. He proposed asking questions like "How much money would I have to pay you to take a black pill that has a .001 probability of causing instant painless death?" (see also Greene, 1980). Postulating reasonable answers to this question, Howard calculated a "small-risk value of life" in the range of $1 million to $4 million. Similar techniques might be developed for evaluating loss of limb or health assuming that people can imagine such states (Calabresi, 1970). Unfortunately, however, novel questions on a difficult topic may produce poorly informed and labile responses.

Despite their flaws, these various methods for determining the value of a life have produced estimates varying by only a factor of 20 (between \$200,000 and about \$4,000,000). These extreme values could be used in a sensitivity analysis and might lead to the same decision, although, of course, they might share a common bias.

Future costs and benefits. In cost-benefit analysis, future consequences are evaluated by first computing their future economic value (in today's dollars) and then applying a discount rate to find a (lower) value that represents their present discounted value. The rationale for assuming that a future outcome is worth less than an equivalent one today is that instead of setting aside today the total future value, K, we could invest a lesser amount, K_0, which would grow to K by the time it is needed. The rate of return on investment that takes K_0 to K in N years is called the "discount rate." K_0 is the present discounted value of K; it represents an opportunity cost, the amount one could spend on something else now if one did not have to have K on hand N years hence.

Technically, discounting is hampered by the great sensitivity of decisions to the particular rate used and the absence of a consensus on the right rate. For example, Schulze (1974) argues that if we want to minimize future generations' regret about our present decisions, we should use a rate of zero. Failing to find a generally accepted rate, a National Academy of Sciences panel (1975) suggested a sensitivity analysis using a variety of rates (hoping that they would lead to similar recommendations).

Conceptually, discounting is limited whenever costs and benefits cannot be converted into interest-yielding investments. According to Lovins (1977),

> Until recently risk discounting made it attractive to jerry-build British bridges and buildings that could fall on someone's head in twenty years, as a twenty-year risk discounted at the 10 percent annual rate recommended by Her Majesty's Treasury was valued at 15 percent of an equivalent present risk. British authorities slowly realized, however, that safety and lives cannot be banked at interest as money can and that discounting risks is neither morally nor theoretically sound (p.918).

The fact that British civil engineers are typically accused of being overly cautious (Cohen, 1980) suggests that professional judgment has supplemented this economic reasoning.

The accelerating speed at which even small discount rates compound can produce absurd results for long time periods. Mishan and Page (1979) showed that conventional discounting methods would assess the cost in 100 years of banning a hypothetical chemical today as almost 10 times the GNP calculated for that future date.

Decision analysis copes with future consequences by eliciting decision makers' preferences for different streams of costs and benefits over time, which could reflect discount rates or anything else that seems relevant. Owen (1978) has developed an elegant decision-analytic model for treating trans-generational equity issues, using as inputs the answers to such questions as "How much would you pay now to raise the standard of living in the year 2080 by 5%?"

Equity. The potential Pareto improvement (Kaldor-Hicks) criterion which guides cost-benefit analysis explicitly disregards equity considerations. Although some analysts have proposed weighting schemes for avoiding unfair distributional effects, other analysts claim that equity issues have no place in an analysis, arguing that (a) the distributional inequities for different technologies tend to balance one another (I have a garbage dump in my back yard; you have an electrical plant in yours), (b) equity issues should be resolved independently of hazard management (e.g., through tax credits or progressive income taxes), or (c) cost-benefit analysis cannot do the job adequately. A compromise solution is to calculate the distributional effects of the different options and report them alongside the analysis.

Equity issues have received little attention in decision analysis. Although it would seem simple enough to include an equity dimension in the value model, Keeney (1980) raises a perplexing issue. He shows that it is inconsistent for an individual who follows the axioms of decision theory both (a) to prefer more equitable distributions of risks over society's members and (b) to be risk averse regarding losses of life. Tversky and Kahneman's (in press) finding that people may be risk prone for losses (including losses of life) suggests that, when pressed for consistency in Keeney's dilemma, people may give up risk aversion first (if they do not choose to give up the axioms).

Attitudes toward risk. Decision analysts routinely ask decision makers whether they are risk prone or risk averse regarding the problem at hand. On the other hand, risk attitudes have little place in the theory or practice of cost-benefit analysis. An ad hoc way to incorporate people's presumed risk aversion when human lives are at stake is to raise the number of lives lost in a single accident to some power (e.g., N^2) to reflect the gravity of catastrophic accidents (Wilson, 1975). An alternative response is to argue that no explicit consideration of risk attitudes is needed since they are automatically incorporated into the market data used in cost-benefit analyses. If people are risk averse, they will pay more for safer goods, making those prices rise. The validity of that argument depends, of course, on the extent to which a free market operates with regard to risk issues.

One might argue that those who make acceptable-risk decisions on behalf of others have a moral duty to be risk neutral even when the people affected by their decisions are risk averse or risk prone. One reason is that the expected number of lives that will be lost by taking a risky decision is greater for risk-averse or risk-prone decisions than for risk-neutral ones. A second reason is that one's right to be risk prone or risk averse regarding one's own life confers no right to make such value judgments when deciding others' fate.

Coping with the Human Element

All forms of formal analysis are built on strong behavioral assumptions whose common element is viewing decision makers as highly rational, sensitive to the limits of their own knowledge, and ready to ask for help when it is needed. Cost-benefit analysts rely on rationality when they use market data to reveal people's preferences; decision analysts do so when they trust decision makers' judgments.

As mentioned in several previous contexts, the interpretation of market data is rendered ambiguous to the extent that freedom of choice is restricted (e.g., by restraint of trade, regulation) and wisdom of choice is limited (e.g., by cognitive overload, overconfidence). Interpretative problems also arise when social values are in flux. According to Mishan and Page (1979):

> . . . inasmuch as the untoward consequences of consumer innovations tend to unfold slowly over time, their valuations at any point of time . . . as determined by market prices . . . may bear no relation whatever to the net utilities conferred over time. Indeed, the very pace of change today . . . is such that it is no longer possible for the buying public to learn from its own experience to assess the relative merits of a large proportion of the goods coming onto the market. In consequence, society can have no confidence that the valuations of such goods have any ex post correspondence with people's subjective wants . . . .
>
> Within a modern growth economy . . . in which there is ample evidence for the allegation that the "Jones' effect" is growing, or that personal attire is increasingly exhibitionist, or that norms of taste are declining, or that much of the economy's outputs for mass consumption is increasingly trivial if not regrettable, the task of the allocation economist is not an enviable one. In such circumstances, it can reasonably be contended that the ethical consensus to which the normative economist has to defer is itself breaking up. Wherever the

consumption of some goods, or the indulgence of some commercially provided activities, are believed by some proportion of the population to be unworthy or degrading and, at the same time, are believed by others to be innocuous if not liberating, the task of the welfare economist becomes impossible (pp. 21-24).

Decision analysis avoids at least some of these problems by being inherently au courant; it asks decision makers what they believe and want at the moment of decision. There is, however, no guarantee that the respondents will have understood, for example, how their values are changing or how they have been manipulated by advertisers. Few decision makers may be ready to establish by fiat a new "ethical consensus;" those who do may not be trusted or empowered to do so. Observers also worry about the possibility that people's expressed opinions will be inconsistent with their behavior. Research (e.g., Fishbein & Ajzen, 1975; Schuman & Johnson, 1976) suggests that attitudes often predict behavior quite well if several conditions are met: (a) attitude questions are formulated so as to make their logical links to behavior clear; (b) the respondent has an articulated position on the question; (c) the respondent is not strongly motivated to lie. Even when decision analyses violate these conditions, they still offer a clear record of what was done, allowing reviewers to assess the credibility of the judgments used.

Assessing Decision Quality

Realizing the fallibility of the inputs they use, good analysts perform sensitivity analyses as a matter of course. The final calculations are repeated using alternative values for questionable inputs. The robustness of the conclusion is determined by the extent to which these reanalyses produce similar results.

The discussion in Chapter 2 of the potential and limitations of sensitivity analysis was drawn from the work of the analysts. Among the issues cited there as key determinants of the value of sensitivity analysis were: (a) the extent to which the exercise of fallible judgment is needed for identifying troublesome inputs and choosing the range of possible values, (b) the threat of intellectual common-mode failure, by which an analytical procedure repeatedly introduces the same bias (e.g., an elicitation method persistently evokes only one perspective, or a costing technique consistently shortchanges health or productivity concerns), and (c) the difficulty of compounding uncertainty over all aspects of an analysis.

Empirical research into the judgments required to evaluate analyses is one source of guidance. For example, apparent tendencies to overestimate one's knowledge and neglect omissions in problem representations suggest a bias toward putting too much faith in formal analyses. Additional sources would be empirical studies of the success of analyses conducted in the past and a general error theory for formal analyses (Fischhoff, 1980a). That theory would provide general guidelines as to what errors may enter into analysis, how virulent they are, how they are propagated through the analysis, what can be done to mitigate their impact, and what such errors mean in terms of action.

How Adequate Are Analytic Techniques for Resolving Acceptable-Risk Problems?

Comprehensive

A strength of decision analysis is its potential for affording some representation of whatever fact or value issues interest the decision maker. Cost-benefit analysis stumbles, in this regard, when there is a need to accommodate uncertainties or consequences without immediate, tangible economic consequences. On the other hand, grounding in economics may enable the cost-benefit analyst to provide some substantive guidance as to what issues should be included in an analysis. Purveyors of both methods hope that the conceptual framework and vocabulary they offer will help to identify issues that are omitted and to sharpen the debate around those that are included.

Logically Sound

At the core of both cost-benefit analysis and decision analysis lies a coherent theory describing how to integrate fact and value issues so as to produce recommendations that are in the decision maker's (or society's) best interest. The strength of these prescriptive rules for decision making is bounded, in part, by the descriptive validity of their underlying behavioral assumptions. To the extent that market data do not reveal preferences or people reject the axioms of decision theory, the techniques provide less viable guidance. The soundness of the methods for treating some difficult issues (e.g., equity) is still open to question and research.

Practical

Although these methods are willing to attack complex problems in great detail, they are not always able to do so. Cost-benefit analysis has no procedures for solving some measurement problems (e.g., value of a life); such issues are either ignored or treated with ad hoc procedures that may please few knowledgeable consumers. Although decision analysis faces fewer conceptual problems in developing such techniques, workable, validated procedures are not available for all topics (e.g., assessing future values).

Full-blown methods are expensive and time consuming; even fast, limited analyses may require an abundant supply of highly-trained experts. As a result, the methods are not always thoroughly and competently applied. The possibility of an approach not being implemented as its designers intended raises a thorny problem for the evaluator. Obviously, formal analysis should not be held accountable for crude and ineffectual analyses done by poorly trained individuals or under severe resource constraints. Or should it? If only a select few can master a craft and the masters do not monitor those acting in its name, then its usefulness is limited. Since the resources needed for a thorough and competent analysis will not always be available, the practicality issue may hang on how gracefully analyses degrade. Research is needed to tell when a partial analysis is better than a full-blown one or none at all.

Open to Evaluation

A strong selling point for formal analysis is not only that it is open to evaluation, but also that it provides evaluative techniques such as sensitivity analysis. The analyst is, in principle, saying to critics, "Here are the inputs and models that I used. If you don't like them, let's try it your way." This potential can, however, be realized only if adequate funds and expert assistance are made available for these reanalyses. Without them, the mass, complexity, and technicality of some analyses may keep observers from seeing whether their point of view was adequately represented. Here, as with other techniques, scrutability is particularly limited when value-laden assumptions are embedded in the problem statement. The judgmental component of any application may allow the unscrupulous analyst to alter many inputs in minor ways, changing the result without making any single input clearly objectionable. Fear of such "number games" may lead to unjustified suspicion of sincere analyses.

A potent aid to evaluating both the contribution of analysis in general and the quality of any particular application is keeping detailed records of its assumptions and operations. Then both contemporary and future critics can judge more fairly the adequacy of the analysis.

Scrutability is, of course, not just a sop to critics, but fundamental to the production of competent analyses. Since in many complex problems one cannot "get it right the first time," analysis must be an iterative process. Criticisms should not just be filed, noted, or appended to a report, but incorporated in the revisions that they stimulate. Too often, analysts and their clients may adopt a siege mentality, defending their figures against all comers, rather than assuming that vigorous critiques may mean that the analysis has succeeded in illuminating the problem.

Politically Acceptable

A number of themes emerge from criticisms to which formal analyses have been subjected in the political arena. Some critics are concerned about the extent to which analysis transfers societal decision-making power to a technical elite, comprised of those who perform analyses and interact with the analysts. A member of that elite might respond that the technical nature of the issues and the vagaries of lay judgment render this transfer of power in the public's own best interest. "If you let someone competent do the job, we'll all be better off." The counter-argument has several facets: (a) On questions of value, superior technical knowledge does not imply superiority of experts' value systems. (b) On questions of fact, the recurrent need to go beyond available data and rely on intuition erodes the experts' advantage. Indeed, lay people may be privy to perspectives that the experts lack. (c) Even if expert judgment provides the best assurance of maximizing the efficiency of a particular project, there are higher goals that need to be considered. These include developing an informed citizenry, preserving democratic institutions, and making people feel in control of their fate.

Other critics argue that the very reasonableness of formal analysis reflects a debatable political-ideological assumption, namely, that society is sufficiently cohesive and common-goaled that its problems can be resolved by reason and without struggle. Although such a "get on with business" orientation will be pleasing to many, it will not satisfy all. Those who doubt that society is in a fine-tuning stage may oppose analysis itself, regardless of its content. Even those who accept the potential legitimacy of analysis may also view it as just one more arena in which political struggles are waged. Such struggles have their own logic and a rhetoric different from that of formal analysis. If the results do not support one's position, unconstructive criticism may seem eminently fair and rational, as may ridiculing analysts who have ignored vital issues (like income distribution) that were outside their analytic mandate.

Compatible with Institutions

Formal analysis not only could be incorporated into present-day regulatory and administrative institutions, but already is being used in many quarters. Its future role will depend in part upon how these institutions contend with the resource requirements for the extensive analyses that many problems require. Possible responses are: (a) always do incomplete analyses, with no hopes or pretense of producing definitive and defensible conclusions; (b) invest all resources in a detailed, initial problem structuring, hoping to derive the maximum educational value, or (c) postpone small analyses until a few landmark cases have been completed in order to establish standards for practice and to develop generally applicable techniques and procedures.

Commissioning analyses is not the same as using them. Both bureaucrats and politicians may be reluctant to endorse publicly the painful, callous-sounding balancing of risks and benefits expressed in these techniques. In a sense, analysis itself was under attack in the recent trial in which Ford Motor Company was charged with reckless homicide based on its alleged decision to manufacture Pintos with a fuel tank design known to increase risks in the event of rear-end collisions.

People seemed shocked that Ford had used analysis to make explicit tradeoffs between costs and lives.

The openness that serves formal analysis so well in other respects may also render it vulnerable to interminable legal challenges, thereby delaying the projects it considers. Recent efforts at regulatory reform (e.g., SB262) seek to shift the burden of proof from risky projects to their regulators, by requiring cost-benefit analyses of all proposed regulations. Given the limitations of cost-benefit analysis and the lack of agreement, even among its advocates, on methodological issues, any analysis could be challenged, thereby postponing new regulations indefinitely.

Conducive to Learning

The long-term impact of formal analysis will depend largely upon its success in meeting the preceding criteria. If ways are found to involve the public meaningfully, analysis can improve citizens' ability to cope with future crises. If evaluation is taken seriously, we will have an open and accessible record facilitating consistent decisions and the cumulation of knowledge. If analyses are well managed, competently performed, and responsibly interpreted, formal analysis may become a fixture, not rejected as another (intellectual) technology that promised too much or fell into the wrong hands.

Summary

The great strengths of formal analysis are its openness and soundness. Both cost-benefit and decision analysis have carefully thought-out logical foundations and, in principle, the ability to encompass a broad range of issues. In some sense, this thoroughness is also their downfall, for it makes their failings, as well as their assets, more visible and better documented than those of competing approaches. By detailing every step of their work, from problem definition through value and fact assessment to bottom-line calculations, good analysts maximize the possibilities for both peer review and political attack.

Formal analysis appeals to regulators in part because it appears to some as a value-free guide to decision making. However, values are an inherent part of acceptable-risk problems. Relative to other approaches, formal analysis treats values quite explicitly. Yet, like other approaches, formal analysis mixes fact and value issues in complex and subtle ways. For example, cost-benefit analysis takes a political stand by restricting itself to economic valuations. Although decision analysis can accommodate diverse values, personal predisposition or institutional constraints may make analysts content to work within timid and narrow problem definitions. The explicitness of formal analysis represents one necessary condition for clarifying the extent to which problem definitions prejudge values issues; additional substantive knowledge is needed to identify options, consequences, and events that have been ignored.

As with other techniques, formal analysis' promise of openness may not be realized in practice. External reviews are not always elicited; when they are, reviewers may not have the financial or technical resources needed to probe deeply; when they do, the original analysts (and their clients) may not be ready to accommodate criticism. Analysts may be tempted to exaggerate the completeness or robustness of analyses, while critics may be satisfied with nit-picking, unmindful -' whether the flaws they find seriously threaten the conclusions of the anaiys. .

Finally, despite their logical soundness, formal methods were not developed for the problems of acceptable risk. Cost-benefit analysis is most appropriate for private decisions in areas with responsive markets, immediate consequences, and well-informed consumers. Decision analysis presumes the existence of an entity (a single decision maker or group) chartered to speak on behalf of society. Typically, however, it is unclear who is empowered to decide that the necessarily incomplete, inaccurate representation of reality found in even the best analysis has successfully identified the most acceptable option.

CHAPTER 7

Comparison of Approaches

Most of this report has focused on the extent to which each approach, in and of itself, provides a complete answer to acceptable-risk questions. Given the stringency (and occasional incompatibility) of the seven evaluative criteria, it should be no surprise that no approach has proven entirely adequate when compared with these absolute standards. Since acceptable-risk decisions must still be made, the decision maker's task becomes choosing the most adequate approach (or combination of approaches). This chapter compares the approaches to each other, as an aid to the metadecision problem of deciding how to decide.

In Table 7.1, each approach is rated on each of the seven evaluative criteria, using a 0 to 10 scale anchored by "completely inadequate" and "completely satisfactory." Comparing a rating with the maximum score of 10 conveys an approach's absolute strength; comparing ratings within rows reveals the approaches' relative strengths. These ratings reflect the authors' best judgment at how the appraisals of Chapters 4-6 should be summarized vis-a-vis each approach's ability to cope with the full range of societal hazards. These numbers represent asymptotes, describing the strength of an approach if competently and faithfully applied; inferior performance is always possible. Subsequent tables (7.2-7.4) make similar evaluations in the context of particular decision problems designed to highlight the strengths or weaknesses of one approach or another.

An explicit evaluative scale was used in an effort to be as specific as possible about our opinions. The numbers themselves should not be taken too seriously. Considerable uncertainty surrounds each; the limits of our understanding are compounded with the limits of our ability to express that understanding in even single-digit precision. The absence of extreme ratings reflects these uncertainties.

Table 7.1

Ability to Cope with the Full Range of Societal Hazards

Ratings of Approaches on 7 Criteria

	Approach		
	Professional	Bootstrapping	Formal
Comprehensive	5	3	8
Logically Sound	6	3	7
Practical	8	4	5
Open to Evaluation	4	6	8
Politically Acceptable	5	4	5
Compatible with Institutions	9	4	5
Conducive to Learning	4	4	6

Note: Ratings were made on a scale ranging from 0 (completely inadequate) to 10 (completely satisfactory), under the assumption that the approach is applied as well as possible, exploiting all its strengths. A range of possible values should be understood to surround each number, both because of the limits of our understanding and because each summarizes the ability of the several approaches in each category to cope with a broadly defined universe of hazards. Necessary interpretative material is found in the accompanying text.

Global Ratings

The numbers in Table 7.1 are summary measures in several senses. They pool the opinions of the authors, ignore differences between the several approaches grouped under each heading, and make no reference to the various facets of each criterion. However, even this level of aggregation sheds some light on what each approach was designed to do and how well it might accomplish its goals.

Comprehensive

Formal analyses, particularly decision analyses, are non-substantive theories of decision making. By making few assumptions about how problems are to be defined, they promise to accommodate any conception offered by the commissioning client (with the possible exception of non-economic consequences and equity issues in the case of cost-benefit analysis). The analysts' breadth and depth of vision are limited primarily by their clients' acuity and communicative ability. If communication fails, then clients' desires and substantive experts' knowledge may not be expressed fully in the analysis.

The professional approach makes the most of experts' knowledge by placing experts at the center of the decision-making process. Those who employ professionals can, of course, mandate whatever problem definitions they deem appropriate. In practice, however, professionals define and solve problems in habitual ways that may restrict the range of the problems and lead professionals to overemphasize factors within their areas of competence. For example, a civil engineer might neglect the possibility that a highway-safety measure will encourage drivers to increase their speed, thus negating its impact, or the possibility of making roads appear more dangerous than they are in order to outsmart the drivers.

The comprehensiveness of bootstrapping approaches is even further restricted. Each of these approaches characterizes technologies according to one particular set of risk (and perhaps benefit) measures. Each derives its standards from one particular past. A broad set of alternative options, consequences, and so on, may have influenced the evolution of those historic standards, but all that remains is what we interpret as a final equilibrium state. A few indicator statistics of that state are then compared with the same few indicators extracted from the present.

Logically Sound

An approach should produce a timely and defensible recommendation from whatever broad or narrow segment of a decision problem it addresses. Professional and formal analyses meet one of these conditions by almost always providing a concrete answer that suggests what to do. However slim its margin, one alternative action emerges as best. The emergence process may be somewhat different in the two cases, with tendencies for the professional to fine-tune an apparently superior option until no further effort seems justified and for the formal analyst to look simultaneously at a fixed set of options. Bootstrapping methods fail in this respect by offering acceptability ratings, not preference orderings. If more than one action option passed their threshold of acceptability, some other procedure would be needed to select the best one; the same would happen if no option (even "do nothing") were judged acceptable. In this light, bootstrapping is a screening procedure rather than a decision-making tool.

In generating its conclusions, each approach embodies an alternative concept of how rational decisions should be made. The arguments by which they justify their recommendations might be characterized as lying along an empirical-theoretical dimension. At the empirical extreme, professional judgment is advocated because it has worked in the past, where "worked" means some combination of: made people happy, identified superior solutions, reflected societal values, and exploited scientific knowledge. The validity of this claim would seem to be context- and observer-dependent. The "6" in the table suggests that practitioners often do a fairly good job of integrating most relevant concerns in creating their solutions.

At the theoretical extreme lies decision analysis, which identifies the elements of a decision problem with the elements of decision theory as derived from an axiomatic base. The recommendations are then generated according to the rules of formal logic. As a result, the soundness of the recommendations (vis-a-vis the abstracted problem) could only be flawed if one rejected the axioms. Although the axioms are generally uncontroversial (e.g., one's preferences should be transitive), some of their unstated assumptions may be more open to question. One is that a decision-making entity, willing and able to provide information about beliefs and values, can be identified; another is the insistence that beliefs and values are inherently subjective.

The rationales of the remaining approaches reflect a mixture of empirical and theoretical arguments. Empirically, they rely on claims that some aspect of the world has functioned superbly, achieving ideal risk-benefit tradeoffs (revealed preferences), appropriate market prices (cost-benefit analysis), or best-adapted species (natural standards). Their argument for preserving these historic relationships in the future is, in part, empirical (we could do no better if we tried; let us short-circuit the historical process and go immediately to the best answer without recourse to trial and error) and, in part, political (whatever was, is right; we live in a balanced world and should maintain that balance). The low rating given to bootstrapping (and the lower rating that would be given to cost-benefit analysis within the formal analysis category) reflect the lack of empirical support and political consensus for the validity of their claims. Within the bootstrapping category, risk compendia would receive particularly low marks as a decision-making method because their interpretation is not altogether clear. Apparently, they represent a form of revealed-preference analysis whose usage requires additional ad hoc assumptions.

Practical

One road to practicality is to reduce the scope of the problems that are attacked. Professional judgment strives to be practical by focusing on the technical issues with which professionals are most comfortable. The decision-making process centers on selecting and refining concrete options. Since these options undergo some prior screening for feasibility, whatever is expressed on paper is likely to be realizable in reality. Another practical aspect of professional judgment is that the amount of available decision-making personnel is likely to be roughly commensurate with the size of the problems; since professionals are needed before a hazard can be created, they are likely to be on hand for its management. This practical potential is belied to the extent that professionals promise to incorporate society's values without specifying how that is to be done. Even when professionals have a method for getting at society's values, they may be prevented from doing so by clients who want them to concentrate on design issues or by critics who feel that value issues are none of the professionals' business.

Reduced scope enhances the practicality of bootstrapping methods as well. The revealed-preferences analyst who has measured historic risk-benefit tradeoffs needs only two summary statistics, risk and benefit, to decide the fate of any proposed technology. The risk-compendia "method" requires only the risk statistic to characterize a technology. Application becomes easier still to the extent that any convenient measure of risk (e.g., per year, per hour of exposure) and any convenient set of statistics on comparison technologies will suffice. The popularity of bootstrapping methods in some circles may indeed reflect a willingness to sacrifice other goals in order to get on with business. Failure to specify exactly which numbers are needed can, however, hinder application when disputes arise about how to define such terms as risk, benefit, relevant past, or comparison technologies. Once agreement is attained on these questions, considerable ingenuity and faith may be needed to produce the requisite data from a past that was unaware of our need for documentation.

Cost-benefit analysts face similar problems in their quest for market indicators of value. One difference is that attempts to get by with ad hoc numbers may be thwarted by the legions of economists capable of mounting critiques based upon economic theory. The presence of competing analyses of how various quantities should be measured makes it difficult for the practicing analysts to give critics a definitive answer and proceed with implementation. When they do agree about measurement, these economists may show great resourcefulness in getting the most out of whatever data do exist. The new techniques that they generate enhance the practicality of future analyses.

By utilizing subjective judgments, decision analysis is able to translate any concept in the problem definition into operational terms. It can use economic and statistical estimates when they are available (and appropriate) and fall back on judgment when they are not. This judgmental strategy fails when respondents cannot produce the required assessments, as might happen when they do not have a coherent, articulated view on a topic. Such failure can be identified within the context of decision analysis through the judicious use of consistency checks. It can be suggested from the outside by behavioral research identifying kinds of judgments that are not to be trusted (e.g., introspections about why one has made particular decisions; Ericsson & Simon, 1980; Nisbett & Ross, 1980). Continuing research into how to model particular issues signifies both that decision analysis cannot as yet cope with every issue and that its practitioners are concerned about these deficiencies.

Open to Evaluation

Professionals exercise their judgment outside the public's view, in offices, laboratories, and construction sites. To the extent that they make their decisions intuitively, the components of those decisions may be outside their own view as well. Making a virtue of a necessity, some would argue that the fallibility of professionals' introspection is a sign of their prowess, for they have mastered inarticulable intellectual habits that can only be acquired through an apprenticeship that begins once one has acquired the knowledge that can be written in the books.

Promulgation of written standards is one way that professionals cope with pressure for accountability. These standards are themselves typically generated by the exercise of unanalyzable judgment, in which it is hard to know just how risks and benefits have been balanced, or even what options and consequences have been considered. Standards, do, however, facilitate the monitoring of practice, particularly when it is formalized through licensure. As critics are quick to note, licensure is not synonymous with impartial evaluation. Like guilds, professions face a traditional conflict between maintaining enough quality assurance to keep the public's confidence but not so much as to make life too difficult for members or to cast doubt on the profession's claim to efficacy.

By contrast, formal and bootstrapping analyses were designed for ready evaluation. Their numbers and calculations are all laid on the table, open to view and review. For this potential to be realized, analyses must be explicated clearly enough for outsiders to follow their details. Moreover, these outsiders need the technical and financial capabilities to generate independent positions. Decision rules may be as well hidden in the bowels of computers as in the minds of professionals. In this respect, the judgmental component of decision analysis may become as much of a liability as it was an asset in practicality. Help may be particularly needed when observers attempt to identify the underlying assumptions about problem definitions, facts, values, human behavior, and decision quality. Although it is not uncommon to find some discussion of technical uncertainties, it is most uncommon to find discussion of the theoretical uncertainties that render the approaches themselves somewhat inconclusive.

Openness in this regard may be achieved only be beginning each application with a briefing on the debate about social discount rates, the problems of aggregating over individuals in decision analysis, the unclear relationship between the economists' notion of "revealed preferences" and that represented in the acceptable-risk procedure of the same name, or the ambiguities of operationalizing concepts like "risk" and "exposure."

Politically Acceptable

Even the most open of approaches may not invite criticism. The job of the experts who implement each approach is hard enough without looking for trouble. Outsiders are unlikely to volunteer for critic duty unless it seems worth their while, that is, unless they are out to discredit an approach that has produced a displeasing conclusion. Hence, the entry of approaches into the political arena often begins in an atmosphere of distrust. The experts had been left alone until they were "caught;" now a shadow falls on the approach itself as well as on the offending decision.

One way to avoid these problems is to make decisions that make everyone relatively happy. Professionals seem to have achieved this goal in many of their routinized decisions (e.g., prescribing medical treatment, ascertaining that a girder is strong enough). By trial and error, they have found what breeds satisfaction as well as what works technically. In doing so, they are aided by the credit afforded to prestigious professions and the absence of organized critics capable of questioning technical decisions. Some recent attacks on the medical profession (e.g., for its practices regarding DES, breast cancer, laetril, and fluoridation) suggest that once professionals are mistrusted, political opposition may arise quickly.

When it is impossible to make everybody happy, one way to maintain a low profile is to avoid making recommendations that persistently upset one group. Cost-benefit analysis is likely to fail in this regard, since it gives little attention to consequences without readily calculable economic value; witness the increasing suspicion of workers who feel that their health is given short shrift in analysis after analysis (Ruttenberg, 1980), not because the analysts do not care, but because health is hard to measure in dollars.

A more assertive strategy for political popularity is to involve potential critics in the decision-making process, either incorporating their concerns or co-opting their opposition. Decision analysis is particularly amenable to public participation; anyone's perspective could be represented in it. A handicap for decision analysis (or any other novel technique) is the need to convince participants that they are not being bamboozled in a sophisticated numbers game. Reassuring the skeptical may require extensive briefings, sensitivity analyses, and even the conduct of parallel analyses.

Professionals can listen to a broad range of people before rendering their judgments, but it may be hard to demonstrate that their decisions have reflected particular views. Cost-benefit and bootstrapping analyses are expert rather than participatory tools and can do even less to accommodate outside input, except by allowing various parties to participate in shaping the definitions of the problems they solve (e.g., choosing possible options).

No amount of public participation or public relations can, however, eliminate opposition generated by the inherent political biases of the different approaches. To the extent that they afford such a central role to experts, each approach raises fears of creating a technocratic elite. Those fears may only be alleviated by embedding the techniques in a political process that makes laypeople as well as experts essential to application of a technique. Creating a satisfactory political process may be impossible with bootstrapping approaches, which hold the present and its actors irrelevant except for defining the options to be evaluated. Nor is any process likely to satisfy those who dispute the assumption of most cost-benefit and bootstrapping analyses that current economic and social relations should be preserved in the future.

Compatible with Institutions

Professionals and their clients determine the initial safety levels of the technologies they create. Unless problems arise, decision making is likely to remain within the creative organization and to rely on professional judgment. Even when a technology is forced to conform with general standards, professionals are still the decision-making institution. When decision making is displaced to governmental bodies, professionals' knowledge and willingness to provide summary judgments ensures them an active role. Only when the adversarial context of the courts becomes the decision-making body might professionals' influence be frustrated. Indeed, one might fault professionals for undue deference to the institutional constraints thrust upon them. Their role as servants, the unclear authorization of their decision-making function, and the penalties for deviating from traditional practices combine to discourage professionals from being too assertive.

Despite being a more recent development, formal analysis has earned a niche in many relevant institutions. Regulators, industry, professional organizations, labor unions, and consumer groups have all learned to commission at least the occasional analysis to guide their thinking or justify their conclusions. None, however, would bind itself to abide by the conclusions of these analyses, knowing that ambiguities and omissions leave even the best analyses somewhat indeterminate. The broader acceptance of cost-benefit analysis may reflect its seniority to decision analysis and its promise of objectively measuring values. Bureaucrats who hope to avoid both litigation and accountability may be wary of acknowledging the subjectivity that decision analysis holds to be inherent in all decisions.

The status of bootstrapping is akin to that of formal analysis. Bootstrapping's strengths are ease of application and provision of a number that decision makers can grasp; its backward-looking perspective allows users to point to historical or legal precedents as justifications. On the negative side, bootstrapping procedures are new, untested, and not mentioned in enabling legislation. Currently pending legislation, introduced by Representative Ritter, calls for the use of "comparative analysis," which appears to be a mix of bootstrapping and formal analysis. It is unclear how much enthusiasm this proposal will generate among the institutions empowered with its implementation. Uncertainty about how to justify comparative analyses, how to monitor their use, and how to avoid deleterious side effects may make bureaucrats reluctant to try them out.

Conducive to Learning

An approach should help us get smarter in the long run in addition to helping us to get by with reasonable decisions in the short run. One key to enhancing society's sophistication is educating the participants in each decision about the issue in question and decision making in general. A second key is creating a clear cumulative record upon which future decision makers may draw. A sign of wisdom is making decisions that are increasingly consistent and predictable.

The different approaches reflect rather different time horizons. Bootstrapping promises to short circuit the cumbersome processes of history and immediately institute safety standards that represent perfected versions of previously negotiated compromises. If society's standards are changing, that would be reflected only as gradual shifts in the historical relationships, assuming that they are periodically updated. To those who doubt that society has nothing more to learn about how to make acceptable-risk decisions, this quest for consistency could represent striving for more of a bad thing. By working for consistency with values expressed in more localized marketplace decisions of the immediate past, cost-benefit analysis promises to be somewhat more responsive than bootstrapping to changing values. In general, highly consistent historically-oriented approaches attempt to produce predictable decisions at the expense of any educative function. Confidence in the wisdom of the past may even negate the importance of working to create a more enlightened society.

H. G. Wells once predicted that the day would come when statistical thinking would be as necessary a skill as reading or writing. Acquiring that skill requires, among other things, acknowledging the subtleties of acceptable-risk decisions and abandoning the hope for simplistic solutions. To the extent that they hold out the hope of easy answers, bootstrapping approaches may actually represent impediments to learning. By contrast, a theoretically-based technique like cost-benefit analysis could enhance a society's understanding if its underlying principles were broadly disseminated to citizens, scientists, and regulators. Since participatory analyses or educational programs would constitute a significant departure from present practice, one can only speculate about whether they would induce people to behave in accordance with economics' model of rationality.

Much of the educational potential of decision analysis derives from the protracted interactions between analysts and clients, designed to help the latter to understand and express their beliefs regarding any particular decision in a coherent fashion. On the other hand, by being atemporal, decision analysis imposes no consistency across decisions. In principle, of course, the result could be chaos, with values and conclusions fluctuating from analysis to analysis or even in replications of the same analysis performed at different times or with a different cast. This threat is reduced when there is stability and consensus in societal values and when analysts turn to the same sources for assessment of those values.

Professional judgment effects a continuous compromise between the decisions of the past and values of the present, achieving relative consistency by gradually adapting traditional standards and solutions. The closed nature of professional judgment, however, reduces opportunities for educating non-professionals. It may also restrict the creation of a useful cumulative record; even when professionals' conclusions are made explicit, their underlying logic may not be detailed beyond statements like, "according to standard operating procedure." Both bootstrapping and formal approaches can leave more of a record if their deliberations, assumptions, data bases, and so on are preserved in public view. Indeed, once a bootstrapper has adequately identified and characterized the relevant past, that historic tradeoff may be used again and again. Formal analyses do not envision establishing eternal standards. However, if properly conceived and managed, such analyses might be modularized so that components could be reused in subsequent analyses. For example, serious studies of the value of a life, the manner in which errors compound in an analysis, or the way to think about intergenerational equity could inform many analyses.

In hazard management, as elsewhere, short-term pressures are often the enemy of long-term planning. The need to make decisions may encourage decision makers to press into service techniques that still need theoretical and practical development. The long-term contribution of a technique may decrease to the extent that it promises definitive answers in the short run, thus frustrating its own development.

Choosing an Approach

If one took the numbers in Table 7.1 seriously, the choice between bootstrapping and formal analysis would constitute no contest: formal analysis dominates bootstrapping by being better on every criterion. On the other hand, choosing between professional judgment and formal analysis requires setting priorities among the criteria. If practicality and institutional compatibility are critical, the edge would go to the professionals. A stress on logical soundness or comprehensiveness would tilt the balance back toward formal analysis. Only if openness to evaluation of were of overriding importance would one choose bootstrapping over professional judgment.

However accurate these assessments might be, they are aggregated over a hard-to-define universe of possible usages. Tables 7.2-7.4 offer speculative characterizations of the approaches' ability to cope with three specific situations in which acceptable-risk questions must be addressed: (a) a routine decision with an individual decision maker, e.g., a woman deciding whether to use an IUD; (b) standard setting for the reliability of one component of a complex technological system, e.g., a valve in an LNG facility; and (c) deciding if and how to go ahead with a new technology, e.g., genetic engineering.

These numbers, like those in Table 7.1, are rough summaries of how we rate the various methods in each approach category on a hypothetical sampling of problems drawn from each case category. Unlike the numbers of Table 7.1, these are not estimates of potential, but assessments of how well an approach is likely to perform given the pressures and constraints of actual problems. Except where one approach appears to dominate the others, these estimates do not dictate the choice of an approach. One still has to determine the relative importance of the respective criteria.

Routine Individual Decisions

Such decisions are usually made by professionals after some consultation with the client, a division of labor whose reasonableness emerges in Table 7.2. Professional judgment shines relative to its competitors and relative to its overall capability (as represented in Table 7.1). Professionals are the decision-making institution and they know how to produce answers that have been shaped by trial-and-error experience. This legacy of repeated decisions even offers some opportunity for external evaluation, although that potential may not be exploited very often (Bunker, Barnes & Mosteller, 1977).

Perhaps it makes more sense to explain why professional judgment does not get perfect marks. Its most glaring weakness is failure to promote long-term management. Even when satisfied with the professionals' solutions to their immediate problem, clients may learn little that would enable them to make more independent decisions or better use of professionals in the future. The professionals' own development may be stunted to the extent that inertia, unchanging standards, isolation, or liability worries bind them to the increasingly outdated practices common when they received their schooling. Although routine professional practice is seldom a political topic, it can become very controversial when critics spot a questionable tendency. Recent critiques have accused professionals of not seeing the "whole" client, of treating symptoms rather than problems, of adopting overly cautious practices that protect the professional at the expense of the client, and of overpromoting solutions within their own areas of competence.

These problems are minor compared to those that arise in applying bootstrapping approaches to such decisions. Not only must analogous problems be found in the past, but the individual must be convinced that they are personally relevant. One need not follow a course of action just because others have done so; who knows how wise they were or what values they had? Nor need one repeat one's own previous decisions or even maintain the same attitude toward risk that they reflected. It is easy to imagine responses like "driving is one thing and health is another" or "I would have chosen a safer alternative, had I had the opportunity."

Table 7.2

Ability to Make Routine Individual Decisions

Ratings of Approaches on 7 Criteria

	Approach		
	Professional	Bootstrapping	Formal
Comprehensive	8	2	8
Logically Sound	8	2	8
Practical	9	3	3
Open to Evaluation	6	5	7
Politically Acceptable	7	3	5
Compatible with Institutions	9	4	2
Conducive to Learning	3	4	8

Formal analysis may eventually become a useful tool for this sort of decision (Jungermann, 1980; Wheeler & Janis, 1980). Decision analysis, which is designed for situations with an identifiable decision-making entity, has already been proposed for problems like genetic counseling or weighing coronary by-pass surgery (Pauker, 1976). Such schemes could teach the client something about decision making in the course of treating the immediate problem. Unfortunately, adoption seems far away. Such a cards-on-the-table approach would be threatening to many professionals, undermining their status, forcing confessions of uncertainty, and demystifying their judgment. Building clients' trust and understanding of formal analysis may require educational efforts beyond the scope of many counseling settings. Without such efforts, some clients may be so intimidated by the technique that they may prefer to let someone else decide.

Setting Standards for a Component of a Complex Technology

Most standard-setting decisions (considered in Table 7.3) are made by experts or within expert-dominated institutions. Hence, professional judgment is the order of the day, with great deference being shown to consistency with past decisions. The focus on technical issues and the lack of authorization for tackling broader problems lead to minimal emphasis on other aspects of long-term management (e.g., public education), as well as a fairly restricted problem definition. Like other activities conducted outside the public eye, these decisions are likely to be noncontroversial. Even when feelings run high about a technology, attention is likely to focus on overall safety rather than the reliability of particular components. As a result, when professionals are singled out as the locus of decision, attacks may center on the general propriety and competence of their judgment rather than on any specific decisions. The unclear link between component reliability and overall safety may produce frustrating confrontations, with professionals unable to demonstrate that they have addressed the public's concerns and the public unable to provide guidance that the professionals can translate into operational terms.

Table 7.3

Setting Standards for a Component of a Complex Technology

Ratings of Approaches on 7 Criteria

	Approach		
	Professional	Bootstrapping	Formal
Comprehensive	5	3	5
Logically Sound	7	2	7
Practical	9	4	6
Open to Evaluation	4	6	7
Politically Acceptable	5	4	6
Compatible with Institutions	9	2	6
Conducive to Learning	4	3	6

Formal analysis is readily adapted to such decisions and to the institutions that make them. The promise of openness to evaluation may make them an attractive adjunct to the more closed professional judgment, although the result may be justificatory analyses conducted to legitimate decisions made intuitively. In these interactions, the formal analysts' familiarity with a variety of decision problems may compensate for their lack of substantive knowledge and help the professional to transcend unduly narrow problem definitions. A possibly unattractive aspect of formal analysis is directly facing difficult questions of quantifying risks and benefits. For example, just what is the cost-saving (in lives or property) of reducing the expected failure rate of a valve from 2×10^{-6} to 1.7×10^{-6}?

It is difficult to see how bootstrapping approaches can be applied to component decisions. A detailed analysis would be needed of the relationship between the component being considered and the technologies that have been managed by society in the past.

Deciding the Fate of a New Technology

Here, if anywhere, the conditions for applying bootstrapping methods are met (Table 7.4). One may be able to identify comparison technologies and argue plausibly that society should be managing the balance of costs and benefits in a consistent fashion. The statistics are most likely to be available for evaluating entire technologies. To the extent that bootstrapping focuses attention on overall acceptability and affords a readily explicable decision rule, it may attract adherents among individuals who do not want to be bothered by confusing technical discussions about components. On the other hand, the stakes riding on such big decisions will tend to generate intense scrutiny of decision-making processes and methods, scrutiny that is likely to uncover the logical weaknesses of bootstrapping (e.g., failure to consider available alternatives).

Formal analysts could outflank the bootstrappers by using the latter's characterization of society's historic values as inputs to their own analyses. If critics accept bootstrapping's rationale, then the formal analyst may be able to escape charges of "just whose values are represented?" in the more comprehensive modeling of options, events, and consequences possible in a good analysis. The inevitable omissions and complexity of such models and the uncertainty surrounding their components still make them a ready target for critics unhappy with their conclusions or mistrustful of their machinations. To some extent, the force of these critiques will reflect the analysis' success in identifying key issues. Identifying pockets of uncertainty may also help direct scientists to topics of the most immediate policy relevance.

Table 7.4

Deciding Fate of a New Technology

Ratings of Approaches on 7 Criteria

	Approach		
	Professional	Bootstrapping	Formal
Comprehensive	4	6	8
Logically Sound	4	5	7
Practical	3	5	5
Open to Evaluation	3	7	8
Politically Acceptable	4	5	5
Compatible with Institutions	6	5	6
Conducive to Learning	5	5	6

The primary limits of professional judgment is the absence of individuals with demonstrated competence in passing judgment on complex and novel technologies. There may be no one with hands-on experience and a practical grasp of the problem. Even if there are professionals with claims to such understanding, they may be restrained politically by those who believe that some problems are too important to be left in the hands of those who know most about them.

CHAPTER 8

What Have We Learned?

We began this inquiry by asking the seemingly straightforward question "How safe is safe enough?" Like others before us, we discovered that there are no easy answers. To understand what various possible answers entailed, we had to step back and characterize (a) acceptable-risk problems, (b) the generic approaches available for resolving them, and (c) the considerations that govern the choice of an approach. The ensuing analysis used this conceptual framework to clarify the strengths and weaknesses of the various approaches. In addition to offering some guidelines to the selection of an approach, this enterprise suggests some general observations about acceptable-risk problems and their management.

Acceptable-Risk Decisions Concern the Relative Desirability of Options

All decisions involve a choice between alternative courses of action, including, perhaps, inaction. A sensible decision-making procedure enables one to identify a plausible candidate for the most attractive (or most acceptable) option. Whether or not one follows the procedures' recommendations, one accepts or adopts an option, not a risk. This choice of option is conditional on the alternatives considered, the evidence consulted, and the consequences weighed. Hence, the most acceptable option could change whenever new evidence comes to light, new options are invented, different values become relevant, or different procedures are used.

One may call the risk associated with the most acceptable option an acceptable risk. Whenever the decision maker wishes to consider benefits as well as risks, the most acceptable option need not be the option with the least risk. Nor need its risks be considered acceptable in any absolute sense. Since the choice of options is context dependent, there are no universally acceptable risks.

There Is No Definitive Method for Choosing the Most Acceptable Option

Selecting an approach to acceptable-risk decisions is complicated by the difficulty of satisfying all seven of the evaluative criteria simultaneously. The most frequent conflicts between criteria arise between comprehensiveness and logical soundness and between comprehensiveness and practicality. It is often much easier to produce a defensible, or at least plausible, answer if one first reduces the scope of the problem under consideration.

In order to produce explicit recommendations, each approach restricts itself to a subset of issues that it abstracts from the complex problems. In doing so, it must make simplifying assumptions about the nature of the world (e.g., fully informed consumers, stable and articulated values, identifiable states of societal equilibrium). Unless these limits are appreciated, the advice produced by an approach may have an unjustified aura of understanding, analyzability, and finality. On the other hand, if these problems are taken too seriously, the potential benefits of these approaches may be lost. Rejecting all approaches means accepting intuitive judgments or raw politics, with their attendant dangers, as the decision-making process.

A more balanced perspective views these techniques as decision aids, ways to enhance understanding that need not dictate choices. Much of their usefulness comes from structuring and organizing those parts of the decision problem and available data that each approach addresses. The only reason for taking the next step and computing a bottom-line recommendation might be to avoid the calculation errors that would arise if people did that task in their heads. This view values the advice-givers not as the bearers of sophisticated calculi, but as critical outsiders with unique perspectives and the ability to propose and explore alternative representations of complex problems. It lauds their intuitions, not their numbers. One should always want to know what a cost-benefit analyst, bootstrapper, or professional has to say about a particular problem. Bearing the limits of their viewpoints in mind, however, one should never hear them alone. Although these approaches can improve our understanding if used judiciously, none is sound enough to be trusted as a sole guide to policy.

<u>There Are No Value-Free Methods for Choosing the Most Acceptable Option</u>

A recurrent hope is that we will find a purely technical method for objectively resolving acceptable-risk problems, one that protects decision makers from any charges of having imposed their values on society. Unfortunately, however, the distinct strengths and weaknesses of the respective approaches mean that the choice of an approach is also a decision to emphasize particular concerns.

In addition, each approach embodies a particular view of what society is and how it should operate. Each represents some view on the locus of societal decision making, thereby lending credibility to the actions of the market, the regulatory system, the courts, or various technical elites. For example, the limited role of the lay public in professional judgment affects future decisions as well as present ones by reducing the public's opportunities to learn about hazard management. Each approach also prejudges particular value issues that one might want left open to discussion. For example, bootstrapping approaches are biased toward preserving the social-political status quo, whereas some formal analyses give short shrift to equity issues. Choosing an approach means taking a position. One goal of the present analysis was to help all parties to spot the value assumptions implicit in any approach with which they might be confronted.

Whatever approach is adopted, honesty requires a serious effort to separate issues of fact from issues of value. It also requires the realization that facts and values are often highly intertwined. They are mixed in the way we define decision problems, the units we use to measure vital quantities, the alternatives and consequences we consider, the research we sponsor, the standards we use for interpreting evidence, the way we treat divergent views, and the respect we afford lay risk perceptions. The decision-making process cannot proceed without adopting a perspective on these questions; doing so affects various parties' chances of getting what they want. An approach cannot overcome the biases built into the problem definition that constrains its activities. It should, however, help users identify these biases.

Acceptable-Risk Decision Making Takes Place Throughout Society

Common to the approaches considered here is an image of decisions as being made at discrete points in time and space. With many hazards, however, identifiable decisions are as much an idealization as the "individual decision maker." Such heavy stakes ride on the outcomes of decision processes that hard lobbying and even dirty tricks can be expected as the sides jockey to have their facts, values, options, and problem definitions adopted. By the time many "decisions" are reached, they have only symbolic value, legitimating conclusions that have already emerged from the preceding process. The battle then resumes over issues of implementation, monitoring, and revision. Any approach to acceptable-risk decisions may become a pawn in this game, manipulated to sanctify or bolster choices that have been made for other reasons.

Some decisions are made at identifiable points, but have only an accretive effect on society's acceptable-risk decisions. Those larger decisions are shaped every time a consumer returns a risky product, a worker enters a risky job, a court awards damages, or a profession decides to censure a member. In one way or another, each of the approaches depends upon the wisdom of these decisions to inform it regarding society's values. Any act that improves these decisions also enhances the larger decision. Examples might be informing workers better about occupational hazards, providing courts with better guidelines regarding the foreseeability of product defects, or reducing impediments to efficient pricing of safety in the marketplace.

The Expertise Needed for Acceptable-Risk Decisions Is Dispersed throughout Society

The term "expert" may have a rather different meaning in hazard management than in other spheres. Whereas there are people who know nearly all there is to know about grammar or auto mechanics, for many hazards there is no one who understands their full impact on nature and on society, in the present and in the future. Those who know how a system operates in theory may not know how it operates in practice. Even those who know both theory and practice may not understand how it interacts with related social and environmental systems. When experts are forced to go beyond the data available to them and rely on educated intuition, their opinions should be treated with some of the same caution due the speculations of lay persons.

Exaggerating the breadth of an individual's expertise can be as dangerous as exaggerating its depth. People familiar with one hazard may not be particularly equipped to deal with another. Experts in the magnitude of risks need know nothing about their acceptability, nor need they understand what it is like to experience the effects they measure. If society is to apply its cumulative wisdom effectively, it should "domesticate" acceptable-risk problems to make them accessible to experts in similarly complex problems. Anyone who can shed any light on court-ordered bussing should be given a crack at nuclear power. Yet, leading lights in other established intellectual fields may not be able to grasp immediately the subtle wrinkles of hazard issues, with their complicated constituencies, ambiguous problem definitions, and poorly discriminable effects.

Disciplinary training and personal experience teach one how to find a reasonable answer to a fairly small class of narrowly defined problems. Hazard management is too complex for any one individual, group, institution, discipline, or approach to have all the answers or better answers than all others. Some of the worst surprises in hazard management have involved the occurrence of events or consequences that were not anticipated by the experts, but which might at least have been suggested by members of other disciplines, operators, people living on site, and so on. Rather than looking for techniques that will provide the right answer, we might better focus our efforts on avoiding the mistakes to which various perspectives are attuned. If each new perspective has some unique contribution, we may want to lend an ear to parties not often heard in policy-making circles--the poor, the philosophers, the artists--in hopes that their life experiences will illuminate hitherto-obscure options, events, and consequences. Even when experts may have a near-monopoly on technical facts, they need not have a monopoly on alternative perspectives, and may suffer from ingrained disciplinary blinders.

Acceptable-Risk Decisions Affect as Well as Reflect the Nature of a Society

A persistent tension in all societies is the division of power between technical experts, political leaders, and the laity. To some extent, this balance depends on how much the various parties know. People are often willing to surrender some power to those who know more. However, when the knowledge of experts is limited, one must worry about how much our political processes should be distorted to gain the (possibly limited) insights they possess. If, for example, the best available formal analysis is so sophisticated that only a handful of individuals can understand and monitor its assumptions and workings, one may prefer a more modest approach that does not confer as much power on experts and their immediate clients.

Some would argue that an active citizenry is the greatest asset of a democracy. Unless it is well informed, however, even the most involved public may not make decisions in its own best interests. The evidence suggests that, all in all, lay people have done a fairly good job of tracking the risk information that is presented to them. Often, however, that presentation is confusing, incomplete, biased, and contradictory. As a result, lay people seem to be highly educable, but only moderately educated. Approaches to acceptable risk that fail to educate the lay public in the short run also disenfranchise them in the long run.

Once the political decision has been made to adopt an approach that affords a role to "the public," an additional political decision is needed to define that term. There is no all-purpose public. Those who speak in its name may be recruited by a haphazard process. Often the individuals most directly affected are not represented, because they were not informed, lacked the skills to gain a hearing, or were not born when the decision was made. Moreover, when the opportunity is provided for public input, it may be exploited by technology promoters and regulators eager to influence our political agenda and thinking. Like "the public," promoters and regulators are heterogeneous groups. Just as one can ask, "Who appointed Ralph Nader to speak in the public interest (and not just an anti-corporate lobby)?" one can ask, "Who appointed the Business Roundtable to speak for business (and not just major corporations)?" or "Who appointed the AFL/CIO to speak for workers (and not just a relatively powerful and politically conscious sector of the labor force)?"

Acceptable-Risk Decisions Do (and Should) Evolve over Time

As described above, acceptable-risk decision making is a messy, diffuse, and dynamic process; although such a process may frustrate efforts at consistency and expediency, that may be a virtue as well as a necessity. Only as time goes on do we learn about how a hazard behaves and how much we like (or dislike) its consequences.

A good decision-making process will contribute to this learning. As a result, we must be ready to go through the process more than once, with each iteration being fed by the insights and criticisms arising from its predecessors. Indeed, a sign of a good analysis might be that it deepens one's understanding sufficiently to require an iteration, involving perhaps a complete redefinition of the problem. It may be a misallocation of resources to spend, say, 95% of a budget on a sophisticated analysis and only 5% on an external review followed by begrudging cosmetic revision. Whenever possible, a better division of resources might be 40-40-20 (for the first, second and third rounds of analysis). One result should be better-informed decisions. Another result might be somewhat different kinds of decisions. Admission of our relative ignorance may encourage us to procrastinate until better information is available, to avoid actions with irreversible consequences, or to hedge our bets through tentative and diversified strategies.

The educational potential of an approach is particularly important in situations not structured to facilitate learning from experience. Too often, life's messages are obscured by the complexity of the problems we face or by the distortions of hindsight, wishful thinking, and overconfidence, all of which can reduce our perceived need to learn. The education of experts can be speeded by subjecting their work to rigorous peer review; the education of hazard managers can be aided by the development of improved decison-making methods; the education of a society can be enhanced by treating its citizens as integral parts of the decision-making process. In this light, public participation is not a necessary encumbrance to the decision-making process, but an important element in assuring its validity.

Summary

• The phrase "acceptable risk" refers to the risk associated with the most acceptable option. This choice depends upon the problem definition and inputs used. Going beyond the choice of the best available alternative and determining the absolute acceptability of a risk is a separate, unsolved, and perhaps unnecessary problem.

• No approach to acceptable-risk decisions addresses more than a portion of complex hazard problems. Their greatest contribution may be structuring those issues with which they do deal. If we feel compelled to calculate a bottom-line recommendation, we should not forget the heavy qualification that should surround it.

• There are no value-free approaches to acceptable-risk decisions, nor is it possible to effect a complete separation between facts and values. The choice of procedure affects the strength of various parties and proposals and might be best resolved in the political arena.

• Decisions about hazards take place throughout society. Care must be taken to cultivate each component of the decision process.

• No one knows enough about the management of many hazards. Expertise is best viewed in a relative rather than absolute sense. It may be shared by many in a society.

• The choice of an approach affects society as a whole as well as the distribution of power and expertise in specific decisions. Confronting those broader political issues is a part of acceptable-risk decisions.

• Society will be dealing with hazards for a long time. If our managerial ability is to improve over time, we must recognize the limits of our knowledge and structure our experience to facilitate learning.

CHAPTER 9

Recommendations

As described in Chapter 8, acceptable-risk decisions are often made by a variety of individuals and institutions acting in an uncoordinated, piecemeal fashion. Each of these "actors" has some unique contribution to make to those decisions, if their strengths and weaknesses can be put in proper perspective. The present chapter translates this general message into recommendations directed at the four major components of the acceptable-risk world: the technical community, the public, the marketplace, and government. Since these recommendations are non-exclusive, no attempt is made to establish priorities among them. Perhaps a more important distinction is between those that could be accomplished overnight and those that would take years to implement, even if adopted today (e.g., where education is involved). Where time, resources, or politics limit the implementation of a recommendation, a complementary recommendation is to remember that we are living in a world with that problem unsolved.

Recommendations for the Technical Community

The technical community includes all those whose role in the decision-making process is legitimated by some trained expertise. Professionals, formal analysts, and bootstrappers all fall into this category; thus, these recommendations are guidelines for getting the best out of any of their techniques. To stress the common elements of these diverse approaches, we will use the term "technical analysis" to refer to any expert-produced advice, whether its logic is intuitive, formal, or comparative. The terms used below will resemble those of formal analysis because that method is both most comprehensive and most explicit about what it does. However, the points are more general.

The premise of technical analyses is that we can think our way to a better understanding of acceptable-risk conundrums. The case for incorporating some, or several, such analyses in every decision-making process is easy to make:

• However restricted it may be, the technical analysts' perspective has some insight to offer.

• Cognitive limitations make it highly unlikely that anyone can perform such analyses intuitively.

• As long as it is explicit and scrutable, even a flawed analysis may provide an excellent point of departure.

• Most analyses can address some of the concerns of many participants and help focus their debates.

• An analysis may organize and summarize technical details in a form that allows systematic updating as new facts emerge.

This potential is, of course, not always realized in practice. When analyses are poorly performed, inadequately embedded in the decision-making process, or used for political ends, they may confer risks as well as benefits. These risks include:

• Obscuring value issues (that are buried in technical language or unstated assumptions).

• Systematically biasing decisions (by underrepresenting concerns such as equity or less tangible costs and benefits).

• Disenfranchising lay people (by restricting the participation of citizens, journalists, or legislators).

• Weakening society over the long run (e.g., by failing to educate).

• Creating a myth of analyzability (and overconfidence in society's ability to understand and manage hazards).

• Slowing the decision-making process (by making the analysis, rather than the problem, the focus of debate and litigation).

• Generating solutions that cannot be implemented (because they have not evolved within the regulatory, professional, industrial, and intervenor communities).

Of course, even with these risks, technical analysis may be a more acceptable option than the alternatives of purely political or intuitive decision making. Our first recommendations concern ways to get the most out of our analytical resources.

What Should Technical Analyses Contain?

As every politician knows, controlling the agenda in a policy debate is part of a winning strategy. The agenda of an analysis is embodied in its problem statement. Its terms can foreclose decision optio lirectly by not raising them as possibilities, or indirectly by neglecting the consequences that those options best serve. Knowing the power of these definitions, experienced warriors in hazard disputes fight hard to have their concerns reflected in the analyst's mandate; failing that, they may fight dirty to impeach the resultant analysis. To the extent that ignored consequences do not go away and overlooked options dominate considered ones, comprehensiveness is crucial to sound advice, as well as political acceptability.

Incompleteness is usually justified by limited resources, limited data, or limited authority. Unfortunately, however, components that are out of sight also tend to be out of mind. If analysis is designed to enhance our intuitions by framing the overall acceptable-risk problem, breadth may be more important than depth. Guaranteeing minimal representation to all topics should precede elaborating any one topic with costly numerical or modeling exercises. One way of defining the minimal scope of a formal analysis appears in Table 9.1.

Consider all feasible options. Hazards may be conceptualized as a causal chain leading from general needs to specific wants to technologies to initiating events to intermediate outcomes to deleterious consequences (see Figure 2.1). Each link offers possible action options. One can, in principle, modify wants, alter technologies, mitigate consequences, etc. By contrast with this range of possibilities, many analyses consider only one option (build the plant), or only variants on one option (build it here or there), or only alternate forms of the same kind of solution (Pesticide X or Pesticide Y). Even when these omissions can be

Table 9.1

Minimal Scope for a Formal Analysis

Consider all feasible options

- Modify wants
- Modify technology
- Prevent iditiating event
- Prevent release
- Prevent exposure
- Prevent consequences
- Mitigate consequences

Consider all major consequences

- Economics
- Environment
- Societal resilience
- Equity

Consider all sources of uncertainty

- In scientific knowledge
- In society's values
- In decision-making methods
- In implementation

attributed to the analyst's limited mandate or political and economic realities, decision makers and impactees alike should benefit from knowing what possibilities were precluded by practicalities or presumptions. Only if limits are acknowledged is there any chance of their being lifted.

Consider all major consequences. Most analytical methods were developed to help individual or corporate decision makers cope with primarily economic concerns. Over time, they have been extended to society's economic decisions, to decisions with environmental impacts, and to effects on social structures (e.g., neighborhood deterioration). If all of these consequences are legitimate societal concerns, all should be addressed in any given analysis, if only to list them and then officially ignore them.

Although environmental and social impact assessments are designed to expand the range of consequences that are considered, readily monetized effects still get the most attention, to the point where other concerns are often mislabeled "intangibles." "Economic" should be interpreted as "any effect that someone might pay to get or get rid of," regardless of whether the economists have agreed on how to measure it. Thus, it would include both health impacts and the economic consequences of environmental enhancement or degradation (despite the difficulty of pricing lives, limbs, and scenery). "Environmental" impact assessments would deal with the intrinsic value of preserving or enhancing natural systems, whereas "social" impacts would mean changes in a society's structure, resilience, and ability to cope with future challenges. Such assessments would ask questions like: Will innovation be hampered? Are future options foreclosed? Will trust in government and one's fellows be eroded? Is understanding being spread?

Finally, a comprehensive analysis would review all consequences with an eye to who gets what. This "equity" impact assessment would consider both direct consequences, like money and lives, and indirect ones, like shifts in political power or access to information. Reference groups will vary from problem to problem; they might include present versus future generations, workers versus non-workers, rich versus poor, or those living close to the hazard versus those living far away.

Consider all sources of uncertainty. Treating all feasible options and all major consequences helps assure that the technical analyst is addressing the right problem. Solving it adequately means considering the uncertainty that arises whenever (a) scientific knowledge is absent, inconclusive, or in dispute; (b) society's values are unarticulated, unstable, or conflicted; (c) political pressures and resource limits threaten to keep options from being implemented as planned; and (d) the analyst's own techniques are fallible. A technical analysis should address these possibilities, not just by a compartmentalized listing but by working through their implications for the robustness of its recommendations.

How Should an Analysis Be Presented?

When technical analyses cannot produce binding decisions, their decision-*aiding* function must be taken very seriously. Table 9.2 summarizes recommendations for exploiting the user's current sophistication and enhancing it over time.

Table 9.2

How Should an Analysis Be Presented?

Use a standard presentation
List the behavioral and value assumptions of the analysis
Detail the comprehensiveness of the analysis
Qualify inputs and conclusions
Offer summary statements
Identify sources of information and potential bias

Use a standard presentation. For most lay consumers, technical analysis is conducted in a foreign language. Learning that tongue is complicated by the terminological and conceptual differences among different forms of technical analysis. The reasons for these differences vary from theoretical disagreements to deliberate relabeling for some strategic purpose (e.g., having a special tool to promote or escaping the criticism leveled at a familiar technique). However justifiable such shifts might be in the abstract, using similar terms and formats would facilitate learning and comparison across problems. One might even argue against adopting improved techniques unless they represent major steps forward. Aside from confusing users, new techniques have not been tested over time so as to reveal their subtle flaws, create a coterie of critics, and generate an art of implementation.

List the behavioral and value assumptions of the analysis. Discussed at length in Chapters 4-6, these assumptions embody the inherent biases and limitations of the techniques. Like the Surgeon General's warning on cigarette packs, this listing might be repetitious for the repeat users. However, it will be news for others and an affirmation of frankness for all.

Detail the omissions. When an analysis fails to address the "wish list" of topics in Table 9.1, the analyst(s) should be forthright about what has been ignored and why. Candidness can forestall participants' fears of being deceived, clarify the legitimate topics for discussion, and identify the sources of restricted agendas.

<u>Qualify the inputs and conclusions</u>. Technical analysts who have addressed the various sources of uncertainty need to inform consumers about the robustness of their conclusions. Since responsible qualifications are difficult to make or comprehend, more is needed than a last-minute tack-on or an obligatory "nobody is perfect." In addition to hearing where the greatest uncertainties and disagreements lie, the user needs to know whether the whole analytical enterprise is in danger of collapsing under the cumulative weight of the problems the analyst has encountered.

<u>Offer summary statements</u>. Just as summaries are inadequate (thus requiring qualification), so are they indispensible. The mind cannot comprehend lengthy compendia of statistics, tables, arguments, and figures. In self-defense, observers will produce their own summaries, risking a higher rate of conceptual and computational errors than one would expect with a trained analyst. One way to get the benefits of expert-produced summaries without having them inspire undue confidence is to provide several, representing the conclusions reached using different problem definitions, inputs, and combination rules.

<u>Identify sources of information and potential bias</u>. In scientific research, incomplete documentation suggests sloppy work; in politicized risk analyses, bias may be suspected as well. Critics may wonder: Were these promoters' or opponents' data? Is the analyst making too much of hot, new results? Is the testing laboratory trying to hide some problems? Although awkward, acknowledging such fears may forestall problems in

the long run. To avoid having its panels' conclusions challenged by post hoc attributions of bias, the National Academy of Sciences now asks panelists to disclose their financial interests.

How Should Technical Analyses Be Managed?

When analytical resources are limited, attention turns to how to allocate them. Three managerial principles are set out below, along with their immediate corollaries.

Table 9.3

How Should Analyses Be Managed?

Insure adequate problem structuring
Avoid premature closure
Coordinate analyses

Insure adequate problem structuring. The eventual wisdom, comprehensiveness, and responsiveness of an analysis are constrained once its structure or definition is set. When a single analysis is being managed, elaborate calculations should be postponed until an adequate structure has been developed. When several problems are involved, analysts may contribute more by characterizing each from their unique perspective than by working out one in detail.

Avoid premature closure. The structuring stage of a good analysis is never completed. The insights from the first round should reshape the problem for subsequent iterations, suggesting new solutions, identifying issues regarding which decision is most sensitive, and factoring in new understandings about what we really want. Exploiting this potential requires allocating resources to diverse reviews and to comprehensive responses.

Coordinate analyses. Time and analytical resources are too limited for studies to be conducted in relative isolation from one another. Thus technical analysts should: (a) use the results of previous analyses wherever possible; (b) modularize analyses for easy reuse; (c) make generic decisions; (d) leave a clear, concise record of deliberations and the reasoning underlying decisions; (e) avoid repeating the same omissions in analysis after analysis when all aspects of problems cannot be analyzed in depth.

To some extent, using technical analysis to solve particular problems conflicts with its long-term development. Existing analytical resources may be best exploited by spreading them around to shed some light on many issues. However, advancing the craft itself may require heavy investment in a few thorough analyses capable of recruiting scientific talent and serving as models for subsequent analyses.

How Should Technical Analysts Be Prepared?

Public policy analysts often have more of the rights than the responsibilities of a profession. There are research contracts, publication outlets, and opportunities to speak or testify, but relatively little in the way of standards, licensure, qualifying exams, or peer review. At times, risk issues are needlessly mystified as phenomena that can only be penetrated by veteran risk buffs; at other times, the subtlety of these issues is underestimated, leading otherwise perceptive individuals to offer simplistic solutions. The recommendations summarized in Table 9.4 are designed to improve analysts' ability to serve society.

Table 9.4

Recommendations for Preparing Technical Analysts

Educate technical analysts
Training programs
Texts and workshops
Internships
Improve professional standards
Develop professional codes
Promote public interest work
Guarantee external review
Formulate guidelines for testimony
Refuse biased mandates
Respect other disciplines
Validate techniques

Educate technical analysts. Analysis should be a clinical science, grounded in theory, but demanding considerable art in practice. Three ways to provide more systematic training are:

- Graduate programs combining social and technical theory with applied experience (like Carnegie-Mellon University's Department of Engineering and Public Policy).

- Advanced texts and workshops in risk issues to facilitate the involvement of scientists from existing disciplines.

- Internships in government, industry, labor, and public interest bodies.

Improve professional standards. Risk policy analysis is in the pre-profession stage. That status confers the benefits of being open to innovations from contributing disciplines as well as the liability of being weak on quality assurance. Some steps that might confer the positive controls of a profession without its exclusionary aspects are:

- Develop a code of professional responsibility before it emerges haphazardly from the legal system.
- Set up a "public interest risk analysis group" like the organization founded by some large U.S. accounting firms to "give accounting away."
- Insist that a fixed portion of the funds (e.g., 15%) in any analysis contract be allocated to independent external review.
- Adopt guidelines for experts giving testimony.
- Refuse to perform justificatory analyses, where the conclusion is predetermined and non-negotiable.
- Ensure that analysis teams have multi-disciplinary capability.
- Encourage studies of the validity of analytical techniques.

Recommendations for Public Involvement

Let's dismiss the public--and elect a new one.

--Brecht

One popular strategy for dismissing the public is to discredit its intelligence, in order to justify letting others speak in its stead. There are, however, both practical and political reasons for doubting the wisdom of that strategy. Practically, hazard management often requires the cooperation of a large body of lay people. These people must agree to do without some things and accept substitutes for others; they must vote sensibly on ballot measures and choose legislators who will serve as surrogate decision makers; they must obey safety rules and use the legal system responsibly. Even if the experts were much better judges of risk than lay people, giving experts an exclusive franchise for hazard management would mean substituting short-term efficiency for the long-term effort needed to create an informed citizenry.

Politically, exclusion may breed anger as well as ignorance. Citizens in a democratic society will eventually interfere with decisions in which they do not feel represented. When lay people do force their way into hazard decisions, the vehemence and technical naivete of their response may leave the paid professionals aghast, reinforcing suspicions about the "stupidity of the public." By avoiding these conflicts, early public involvement may lead to decisions that take longer to make, but are more likely to stick.

Table 9.5

Recommendations for Public Involvement

Avoid

- Predetermined problem definitions
- Secrecy
- Lip-service testimony
- Superficial public-opinion polls
- Manipulation of public opinion

Provide

- Guides to understanding tools
- Financial and technical support

Consider that the public

- Knows something
- Has reason for skepticism
- Is deeply involved

Conditions for Involvement

Recurrent appearance of the adjective "meaningful" in discussions of public participation suggests a legacy of less-than-satisfying experiences. Appropriate involvement may be defined by listing features that negate it: (a) excluding the public from the problem-definition process; (b) making portions of the decision-making process inaccessible to the public; (c) soliciting testimony that will be filed and forgotten; (d) representing public opinion by superficial polls; (e) defining education as "manipulation" and consensus as the state in which "the public agrees with the experts".

Of these pathways to alienation, only (d) may require elaboration. Although public-opinion polls appear to provide a ready, albeit expensive, way to find out what "the people" think, even methodologically competent surveys have limits as guides to policy makers. One is that respondents can offer opinions only on questions that interest those who commission the polls; their formulation typically restricts further the range of views that can be expressed. A second limit is the assumption that people have well-formulated opinions on any question the pollster chooses to ask and that those feelings can be matched to one of a set of multiple-choice answers. The opportunity to interact with the interviewer, clarifying the meaning of questions and the implications of answers, may be necessary to allow respondents a fair chance to understand and express their views and interests.

Tools for Involvement

Technical experts owe their centrality in acceptable-risk decisions to the power of the tools they wield. To join the experts responsibly, the public needs to understand those tools. One necessary step is clarifying their strengths and weaknesses. The present report is designed, in part, as a consumers' guide to decision-making methods. Kindred analyses would explain in plain language what one can reasonably expect of epidemiology, mega-mouse studies, and computer simulations. Offering abbreviated versions of such explications whenever techniques are used might defuse suspicions that they are arcane tools for confusing and disenfranchising the public.

A second necessary step is providing the public with the technical and financial support needed to understand and criticize analyses. Those who review analyses are naturally most sensitive to errors and omissions prejudicial to their own interests. If competent reviews are commissioned by only one side in a controversy, only one kind of error will be corrected, leaving the conclusion biased.

These steps should help the public place the wisdom of tools in appropriate contrast to the wisdom of intuition. The right to participate carries with it the responsibility of realizing the limits to one's own knowledge and intellect.

Procedures for Conflict Resolution

What do we do if disagreements persist between the experts and the public? In a democratic society, "we" don't do anything; the political process resolves the issue, for better or worse. Assume, however, that some wise and dispassionate institution is entrusted with resolving these disagreements (or that our courts, legislatures, or bureaucracies constitute such institutions); could it responsibly act according to the public's "fears" rather than the experts' "facts"? The answer could be "yes" if at least one of the following conditions holds:

(a) The lay public knows something that the experts do not; the dispassionate institution should then change its best estimate of what the facts are.

(b) The lay public knows nothing special, but has good reason to be unconvinced by the experts' testimony; the institution might leave its best estimate unchanged, but increase the confidence intervals around it. The result might be delay, hedging, or switching to a more certain course of action.

(c) The public is unreasonable and unresponsive to evidence, but has a deep emotional investment in its beliefs. There are costs to a society for overriding the strong wishes of its members; these include anomie, resentment, distrust, sabotage, stress, and psychosomatic effects (whose impact is physical even when their source is illusory). Such costs could tip the balance against the action indicated by the experts' best guess.

Recommendations for the Marketplace

Acceptable-risk decisions are made every time a worker accepts or rejects a hazardous job assignment, a consumer saves money by buying a slightly defective product, or a manufacturer brings out safety-oriented products. The wisdom of these decisions affects not only the fates of those involved, but also the validity of the three approaches to acceptable-risk decisions, each of which refers back to how people think and act for guidance as to human values. Those thoughts and actions are conditioned by the interactions between the actors in the marketplace as they exchange information and negotiate exchanges. The following recommendations are designed to improve those interactions to help ensure that a proper price is paid for safety.

Table 9.6

Recommendations for the Marketplace

Acknowledge the experimental nature of technological innovation

- Monitor warning signs
- Face fallibility
- Provide better risk information to workers and consumers

Increase market sensitivity to safety issues

- Offer safety as an option
- Clarify the costs of safety
- Improve the liability system
- Develop a scheme to cope with risks that cannot be borne by their creators

Acknowledge the Experimental Nature of Technological Innovation

A common refrain of developers runs something like "we build them safe," "we've identified and solved all possible problems," or "we wouldn't sell it if it weren't safe." With complex innovations, such claims tend to be overstatements and to be treated as such by a skeptical public. Admitting the possibility of error would serve not only rhetorical frankness, but also the cause of better acceptable-risk decisions by:

(a) Improving the quality of information and the frequency of safety assessments. A promoter who acknowledges the possibility of problems is presumably more tuned to spotting early warning signs. This may be particularly important when workers serve as guinea pigs for the rest of society. Substances that workers handle in concentrated doses often reach the public in weaker doses (e.g., PCB's); processes that prove themselves in industrial applications often find domestic uses (e.g., microwaves). Since health effects can be most easily detected when large doses are given to a readily defined population, every effort should be made to learn the most from this bitter lesson in which workers (and, often, their supervisors) partake.

(b) Stimulating more explicit discussion of the limits to and costs of safety. Promoters should address the possibility that their technologies are too dangerous or too poorly understood to be promulgated; consumers should face the impossibility of a risk-free existence.

(c) Encouraging fuller disclosure of risk information to workers and consumers. Such knowledge would enhance their ability to negotiate fair compensation for hazardous work and fair prices of safety devices. In some situations, better information may lead them to decide that hazards are less important than they had thought, or that life really involves a choice among risks. In others, they may demand increased wages or safer products, leading in turn to increased prices which may reflect more accurately the full costs of the product. One beneficial side effect of better information would be helping people control risks in the machinery and substances they deal with, by telling them more about which are dangerous and why.

Increase Market Sensitivity to Safety Issues

To the extent that hazards are regulated by the marketplace, the efficacy of the relevant market mechanisms needs to be strengthened. The following suggestions would make for better acceptable-risk decisions in the marketplace:

(a) Offer safety as an option. At times, people are willing to pay a substantial premium for protection (e.g., organic foods for some people, mountain-climbing equipment); other times, they are not (e.g., organic foods for other people; reinforced automobile front ends). While waiting for the psychologists to clarify this apparently confusing pattern of preferences, promoters should offer safety as an option wherever sensible. If safety were marketed with the same fervor afforded other attributes, people could better express their preferences with their pocketbooks.

(b) Clarify the costs of safety. Especially for large-scale developments, the economic costs of safety are paid in such an indirect manner that the implications may not be fully understood. Better knowledge will help consumers understand where too much or too little is being paid for safety.

(c) Improve the liability system. The courts, and more specifically tort liability suits, provide an important cue to risk creators regarding the appropriate investment in safety. However, there are some obstacles to the courts providing useful feedback. At present, workers' compensation laws limit the damages an employee can obtain directly from the employer. In addition to reducing the employer's incentive for safety, this arrangement may force workers to sue the manufacturers of tools used (perhaps improperly) in the workplace in order to gain redress for injuries. Some of these suits are justified, others commit one injustice to alleviate another. More generally, promoters, juries, and users need guidelines as to what risks are foreseeable and what uses are reasonable. The Pinto case suggests another problem: manufacturers may be penalized for keeping good records, thereby making it more difficult to plead ignorance of their products' risks. There should be positive incentives for collecting data and making conscious decisions, and disincentives for incomplete or fraudulent records.

(d) Develop ways to cope with risks that cannot be borne by their creators. Many hazards are capable of creating damages that are larger than the total assets of those who create or use them. Whereas bankruptcy places an effective limit on liability, public exposure may be unlimited. One possible solution is to make the government an insurer of last resort. It would be unpopular with promoters because it invites government meddling in their affairs; it would be unpopular with taxpayers because it represents a public subsidy to private entities. A voluntary alternative might be an industry commitment to cover the damages created by constituent corporations. One side effect would be an increase in the likelihood of firms blowing the whistle on one another for unethical practices, a role for which they would be uniquely suited because of their technical expertise and natural interest in one another's affairs. A court-based scheme would be to treat corporations as partnerships for third-party liability, making the resources of their shareholders subject to claims by victims (Howard, R., 1978). An analogous problem, with no obvious solution, arises when government creates larger risks than it can handle.

Recommendations for Government

Barring a dramatic change in political climate, some government involvement in acceptable-risk decisions is inevitable for the foreseeable future. Even staunch opponents of regulation may feel that an efficient free market is an impossibility with sophisticated technologies that naturally breed monopoly conditions, unequal distribution of critical information, and difficulties in assigning responsibility for damages. Moreover, the national interest may make the management of some technologies too important to be left to those who create and use them. On the other hand, even proponents of regulation may feel that government solutions, like other aspects of our society's response to hazards, have evolved without adequate forethought, evaluation, or coordination. The following recommendations are offered as worthy whenever government has a role in acceptable-risk decisions.

Table 9.7

Recommendations for Government

Managing individual hazards

- Give a clear, feasible mandate
- Avoid mandating inadequate decision-making techniques
- Avoid ad hoc meddling in specific decisions
- Emphasize due process by law
- Give agencies consistent roles

Managing many hazards

- Encourage generic decisions
- Establish priorities for hazard regulation
- Coordinate acceptable-risk decisions

Managing Individual Hazards

Regulatory agencies can be no more intelligent than their enabling legislation allows them to be. Unwisely formulated mandates spell frustration for all concerned. The following guidelines should be useful with most hazards.

(a) Give a clear, feasible mandate. Acceptable-risk decisions require hard choices, especially when it comes to loathsome jobs like setting a value on human life. To avoid responsibility for such decisions, Congress has often passed the buck to regulators without, however, giving them the authority to make binding decisions. As a result, the center of government has shifted toward the courts or those technical analysts bold enough to make such determinations. Making the regulators' task reasonable requires clear, courageous expressions by Congress of what the will of the people appears to be in its eyes. That goal is not achieved by decisively mandating unrealistic standards like "zero risk."

(b) Avoid mandating inadequate decision-making techniques. When legislation or regulations mandate a technique that is unable to produce unimpeachable recommendations, the technique's indeterminacy can lead to interminable proceedings. When one cannot prove anything with, say, a cost-benefit analysis, any action forced to justify its existence by such an analysis could be litigated to death. For example, the National Environmental Policy Act's call for a cost-benefit-like analysis of new projects may have given those projects an impossible task in proving their worth. Conversely, the call for having regulations prove that their costs are less than their benefits might, if taken literally, mean the end of regulation. In the end, we must rely on the wisdom of our legislators and regulators to make decisions, informed, but not replaced, by decision-making techniques.

(c) Avoid ad hoc meddling in specific decisions. Second-guessing through legislative or executive vetoes is likely to make consistent, predictable acceptable-risk decision making impossible. Although some vetoes may stymie unwise regulatory decisions, a more likely role is serving a powerful vested interest. Even those interests may be hurt in the long run if they destabilize the regulatory processes, making planning impossible. When systematic problems are discovered, new mandates could be drafted to guide the entire regulatory process.

(d) Emphasize due process by law. Acceptable-risk decisions rely on a healthy legal system (e.g., for interpreting laws and regulations, for scrutinizing evidence, for holding polluters accountable), but they also place great stresses on that system. The high stakes and time pressures may offer temptations to tinker with these seemingly clumsy processes. For example, an Energy Mobilization Board would short-circuit some standing processes to the consternation of environmentalists; attempts to subpoena proprietary information trouble developers. It is not clear quite where these short-cuts would lead. An alternative approach is to look for creative solutions within the current framework. Possible examples are a regulatory appeals court or a clearing house that could examine sensitive data, to get at facts without prejudicing producers' rights to keep proprietary information secret.

(e) Give agencies consistent roles. The break-up of the Atomic Energy Commission reflected a realization that no entity can promote and regulate simultaneously. The events at Three Mile Island suggested another pair of incompatible roles: an agency designed for routine decision making may be ill-suited to handle crisis situations. The Kemeny Commission's recommendation to replace the current 5-person commission with a single commissioner would seem to change the priorities between these two roles without disentangling them. An alternative solution would be to structure an agency around one role but to have contingency plans for shifting rapidly from routine to emergency procedures (or vice versa).

Managing Many Hazards

Improved decision making in the small is a necessary, but not sufficient, condition for improved decision making in the large. The following suggestions apply to allocating resources over the universe of risk problems:

(a) Encourage generic decisions. Some 60,000 chemicals and 50,000 consumer products are used in the United States. If even a small fraction presented the legal and technical complexities of saccharin or flammable sleepwear, legions of analysts, lawyers, toxicologists, and regulators would be needed. Agencies that try to deal with hazards singly are doomed to overwork, frustration, and glaring instances of not-yet-regulated hazards causing egregious harm. One obvious solution is to concentrate on making sound generic decisions. For this strategy to work, careful thought must be given to the definition of hazard categories. Inevitably, some category members will be treated too leniently or too harshly, relative to their category's ideal type; this, however, may be a tolerable price for society to pay for greater coverage and consistency.

(b) Establish priorities for hazard regulation. A recurrent complaint against the Consumer Product Safety Commission was that it cut its teeth on minor problems (e.g., swimming pool slides). Although there are possible rationales for this selection (e.g., organizational procedures are best developed with non-controversial test cases), failure to argue them effectively has encouraged deprecation of the agency. To avoid such criticism and, more important, to provide timely treatment of problems, some decision-making priorities are needed. The following are some alternative (and inconsistent) schemes that might be suitable for different contexts.

Attend first to hazards with:

1. The most visible consequences (to enhance the agency's image and credibility).

2. The least visible consequences, particularly those affecting politically powerless groups (to ensure that they get a hearing).

3. The greatest catastrophic potential, regardless of their likelihood (to assuage fears and threats to societal resilience).

4. The highest ratio of chronic to acute consequences (to give them more immediacy).

5. The greatest promise of quick, cheap fixes (e.g., child-proof drug caps).

6. The widest range of control options, including substitute technologies (to exploit the potential for action).

A radical alternative would be for an agency to set no priorities and to address problems in a random order. Once an agenda has been laid down, those involved with technologies down the list can relax; unpredictability will encourage them to be wary and "think safety" on all as-yet-unregulated technologies.

(c) Coordinate acceptable-risk decisions. The following regulatory functions are vital for effective acceptable-risk decision making, but seem to be treated unsystematically, if at all:

1. Resolving jurisdictional disputes between agencies.

2. Assessing the consistency of standards, both across hazards and for the same hazards in different domains (e.g., lead in ambient air and lead in domestic water supplies).

3. Identifying multiple-hazard effects (e.g., cumulative doses, synergies, substitutions).

4. Managing information by integrating data bases to increase their accessibility and standardizing research reports to improve their interpretability.

5. Promoting policy-relevant research, in particular, pooling resources from mission-oriented agencies in order to sponsor basic research on common problems.

6. Monitoring and improving acceptable-risk decisions, e.g., spotting recurrent omissions or oversimplifications that repeatedly leave the same concerns underrepresented.

Such coordination is too important and complex to be handled by occasional ad hoc committees. A standing committee, such as the current (since 1978) Interagency Regulatory Liaison Group, is a step in the right direction. Its effectiveness will be enhanced to the extent that agency representatives have enough permanence to acquire expertise and enough standing to influence their own agencies' operations. Failing this, less voluntary arrangements might be needed. Although it is premature (and somewhat grisly) to think about a hazards czar, that idea's time may come before too long.

CHAPTER 10

What Do We Need to Learn?

A recurrent theme of earlier chapters was that our decision-making tools are not commensurate with the challenges posed by many hazards. The result of expecting more of existing tools than they are capable of delivering is a clumsy, unsatisfying decision-making process. The present chapter summarizes areas of ignorance by identifying the most urgent and promising research projects for reducing that ignorance. It ends with a discussion of the social and intellectual context within which such research has the greatest chance of succeeding. Its underlying premise is that research can be a cost-effective alternative to trial-and-error learning, especially for institutions (e.g., agencies, corporations) that are so buffeted by political pressures and fire fighting that they cannot reflect adequately on their own experience or experiment with new procedures. In acceptable-risk decision making, additional theory could be very practical.

Research to Reduce Uncertainty about Problem Definition

Once a problem is defined, its solution may be ordained. Our analysis attempted to identify the key issues in problem definition, in order to characterize the definitional predispositions of different approaches. Additional analysis would reveal further subtleties of acceptable-risk decisions and the tools available for resolving them.

Table 10.1

Research to Reduce Uncertainty about Problem Definition

Extend the present analysis

- Consider additional approaches (e.g., market, procedural)
- Iterate analysis of three approaches

Develop a conceptual framework for hazard definition

- Establish bounds for hazard categories
- Clarify logic of key descriptors (e.g., risk voluntariness)

Develop guidelines for identifying consequences

- Construct a compendium of consequences
- Explore systematic omissions

Design clearer, more workable options

- Identify full range of possibilities
- Develop practical expressions

Extend the Present Analysis

The three approaches considered here are among those most forcefully advocated by participants in acceptable-risk debates. This analysis should be extended to two other families of approaches which might be described as embodying market and procedural logic. These approaches reject the possibility of centralized, analytical decision making in favor of letting standards evolve through the interactions and experiences of the various actors. The locus of this combination of learning-by-doing and negotiated settlements could be either the marketplace or various social processes (including electoral politics and the workings of a bureaucracy designed for sophisticated "muddling through").

The analysis of the present three approaches is itself necessarily incomplete, pending an iteration that exploits whatever insights have been provided. Two particularly useful extensions would be further analysis of the fit between approaches and specific problem types, and the design of hybrid approaches that embody complementary strengths.

Develop a Conceptual Framework for Hazard Definition

Like any new field, acceptable-risk decision making is hindered by disagreements over the definition of key terms. Some misunderstandings between experts and lay people seem due to inconsistent definitions of "risk." Many quantitative criteria, like "reduce the risk of a fatal event from each occupational activity to less than 10^{-5} per year," are rendered indeterminate by uncertainty about what an event or an activity is. In setting air quality standards, the Environmental Protection Agency must avoid "adverse health effects" without a clear definition of that term. The lack of a taxonomy of hazards hampers the development of generic decisions or priorities for research. Even such simple terms as "voluntary" or "exposure" provide problems under closer scrutiny: How voluntary is taking a job in a tight labor market, or airplane travel for scientists, or smoking for veterans? Are we always or rarely exposed to risk of handguns? The power of definitions is such that theoretical disagreements are often suspected of being rooted in vested interests.

A concerted effort is needed to make currently used definitions explicit, to clarify their underlying assumptions, to identify cases that push them to their limits, and to propose standard usages. If a theory of acceptable risk is to be developed, one first needs clear definitions of its primitives.

Develop Guidelines for Identifying Consequences

Given the importance of specifying the set of relevant consequences, decision makers should not have to start from scratch each time. Guides are needed to list effects associated with particular kinds of hazards and to provide a theory of usage describing, for example, which consequences are important to which constituencies, what higher-order and synergistic effects should be borne in mind, where one runs the risk of double counting, and where "indicator" consequences can be used to represent a larger set of possible outcomes. One place to start developing this guide would be retrospective technology assessments that identify systematically neglected consequences.

Design Clearer, More Workable Options

Guidance is needed to identify the set of possible options, along with some notion of the strengths and weaknesses of each. It would help decision makers to know what they can conceivably do and their critics to know what options are being ignored. It would show how to express options in sufficiently explicit and operational terms to keep their implementation from becoming arbitrary and inconsistent. As before, the places to begin would be a theory of hazards (e.g., Figure 2.1) and a review of current practice. Of particular interest would be a look at those options that are now mandated: How specific are mandates? Do some hazards require less specific legislation? How do laws cope with the possibility of lax enforcement?

Research to Reduce Uncertainty about the Facts

We are only better off for knowing more when we know how to use that information. Without a framework for integrating new knowledge with old and for understanding the limits of our knowledge, confidence may increase faster than wisdom. Although the need for substantive knowledge varies from problem to problem, research into some general questions in applied epistemology could inform many decisions under uncertainty.

Table 10.2

Research to Reduce Uncertainty about the Facts

Explore the limits of knowledge

- Characterize its extent and growth rate in different areas
- Devise general rules for when it pays to wait for better knowledge

Understand expert judgment

- Investigate the cognitive processes of experts
- Assess experts' ability to assess the limits of their own knowledge

Improve society's ability to accommodate evidence

- Develop better procedures for expert witnesses
- Develop more adequate formats for public participation

Develop better summary measures

- Perform theoretical analyses of possible risk statistics
- Conduct empirical tests of experts' ability to provide inputs and lay people's ability to understand them

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Explore the Limits of Knowledge

When making decisions under uncertainty, and particularly in deciding when to decide, it is important to have some idea of how quickly our ignorance is going to be reduced. Research here would ask questions like: When does it pay to wait for a few more data points or a scientific breakthrough? How fast will various frontiers of knowledge push forward? Which technological innovations are more and less likely? To what extent is the reliability of technical systems limited by their complexity, with actions designed to solve one problem inadvertently leading to others (e.g., more alarm systems leading to more false alarms leading to reduced vigilance)? A more sociological assessment might try to estimate the extent to which scientists and technology promoters are pressured to make impossible promises in order to gain time and resources for their work. Do they, like lay people, tend to underestimate the time needed to complete tasks?

How much will be known is often bounded by practical limits on how much can be known. An understanding of the ultimate resolvability of different scientific questions would give decision makers a more realistic appraisal of what science can do and how much uncertainty is inherent in their task. Products of this project might explain the limits of epidemiology for untangling complex causal relationships, of theory and experience for assessing very low probabilities, or of clinical trials for establishing the effectiveness of drugs.

Understand Expert Judgment

Decision makers often rely heavily on the intuitions of experts to tell them what the available data cannot. Particularly when it is difficult to get an independent second opinion, guidance is needed in interpreting those judgments. Although the intellectual processes of the highly trained are little studied, existing research methodologies could be readily applied to asking questions such as: Are experts similar enough to lay people in their basic cognitive functioning that one can generalize to experts from research conducted with lay people? Does professional training encourage or discourage particular misperceptions? How independent can the opinions of two experts be when they have gone through similar training? How well do experts understand the limits of their own knowledge? Further research questions arise if one considers experts not as dispassionate interpreters of results, but as individuals strongly motivated to confirm pet theories or satisfy clients.

Improve Society's Ability to Accommodate Evidence

The two recognized founts of wisdom in our society are "the people" and "the experts." Unfortunately, our legal and political institutions seem ill-equipped to accommodate and exploit the insights they offer. The adversarial context of legal settings may not elicit experts' knowledge in a thorough and balanced fashion, particularly when statistical evidence is involved. Although a vaunted ideal, public input is often solicited by powerless junior officials, offering little technical assistance. Proposals for getting more out of these human resources include: instituting a science court, empaneling "representative" citizens to accompany a decision-making process, using alternative procedures for expert testimony, and conducting regular polls of attitudes toward risks. These proposals merit theoretical analysis and field testing. They should be supplemented by procedures that have been used for other social problems or for acceptable-risk problems in other countries.

Develop Better Summary Measures

To be useful, scientific results must be understood. When states of nature (e.g., air quality) are described on several dimensions, each characterized by various statistics and having different effects on each of several populations, comprehension may be next to impossible. Rather than have the consumers or producers of such statistics produce *ad hoc* or intuitive summaries, systematically developed risk indices are needed. Like approaches to acceptable risk, these indices should be comprehensive, defensible, and comprehensible.

A different sort of summary measure is an expert's judgmental summary of his or her experience with a hazard. That experience may not always be organized cognitively in the form desired by the risk analyst. For example, a mechanic, accustomed to seeing problems as they arise, may be unable to estimate failure rates or the likelihood of various malfunctions co-occurring. Theoretically appealing summary measures are of little use if no one can produce them. The development of judgmental procedures requires expertise in both statistics and cognition.

Research to Reduce Uncertainty about Values

Acceptable-risk decisions require people to assess their values on complex, subtle, and novel issues. The following research should help people develop and express coherent, articulated value judgments.

Table 10.3

Research to Reduce Uncertainty about Values

Develop methods for eliciting values

- Find better ways to formulate questions
- Create more suitable interviewer-interviewee relationships

Survey public attitudes toward risk acceptability

- Identify relevant respondent populations
- Conduct appropriate surveys

Conduct theoretical analyses of value issues arising in acceptable-risk decisions

- Identify possible perspectives
- Work out their implications

Identify hidden agendas

- Isolate concerns of different parties that are not directly addressed
- Understand how they might nonetheless be incorporated

Develop Methods for Eliciting Values

A naive view of survey research is that pollsters can find out what the public thinks about any and every question that interests a decision maker. This view is reinforced by the low rates of "no opinion" responses encountered by surveys addressing even diverse and obscure topics. Although capable of providing some answer to whatever question is put to them, people may be expressing a desire to be counted rather than deeply-held opinions.

A research program for improving value elicitation might include structured interactions, in which the interviewer offers alternative perspectives; iterative procedures, which review the issues until a feeling of closure is reached (or rejected); and unstructured sessions, allowing respondents to choose the questions. Substantive experts (e.g., philosophers, economists) would be needed to ensure that questions are well conceived and communications specialists are needed to ensure that they are clearly expressed.

Survey Public Attitudes toward Risk Acceptability

When the voice of "the public" expressed in surveys appears confused or irrational, the trouble may be with the transmitter or the receiver. The methods described in the preceding section could help eliminate the latter explanation. Their application requires some strategic decisions about whom and what to ask.

"The public" is usually defined as whatever population is represented by a probability sample of adults who can be found and will respond. When the issue is so obscure or complex that even the most sensitive interactive interview cannot sufficiently educate the average layperson, the public weal may be better served by questioning intact groups already interested in the topic. Alternatively, a representative group of citizens might be paid to follow the issue over a period of time. There would also be value in repeated surveys that might reveal increased sophistication in thinking about hazards, greater consistency between attitudes and behavior (as their logical links are learned), and the stability of values over time.

When eliciting public opinion, another important strategic decision is whether to ask about specific policy recommendations, such as where to site an energy facility, what kind of containment structure is needed, or what land-use regulations should be. At times, people may be able to develop articulated positions at this level. Other times, they may feel more comfortable answering questions of principle from which specific recommendations could be derived: Should equity be a goal in acceptable-risk decisions (or left to other processes)? Should there be a different standard for the safety of voluntary and involuntary activities? Should policy decisions be guided by what our values are or what they should be? Combination strategies are also possible. The choice of strategy should be guided by research into the nature of people's values.

Conduct Theoretical Analyses of Value Issues in Acceptable-Risk Decisions

Successful decisions and surveys depend on knowing what value questions to ask and understanding the societal implications of different answers. As a result, the interviewer or technical analyst intent on helping people develop positions consistent with their underlying values needs some substantive knowledge of the issues. Rather than relying on the formulations that have evolved, they should have the benefit of theoretical analyses of these issues by multidisciplinary teams of philosophers, economists, psychologists, sociologists, and others. Many decisions could be informed by detailed explorations of questions like: What would it mean if a society failed to place a premium on avoiding catastrophic losses of life? What hazard policies would violate our social contract? If equity is important, in what domains might it be sought, merely in economic effects, or also in changes in political power, knowledge, feelings of entitlement, and faith in society's fairness? Such analyses should be informed by how these issues have been addressed in different political and cultural settings and by how they would be viewed from the perspective of alternative world outlooks. Even non-believers might learn something from seeing a coherent libertarian, Marxist, Hindu, Christian, or Dadaist analysis of acceptable-risk questions.

Identify Hidden Agendas

When participants in a decision-making process find that its official problem definition precludes important issues, they may resort to diversionary strategies. Lacking a forum to discuss what really concerns them, foes of growth may choose to fight the siting of particular power-generating facilities using whatever grounds prove convenient. Companies may feel compelled to fight regulations that they consider reasonable as part of their struggle against regulation in general. A bias toward demonstrating competence may infect the work of analysts eager to be consulted or pundits and professors eager for the limelight. When social policies are decided piecemeal, it is natural to exert leverage wherever one can. Nonetheless, the level of the discussion of the official problem would be raised by having such hidden agendas clarified. What the actors might lose by exposing their biases they might gain by being shown to be less irrational than may have originally seemed.

The existence of hidden agendas suggests the existence of legitimate concerns that are not being addressed. A related research topic would be to investigate ways of handling such neglected issues. For example, although a forum for directly affecting national energy policy might be expensive and unwieldy, it might more than pay for itself by taking the pressure off smaller, more technical decisions such as plant siting.

Research to Reduce Uncertainty about the Human Element

The way people perceive and respond to risks is central to acceptable-risk decisions. Our present understanding of these processes is based on a small body of psychological work, using techniques of varying sophistication, and a large body of speculation by experts. The following research would help experts to understand and serve the public.

Table 10.4

Research to Reduce Uncertainty about the Human Element

Develop methods for studying risk perception

- Understand the terms in which people conceptualize risk
- Produce elicitation procedures for different populations

Survey public perceptions of risk

- Question both general public and interest groups
- Identify educational needs

Develop educational procedures

- Produce curricular materials
- Identify dangers of opinion manipulation

Discover what decision makers believe about the public's risk perceptions

- Determine the perceived substance of public beliefs
- Determine the perceived extent of public understanding

Develop Research Methods for Studying Perceptions of Risk

The straightforward approach to assessing the public's risk perceptions is to elicit risk estimates that can be compared with the best available technical estimates; discrepancies are interpreted as measuring the respondents' ignorance. Although direct, this research strategy prejudges a variety of empirical issues in ways likely to increase the public's apparent stupidity. As a step toward developing more sophisticated methods, these assumptions need to be explored. They include: (a) People are able to translate their knowledge into whatever terms interest the interviewer. Will alternative formulations using more comfortable terms nable people to acquit themselves better in expressing what they kr w? (b) Providing summary statistics is the only way to demonstrate competence. Would proficiency in describing "the maximum credible accident" or the range of ameliorative strategies be a better test? (c) The public has concentrated on the same aspects of risk as the experts. Does their expertise lie in assessing personal risk, rather than risk to the U.S. adult population? Do they worry about catastrophic potential and morbidity, rather than yearly fatalities? (d) Errors reflect poorly on lay people's intellect. Is inaccuracy due to the quality of the information provided by the media and expert testimony? Investigating these issues is essential to understanding what people know and how to go about helping them to know more.

Survey Public Perceptions of Risk

Once developed, improved methods for studying risk perceptions should be applied to both the general population and special-interest groups. Surveys of the former would show ambient levels of interest and knowledge; studies of the latter would show the potential for understanding. Only these studies will allow statements regarding the public's phenomenology of risks. What do people know? What information do they want? What sources do they trust? What does "risk" mean to them? How are their priorities established? How do they define terms like an event, responsibility, foreseeability, controllability, voluntariness? Where do they need help? Where could their perspectives enrich or supplant those of experts?

Develop Educational Procedures

When it can be established that people need to know more, education is needed. People most readily change their minds when given clear-cut evidence, from credible sources, expressed in psychologically meaningful terms. Procedures for providing such evidence need to be developed, based on the products of the research described in the two previous sections. Among the special groups for whom curricula are needed are: workers exposed to occupational hazards, science writers, prescription drug users, and young people (perhaps focusing on recreational drugs and contraception). Given the deep-seated nature of cognitive processes, starting young may provide the best hope for inculcating the intellectual skills for understanding risks. Given the important role of expert judgment, techniques should be developed to help experts make better use of what they know. As with any other study of human behavior, educational research could be used to enhance the public's decision-making ability or to exploit its weaknesses for manipulative purposes. Researchers here have an obligation to provide convenient guides alerting people to how messages about risk can be distorted.

Discover What Decision Makers Believe about the Public

Many risk decisions are founded upon policy makers' images of what worries the public. The accuracy of these images constrains the fidelity of their service. Misperceptions about specific public perceptions may lead to misguided policies. An overall misunderstanding of how much (or little) lay people know may distort the role afforded them in the political process. Research is needed into both what the decision makers know about risks and what they think the public knows, followed by educational efforts on both topics.

Research to Reduce Uncertainty about Decision Quality

Each approach to acceptable-risk decisions envisions wisdom about risk issues as emerging from a particular source, the educated intuitions of substantive experts, the synthetic recommendations of normative experts, or the natural functioning of historical processes. Understanding how these sources function would provide a general guide to the credibility of the decisions they produce.

Table 10.5

Research to Reduce Uncertainty about Decision Quality

Study subjective aspects of professional judgment

- Identify where subjective elements enter professionals' decisions
- Assess size and direction of potential biases

Improve the accountability of formal analysis

- Develop professional standards and evaluation tools
- Assess the quality of existing analyses to establish track record

Clarify the effectiveness of market mechanisms

- Assess the validity of perfect-market assumptions in acceptable-risk cases
- Assess the threat that failure of these assumptions poses to the interpretation of market data

Clarify implementation of proposed decisions

- Characterize changes in options due to exploitation of loopholes and ambiguities
- Anticipate side effects

Study Subjective Aspects of Professional Judgment

Professional judgment enters the decision-making process in three ways: filling in missing data, deciding what the client wants, and defining the problem. Roughly speaking, these judgments belong, respectively, to the domains of fact, value, and the meeting ground of fact and value. Research into the first of these topics was discussed earlier; the latter two are addressed here.

Professionals can represent their clients' interests only to the extent that they understand what those interests are. With vague mandates, labile values, and competing interests, more than one interpretation of those interests is often possible, facilitating intrusion of the professionals' own values, either deliberately or inadvertently (when in doubt, do what makes sense to you). Systematic study is needed to identify the tradeoffs (e.g., between dollars and safety) implicit in professionals' decisions, followed by political analysis of their appropriateness. Analogous studies would look at the psychological and political processes involved as professionals derive a workable definition of hazard problems. What consequences do they consider and neglect? Where do they turn for advice on feasibility? What control strategies are they likely to ignore? In what ways are they the captives of untested theories or of the basic researchers' failure to study potentially useful topics?

Improve the Accountability of Formal Analysis

Any pursuit that fails to evaluate its own performance is likely to raise some suspicions. Technical risk analysis, like other forms of policy analysis, is often justified by claims like "we're doing the best we can," or "my clients like my work." The modest success of such arguments in forestalling criticism may reflect both their kernel of truth and the difficulty of providing more thorough responses.

The sophisticated evaluation methodologies of professions with similarly complicated problems, like psychotherapy, suggest that better answers are possible. One thrust of these methodologies is retrospective case studies. Was criticism solicited from other analysts? Were analyses updated to accommodate new information and insights? Were all relevant perspectives consulted? Were the technical details in order? The second thrust is to subject various forms of analysis to experimental tests of their effectiveness. These might involve standardization of techniques to facilitate comparisons, random assignment of problems to "treatment" by different techniques, or a deliberate effort to leave a clear audit trail and formulate recommendations that are readily evaluated. A third thrust is theoretical analyses regarding the vulnerability of the various analytic procedures to particular problems and their suitability to particular situations.

Clarify the Effectiveness of Market Mechanisms

The adequacy of both revealed-preferences approaches and cost-benefit analysis depends upon the adequacy of market mechanisms. Each assumes an unrestrained and responsive market populated by fully informed and "rational" decision makers, assumptions that are known to be somewhat inaccurate. Although there are theoretical reasons why some inaccuracy might be tolerable, it is unclear how badly the approaches are threatened by the failure of these assumptions. Research into the veracity of public risk perceptions is one key to this puzzle; studies of market concentration are another. Theoretical analyses are needed to assess implications of these and other empirical findings for the interpretation of marketplace data

Acceptable-risk debates often center around assertions about economic facts with a thin evidentiary base. Better studies are needed for questions like: Are people really unwilling to pay for safety (or have unpopular safety features been designed for rejection)? Do companies flee developed countries with strict environmental standards (or do they assume that developing countries will eventually adopt standards from the developed countries)? Have workers negotiated compensation for the risks they assume (or have their unions concentrated on other issues)? Do regulations tend to invigorate industries by prompting technological innovations (or do they give an undue advantage to larger firms, thereby reducing competitiveness)?

Clarify Implementation of Proposed Decisions

A recurrent source of uncertainty about the quality of decisions is what they will look like once implemented in the real world. Research is needed to clarify our chances of getting what we wanted or more than we bargained for. Presumptions about implementation that guide current practices are particularly worthy of study. For example, one such assumption is that as soon as rules are made, the affected parties begin to explore ways to ensure themselves maximum freedom and advantage. Reducing the opportunities for such creative interpretation is one argument for relying on technical rather than performance standards: Although they stifle engineering creativity, technical standards offer ready measures of compliance. Is this claim true? What opportunities are lost by adhering to it? Other researchable aspects of the ways that the results of acceptable-risk decisions get sidetracked include the opportunities for and effects of creative measurement of regulated pollutants (perhaps capitalizing on chance fluctuations), procrastination, nuisance litigation, and manipulating the definition of a technology (e.g., disaggregating a major technology into several smaller ones, each below the threshold of serious regulation).

Problems in implementation that might be studied, anticipated, and prevented can be expected to arise whenever acceptable-risk decisions confront other social systems. Some of the questions raised by confrontations include: What happens whe.. workers' rights to protection conflict with employers' rights to privacy? To what extent does allowing some pollution without penalty affect the property rights of the polluted? How serious are the threats to proprietary information caused by government reporting requirements? Does the protection of nuclear plants and materials really constitute a threat to civil liberties?

An Experimenting Academe

The projects described above demand a set of research skills beyond the capabilities of any individual scientist. A deliberate effort is needed to create a research community with the right mix of disciplines with basic and applied perspectives. The following recommendations are designed to help nurture that profession. Each constitutes something of a departure from current practices, suggesting the need for risk taking by academic organizations.

Broaden the ranks of the risk community. Few of today's "experts" in acceptable-risk decisions were trained in the field, simply because little such training was (or is) available. Rather, they were trained in traditional disciplines and drawn into the risk business through intellectual curiosity or involvement in some substantive problem. As a result, representation of different disciplines is rather spotty. To the extent that risk issues touch all of society, there is a role for members of all disciplines. Accompanying the invitation should be some warning to the effect that although acceptable-risk decisions are more similar to other complex social problems than has been recognized, they still hold some unique subtleties; even intelligent observers are unlikely to produce viable proposals from their first thoughts.

Create a profession of risk management. One reason why few people take the interdisciplinary plunge is that there are often rather meager rewards for doing so. University departments prefer people who can teach the traditional courses and be evaluated by the usual criteria. Joint appointments often leave one doubly orphaned. The notion that "those who can't hack it in basic research tackle applied problems" is widespread. The quality of some past interdisciplinary research has strengthened these views. At times, scientists have borrowed tools from other domains without the full appreciation of limitations that come from extended socialization in those areas. When scientists from different disciplines do work together, they may be tempted to oversell their own wares in order to get a hearing, particularly when corrective criticism from disciplinary colleagues is absent. Quality control problems are exacerbated by the dearth of systematic peer review for interdisciplinary and applied products. Although creating a profession with all the trappings (journals, appointments, standards, etc.) would not solve all of these problems, it could set things in a proper direction.

Involve representatives of different existing professions in the awarding and monitoring of research projects. Academic and research institutions typically evolve into a *de facto* hierarchy of disciplines, reflecting political clout. Real-life problems are often in the lock of just one discipline (e.g., economics, climatology) which is reluctant to share attention or resources. These stratification forces hamper the mutually respectful interaction between disciplines needed to understand complex issues. Little intellectual progress can be expected if, say, political scientists are invited only when toxicologists hope to add a touch of "social relevance" to their own fixed research agenda. One recurrent prejudice contributing to disciplinary imbalance is that technology holds the solution to economic health. A social scientist might believe that the most cost-effective way to increase productivity is to improve social control of existing technologies, thereby getting more out of the tools we have already. Mixing these positions may generate both heat and light.

An Experimenting Society

Acceptable-risk decisions are leading our society into a large, uncoordinated experiment with unprecedented stakes. It behooves us to learn as much as we can from this costly experience. Research is one strategy. Acknowledging the uncertainty in our actions and designing those actions for learning is another. Without such designs, it is difficult to tell what we are doing and what is happening to us; many factors vary at once, systematic data are not collected, processes are curtailed or redesigned in mid-stream, and so on. Even when the stakes would seem to preclude deliberate experimentation, our collective stake in learning may justify efforts like the following to see how far decision-aiding techniques can be pushed.

Perform model analyses. One lesson from the Reactor Safety Study is that massive investments of talent and resources can test, illuminate, and improve techniques. A comparable investment might show what, if anything, can be learned from other approaches when they are undertaken with maximal scope, opportunity for iteration, peer review, varied critiques, and so on.

Sponsor exemplary public participation processes. Clearly, half-hearted hearings with junior officials listening to poorly informed lay people may do credit to no one involved. Carefully designed and monitored efforts are needed to establish the potential of public participation when people are meaningfully involved in the earliest stages of problem definition, allowed to follow the process, and provided technical support.

Establish an "ideal" hazard monitoring system. The Food and Drug Administration, Consumer Product Safety Commission, Center for Disease Control, and Occupational Safety and Health Administration all have systems for detecting incipient hazards in their respective domains. Each is plagued, though, by problems like incomplete reporting, proprietary data, and ambiguous evidence. The potential and details of monitoring may be best understood by a concentrated effort. The workplace might be a likely place to try, since the risks are relatively high and those at risk are generally identifiable. Needed steps might include hiring industrial hygienists to screen workers, protecting companies from increased liability due solely to keeping better records, and concentrating on cases where workers are heavily exposed to hazards that may eventually reach the broader public in smaller doses.

Conclusion

Given the enormous stakes riding on acceptable-risk decisions, our investment in research seems very small. Considering the cost of a day's delay in returning a nuclear facility to service or in approving a pipeline proposal, a research project that offered a 0.1 chance of responsibly shortening the decision-making period would have an enormous expected return on investment. Similar bargains would be found in studies that might improve public involvement in project planning (so as to avoid mid-construction surprises), identify generic categories of new chemicals (so as to reduce testing costs), decrease the uncertainty in drug licensing (so as to encourage innovative research and development), or inform workers about occupational risks (so as to enable them to make better decisions on their own behalf). Such research could be a good place to invest society's venture capital.

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