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3

Hazard Management

Roger E. Kasperson, Robert W. Kates,
and Christoph Hohenemser

Hazard management is the purposeful activity by which society informs itself about hazards, decides what to do about them, and implements measures to control them or mitigate their consequences. Management is not the only way society deals with hazards; people adapt to hazards biologically and culturally over the long term and hazard control and mitigation often occur as incidental byproducts of other activities.

In the United States today, society's management of technological hazards is a significant undertaking. Chapter 6 reveals that technological hazards in the United States are associated with 20-30 percent of male and 10-20 percent of female mortality. Tuller (chapter 7) estimates federal, state, and local expenditures on hazard management at $99-132 billion in 1979, with another $80-150 billion accounted for by damages and losses. Later in the volume (chapter 19), Branden Johnson shows that between 1957 and 1978 Congress passed 179 laws dealing with technological hazards. Coping with such hazards, it is evident, is a formidable managerial task.

In the discussion that follows, we focus on society's management of technological hazards. We describe the principal participants in the management process, discuss the structure of management activity, identify major problems, and indicate ways of utilizing these concepts in the analysis and praxis of hazard management.

Major Participants in Management

Who manages technological hazards? Although it is increasingly common to think of managers as regulators, regulators constitute only one of several classes of managers. In all likelihood, private individuals make the largest management effort in the United States, and industry, rather than government, undoubtedly carries the principal institutional management burden. In our view, there are five major types of hazard managers:

- **Individuals.** Historically, individuals have been the principal managers of hazards. Despite an increasing government and industry role, they are still the prime managers of hazards. And for many hazards, the individual is the most appropriate point of control in hazard management and some means of control (e.g. hazard labelling) specifically recognize this.

- **Technology sponsors.** These are either governmental agencies or private firms that develop or utilize technology to provide goods and services. Their management activity is based on the traditional assumption that technology sponsors should act with sufficient restraint to avoid endangering the public. Thus, most technologies incorporate in their designs purposeful measures to prevent or reduce hazard consequences.
- **Policy makers.** Included are not only legislators and their staffs at all levels of government, but executive branch members. The latter include standard-setting groups that may be quite autonomous.
- **Regulators.** These are officials formally charged by society with identifying and controlling hazards. Since they have customarily evolved in patchwork fashion, they differ widely in authority, resources, and legislative mandates.
- **Assessors.** Included are technical experts who increasingly support decision makers in the hazard-management process. Most prominent in the United States is the National Academy of Sciences/National Research Council, which has conducted over 250 risk assessments during the past five years. But also included are large consulting firms (e.g., Arthur D. Little, MITRE Corporation, Battelle Research Center, Stanford Research Institute), the national laboratories, and the universities.

Looking over the shoulders of the hazard managers are the self-appointed **hazard monitors.** They sound an early alert to the public, influence the agenda of policy makers and regulators, and provide a political counterbalance to the technology sponsor. Recently, as hazard monitors have increasingly become a professional lobby, the lines between officially designated hazard managers and these self-appointed monitors have become increasingly blurred. Involved are two major groups:

- **Adversarial groups.** The growth of "public-interest," environmental, and consumer groups has been one of the most remarkable changes in the American polity during this century. With increased scientific and legal capability and with a growing specialization in expertise, these groups provide a significant monitoring network of technological risks.
- **Mass media.** As principal risk communicators to policy makers and the public, the mass media play an essential role in shaping society's response to technological risk. Through selective attention, the mass media influence greatly what will be society's worry-beads, those issues that will be extensively aired and fretted over while other problems are neglected. They also constitute an early "alert" system for outbreaks of consequences or managerial failures.

Three Theoretical Perspectives

Three broad bodies of theory, each with its own strength and insight, are available for assessing the management process. These are: conflict analysis, self-preservation and expansion, and hazard control as part of society's management of technology.

Since various interests have stakes in the decisions that occur over technologies and their hazards, it is possible to conceive of the management process primarily as social conflict and to view decision making as conflict resolution. This perspective has a broad range of theory, from the materialist conceptions of Hobbes, Hegel, and Marx to modern theories of psychological aggression (Rapoport 1974). Political applications often define entities (such as industry, environmentalists), rather than individuals, as the conflicting parties and go on to assess the sources and objectives of conflict. One specific mode of analysis views conflicts as rational interactions, thereby permitting the application of bargaining and game theory to decision making; yet another sets forth theories of community decision making, elitist and pluralist.

Overlapping with the above is an approach that focusses not on the broad array of societal conflict but on those charged with management responsibility. Again, entities, or actors, must be defined, but this approach often disaggregates the entity into its component parts to understand why a manager, such as a government agency, takes a certain position. In such theories (e.g., see Blau and Meyer 1971;Crozier 1964), the management process is as much oriented to the political goals, systems of rules, organizational structure, and relationships to clients of the manager (as noted particularly by Weber and Mill) as to the responsibilities (e.g., controlling hazards) of the manager.

The third perspective, that adopted in the discussion to follow and emphasized throughout this volume, views management in a functional way, as a predominantly rational set of activities related to certain societal objectives. Regardless of the mix of motivations and sources of behavior, one can evaluate the manager in terms of performance on these objectives. This approach recognizes that the hazard control function occurs in the context of technology management as a whole, for hazard management is inextricably linked to the management of technological benefits a well as to broader societal goals.

All three perspectives must enter into a full understanding of how society responds to technological hazards. By adopting the third perspective for conceptualizing hazard management, we simply acknowledge that our results sketch one "face" of society's responses.

Managerial Activity

Hazard managers and monitors have two essential functions, intelligence and control. Intelligence provides the information needed to determine whether a problem exists, to make choices, and to assess whether success has been achieved. It is partly prospective in that the manager must identify and interpret hazards before the consequences are experienced and partly retrospective in that the effectiveness of control efforts must be evaluated. The control function consists of designing and implementing measures aimed to prevent, reduce, or redistribute the hazard, and/or to mitigate its consequences.

At any moment in time, the seven groups of managers and monitors are busily engaged in different aspects of intelligence and control. A large chemical company is testing the hazardousness of the thousands of chemicals it annually screens, the Consumer Product Safety Commission is monitoring accidents from consumer products as reported by 74 hospital emergency rooms, and the American Conference of Governmental Industrial Hygienists (ACGIH) is busily revising its threshold limit values (TLVs) for several hundred chemicals found in the air of factories and laboratories.

For any specific technological product or process, hazard management may be described, in simplified form, as a sequence of activity beginning with the identification of a hazard and assessment of its risk and concluding with efforts to control or mitigate the hazard (see chapter 2). To conceptualize this process, we begin with the causal structure of hazard (as outlined in chapter 2), extending from human needs and wants through choice of technology, to eventual human and biological consequences. In terms of this chain, management seeks to alter the flow of events in order to reduce or eliminate harmful consequences. The stimulus for such alteration may be multifaceted, but it generally originates in experienced or predicted events that lie downstream in the causal chain. Following a stimulus, management proceeds through a set of societal choices and actions that eventually produce a control intervention. Chapter 2 described this process as "negative feedback" and illustrated with several examples. In this chapter we go beyond the topology of feedback to inquire into the nature and content of managerial activity.

Figure 1 depicts the management process as a loop or cycle. In the center of the diagram, the structure of technological hazards is portrayed as a linked causal chain, through which the deployment of technology may cause harmful consequences for human beings and their environment, economy, and society. Four major managerial activities—hazard assessment, control analysis, strategy selection, implementation and evaluation--surround the chain. Each of these major activities characteristically involves normative judgements concerning scientific knowledge or social values, as illustrated, for example, by assigning priorities, judging tolerability, or allocating the risk.

This schematic diagram is, of course, an idealization and simplification of a process that in reality may not be linear. Each activity may occur in an order different than that diagrammed in Figure 1. It is not unusual, for example, for initial control actions to be instituted prior to a thorough assessment of the hazard. Nevertheless, Figure 1 provides a useful template for organizing an overview of management activity, to which we turn next.

Hazard Assessment

Hazard assessment is a least a four-step process involving hazard identification, assignment of priorities, risk estimation, and social evaluation.

Hazard Identification. Hazard managers do not like surprises. What is unacceptable, indeed downright dangerous, to the

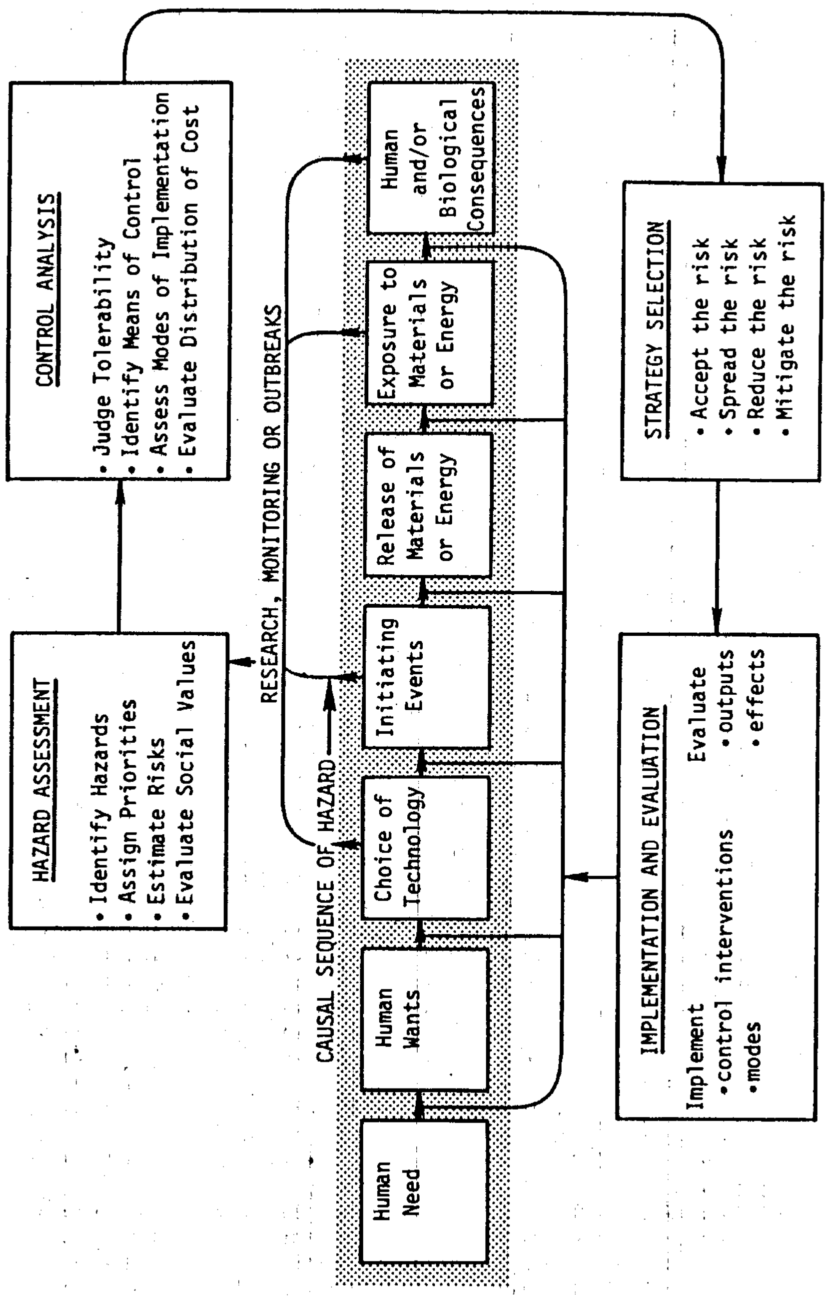

Figure 1. Flow chart of hazard management.

continued well-being of the manager is to miss the existence of a hazard completely. Hazard managers have available to them a variety of methods for identifying hazards, including research, engineering analysis, screening, monitoring, and diagnosis (chapter 11). Some of these sources of information are incidental to hazard identification: thus, new carcinogens may be found as byproducts of cancer research, product failure mechanisms may be recognized in engineering analysis performed for other reasons, and surprise hazards emerge as outbreaks or clusters. Other sources of information are the product of purposeful efforts: thus, screening of chemicals provides early warning of toxicity, and environmental monitoring of pollutants affords estimates of potential health effects.

Despite the availability of this broad range of information and continuous rapid improvement in scientific capability, the present system of hazard identification is far from perfect. Entire classes of hazards may go undetected because there is insufficient initial suspicion to conduct the necessary analysis. On the other hand, escalating monitoring capability is leading to information overload in which society is confronted with more ambiguous warning than it can comfortably digest. Perhaps most important, the current system of identification provides data largely on physical, health, and ecological effects, while neglecting all but the most obvious appraisals of mental health, social impacts, and political consequences.

At the same time, the scientific capability for hazard identification and measurement has improved remarkably. That progress is Janus-faced, however, for it places ever larger demands on the whole complicated intelligence apparatus that results. The growing capacity to identify potential hazards, in short, threatens to overwhelm the more limited societal capability to respond.

Despite an enlarged capacity, some technological hazards escape timely identification, of course, and become known through outbreaks or experienced consequences. Thus, the threat of buried chemical wastes at Love Canal was unrecognized until severe winter storms raised the water table and injected noxious chemicals into the basements of residences (Ember 1982). And the recognition that anxiety was the most serious consequence of the Accident at Three Mile Island came only months after the event that produced it (U.S. President's Commission on the Accident at Three Mile Island 1979).

In such cases, vigilant monitors often act as hazard identifiers, bringing such events to the attention of society and demanding action. Outbreaks are unwelcome news for both the technology sponsor who has a substantial stake in the product and the manager who "missed" the hazard. Despite the publicity that surrounds such events, evidence exists that suggests that hazard identification is becoming more rather than less effective over time and relatively few hazards are escaping the various identification systems (Kasperson 1977;Lawless 1977).

Assigning Priorities. Hazard managers cannot, of course, deal simultaneously with all identified hazards within their domains of responsibility. Somehow the hazard domain must be ordered and priorities attached to the many candidates competing for managerial attention. There are choices to be made--choices between hazards with better known acute consequences or poorly understood chronic consequences, or choices between attending to serious hazards with

few available sources of control or lesser hazards with effective available means of control. The criteria for establishing priorities are laden with value considerations: Is it the aggregate risk or the distribution of risk that is more important? Should ecological risk receive lower priority than health risks? Should children enjoy a higher priority for protection than adults? Should present generations be valued higher than future generations? Inevitably, establishing priorities requires trading off some values to achieve others. Perhaps one of the most value-laden decisions a hazard manager, or monitor for that matter, makes is the initial one of what to work on.

Yet it is often political pressures rather than value conflicts that shape priorities. In its analysis of chemical regulation in the United States, a National Research Council (1975,33) study concluded rather pessimistically that "stories in the morning newspaper probably have more impact on what decisions come before the agency head than most internal agency processes of problem identification or priority-setting."

Crisis management, involving as it does case-by-case response, undermines hazard management because the domains involved are enormous in extent and heterogeneity. The Toxic Substances Control Act, for example, charges the Environmental Protection Agency (EPA) with the formidable task of screening the 70,000 or more chemical substances now in commerce and the thousand or so entering the market each year. Just keeping up would require (EPA) to rule on four new chemical applications every working day--clearly an impossible task (Culliton 1979). In fact, taken together, all federal agencies in the United States had, by the end of the decade, issued regulations to stop or reduce exposure to fewer than 30 carcinogenic substances, yet some evidence of carcinogenicity has been found for about another 400 chemicals (Carter 1979). And even many of these actions are quite incomplete. Although PCBs have recently been banned (see chapter 15), for example, there is still no comprehensive national program that deals with the 750 million pounds of PCBs already in existence.

The Consumer Product Safety Commission (CPSC), as discussed in chapter 16, provides a clear example of how things can go wrong in the absence of clear priorities. The Commission oversees annually a hazard domain that includes some 2.5 million firms, more than 10,000 products, and some 30,000 consumer deaths and 20 million consumer injuries. The CPSC compounded the problem of limited resources by failing in its early years to set clear priorities for action. By dispersing its efforts indiscriminately, the Commission produced regulations that fluctuated erratically between serious and trivial hazards. By 1981, the Commission was beginning to fashion more effective managerial approaches (especially in regard to chronic hazards), but it then encountered the antiregulatory efforts of the Reagan administration.

The message is clear. Effective hazard management requires a well-ordered risk domain. Taxonomic analysis, as described in chapter 4, can assist in that process of ordering. But since creating such a structure is intrinsically normative as well as scientific, it should be rationalized openly and in consultation with the various interested parties.

Estimation and Social Evaluation. Once a hazard has been identified, the next steps in assessment are: (1) to estimate and characterize scientifically the probabilities of specific events and related consequences and (2) to evaluate this characterization in social terms. In the view of many professional managers the steps are separate and distinct. These managers look to scientific experts to estimate the risk of death or injury, while searching their consciences or deferring to the political process for social valuation.

Unfortunately, there is no simple relation between scientifically estimated risks of death and injury and the social valuation of a given hazard. In fact, much to the chagrin of many scientific risk analysts, the public apparently does not respond equivalently to equal threats of mortality. A high mortality hazard such as an auto accident provokes relatively little fear, whereas some low mortality hazards (e.g., botulism or nuclear power) evoke great anxiety. A great deal of confusion and conflict in hazard management arises from this conundrum.

As shown by Slovic and colleagues in chapter 5, understanding the quixotic nature of the social valuation of hazards requires consideration of risk attributes other than mortality levels. Using cognitive data obtained from several lay groups, these authors have shown that the degree of dread (also termed the perceived risk) that people report vis-à-vis a given hazard includes such attributes as whether the hazard is voluntary or involuntary, new or old, prompt or delayed, or kills many or few at a time. Similarly, in a multivariate taxonomy of hazards based on characteristics of the causal sequence (see chapter 4), an appreciable fraction of the perceived risk measured by Slovic and collaborators can be explained only if a wide range of physical and categorical characteristics are included. In short, explaining the risk perceived by lay groups through mortality alone fails no matter how one approaches the problem.

The implications of these findings for management are far-reaching; unless scientific risk assessment embraces the full range of consequences that enter into the public response to hazards, the conflict between the scientific analysis of hazards and their social valuation will certainly continue.

Beyond the question of how best to characterize hazards, assessment presents other serious problems for the management process. There is the recurrent need to attend to secondary and tertiary effects, or, equivalently, to define the full range of possible consequences. A nuclear accident, for example, may produce fatalities, injuries, property damage, and a high level of anxiety. But it can also lead to regulatory change that results in subsequent shutdown of all similar plants, producing disruption, further anxiety, and possible power outages. Such secondary consequences are rarely predicted and infrequently analyzed, even though in many cases they are the most important consequences of a particular event (as at Three Mile Island).

Finally, hazard managers must deal with uncertainty which confounds nearly all estimates of hazard characteristics. Uncertainty arises because characterizing hazards involves extrapolation. Some hazard characteristics may be extrapolated from previous human experience; others require extrapolation from experience with animals; others from analogous events or technologies, and still others may only be calculated theoretically, without direct basis in experience. In some cases, such as the nuclear reactor accident risk, the level of uncertainty is so great the even the best risk assessment, such as the Reactor Safety Study (Nuclear Regulatory Commission 1975), fails to provide an adequate basis for regulation.

Control Analysis

Following the risk assessment, control analysis judges the tolerability of the risk and rationalizes the effort that is made in preventing, reducing, and mitigating a hazard.

Judging Tolerability. The key link between hazard assessment and subsequent initiation of control actions is the judgment of whether a hazard is tolerable or not. One of the most perplexing issues facing hazard managers, it has been mislabeled the acceptable risk issue (Kasperson and Kasperson 1983). It is unlikely that any risk is "acceptable" if it is unaccompanied by benefits or is susceptible to easy reduction. Acceptability, in its strict dictionary meaning, bespeaks consent and this is seldom realized. Many risks are imposed upon individuals, often without warning or information. Such risks are better thought of as "tolerated;" they are suffered in practice, not accepted.

Fischhoff, Slovic, and Lichtenstein (chapter 12) discuss four methods of judging the tolerability of hazards: **cost/benefit analysis, revealed preferences, expressed preferences,** and **natural standards.** According to these methods a technology is deemed safe or tolerable if, respectively, its benefits outweigh its costs; if its risk are no greater than those of historically tolerated technologies of equivalent benefit; if people, when asked, say the risks are tolerable; and if its risks do not exceed those fixed by nature through the process of evolution. These methods of tolerable risk judgments are often in conflict, particularly the results of risk/benefit analysis and revealed preferences on the one hand and expressed preferences on the other.

In the hope of refocussing the debate on the level of risk rather than on unresolvable questions of values, a number of risk analysts (e.g., Okrent 1980;Starr and Whipple 1980;Deisler 1982) have called for quantitative risk standards. Yet clearly this problem of the hazard manager remains unsolved, for there is no adequate synthesis of the many ways of looking at the problem. If anything, a full accounting of the approaches to tolerable risk adds further complexity.

Table 1 provides a broader categorization of methods of determining tolerable risk. The three groups classify tolerable risk judgments according to whether they rely on historical experience, direct expression, or formal analysis. This division, includes **legal precedents** and **incremental decision making** as methods dependent upon historical experiences; **expressed judgments** of professionals, decisionmakers, and interest groups as approaches involving direct expression; and **risk comparisons** and **decision analysis** as methods involving formal analysis.

Whichever methods are used, the judging of risk tolerability employs basically four types of criteria. In the first, **risk aversion**, any level of risk is considered intolerable, either

TABLE 1
Approaches to determining tolerable risk

TYPE OF METHOD	DESCRIPTION
METHODS INVOLVING HISTORICAL EXPERIENCE	
Legal precedents	Judgments are guided by existing legislation and court decisions
Incremental decisions	Judgments are made in small increments following the pattern of earlier incremental decisions.
Revealed preferences	Risks are deemed tolerable if they are comparable to the risks of established technologies with comparable benefits.
METHODS INVOLVING DIRECT EXPRESSION	
By professionals	Judgments are made by professionals or groups of professionals with expert knowledge (e.g., doctors).
By decision makers	Judgments are made by public officials, technology managers, and others with responsibility (e.g., the commissioners of the Nuclear Regulatory Commission).
By interest groups	Judgments are expressed by groups representing a well-defined interest relative to the hazard (e.g., the National Rifle Association).
By lay persons	Judgments are expressed by laity through voting or survey instruments.
METHODS INVOLVING FORMAL ANALYSIS	
Risk comparisons	"Tolerability is judged by comparing risks to standards, such as publicly agreed on quantitative risk standards, or "natural background."
Risk/benefit analysis	Tolerability is determined after comparing risks and benefits in commensurate units.
Decision analysis	Risk decisions are made after formal disaggregation into a sequence of choices.

because of the nature of the product, its use, or its consequences. Thus we ban biological weapons, the use of chlorofluorocarbon aerosols, thalidomide, DDT, food additives that exhibit carcinogenicity in animals, or a government-sponsored construction project that endangers an entire species. Risk aversion is drastic and is applied sparingly.

The other criteria all involve some type of comparison: of risks, of ways of reducing risks, of risks and benefits. By the second criterion, the projected risk level is compared to other prevalent risks (often with the assumption that risks should be balanced). Typically the comparisons are with natural background levels (or some fraction thereof), with similar technologies, with other risk stages of a fuel or production cycle, or with risks previously determined to be tolerable by a given risk manager. In the British chemical industry, for example, if a particular activity contributes more than 4 fatalities to the fatal accident frequency rate (FAFR)--the number of fatal accidents in a group of 1,000 men in a working lifetime (100 million hours)--risk reduction is undertaken (Kletz 1977). Several well-known, and oft-criticized, sets of comparisons are those of Wilson (1979), Cohen and Lee (1979), and the Reactor Safety Study (Nuclear Regulatory Commission 1975).

The third criterion focuses on the cost-effectiveness of risk reduction. The question at stake is how much society wishes to spend to avoid a particular consequence. It is well known that such expenditures vary widely. In Britain $2,000 was spent in 1972 to save an employee's life in agriculture, $200,000 in steel handling and $5 million in the pharmaceutical industry (Sinclair, Marstrand, and Newick 1972). Chapter 14 compares controls for reducing auto accidents in terms of average investment per fatality forestalled. Costs range from $500 for enforcing mandatory seat belt usage to $7.6 million for road alignment and gradient change.

Perhaps the most widely approved criterion is some mode of comparison between risks and benefits. This method recognizes as necessary some level of risk above zero and balances the benefits of the activity or technology against the risk to determine how much risk reduction should be undertaken. Benefit/risk analysis is essentially a subset of benefit/cost analysis, since risks are a component, often the principal one, of social costs. The quality of such analyses depends on such factors as the messiness of the problem, the skill of the analyst, the way in which the analytic question is posed, the existence of appropriate techniques, and the analyst's ability to fashion new ones (Fischhoff 1979).

None of the criteria treated above deals adequately with equity issues in hazard management. Characteristically those who enjoy the benefits of a technology or product are not the same as those who experience the risks. Risks are also seldom distributed evenly throughout society nor are they always confined to the present generation. Attempts to control risks often benefit groups different from those who pay for the controls.

Three major types of inequity, in our view, require analysis (Kasperson 1983). First is inequity among social groups. The adverse side-effects of technology are often concentrated in weak and powerless people. Nowhere is this more apparent than in the workplace where higher exposure standards are tolerated than those which protect the public generally (Derr et al. 1981). Second is the inequity among regions. This problem is apparent in the political controversy surrounding the location of noxious facilities, such as airports, prisons, chemical waste dumps, and dog tracks. Finally, there is inequity among generations. Increasingly there is concern over the risks that may be exported to future generations, particularly if the effects are irreversible.

Few hazards are judged tolerable. How much effort should be expended to control them is determined partly by the value judgment of relative tolerability and partly by the means of control available for preventing, reducing, or mitigating the hazard.

Identifying Means of Control. For identifying means of control, the causal structure of the hazard becomes the central concern. For many cases the use of simple causal chains (chapter 2) suffices. Complex cases require a full fault- or event-tree analysis. Whether simple or complex, an analysis of causal structure must be broadly based and include potential control actions that span the range from human needs and wants to exposure, consequences, and mitigation of consequences. To this end, it is useful to contemplate the control structure for the traditional technological hazard, the simple fireplace, discussed in chapter 2 and represented in Figure 2. Generalizing from Figure 2, within the seven-stage model of causal structure, the potential control actions include: (1) modify wants; (2) choose alternative technology; (3) prevent initiating events; (4) prevent releases; (5) restrict exposure; (6) block consequences; and (7) mitigate consequences.

In contemplating a given control intervention, it is important to recognize its potential to create new hazards. Chapter 2, under the general heading of positive feedback, describes a variety of examples, which demonstrate that ill-conceived hazard control can make things worse and surely accounts for some of the current skepticism toward government regulation of risk.

Modes of Implementation. In addition to identifying the technical means of control, each control action can be implemented in a number of different ways. There are, in our view, three major modes of inducing society to undertake the control action (Table 2). Society can: (1) **mandate** the action by law, administrative regulation, or court order and thereby ban or regulate the product or its use or distribution; (2) **encourage** the action through persuasion or by providing incentives, penalties, or insurance; or (3) **inform** those creating or suffering risk, allowing them voluntarily to reduce or tolerate the hazard. At any moment all of these modes may be utilized in connection with a specific hazard. Thus, as described in chapter 14, the hazard of driving is controllable by 37 different "highway safety countermeasures" and a comparable number of vehicle safety standards, each involving one or more stages of the causal structure of the hazard. For any given case, a lively ideological debate may erupt over which implementation modes are the most desirable.

Cost Analysis. An important aspect of control analysis is to inquire into the relative cost of control interventions (be they technical, behavioral, or informational) and modes of implementation. Known as **cost-effectiveness analysis**, this approach permits the hazard manager to select the most efficient actions available (Schwing 1979). Cost-effectiveness varies widely, both between actions employed for different hazards and for different actions

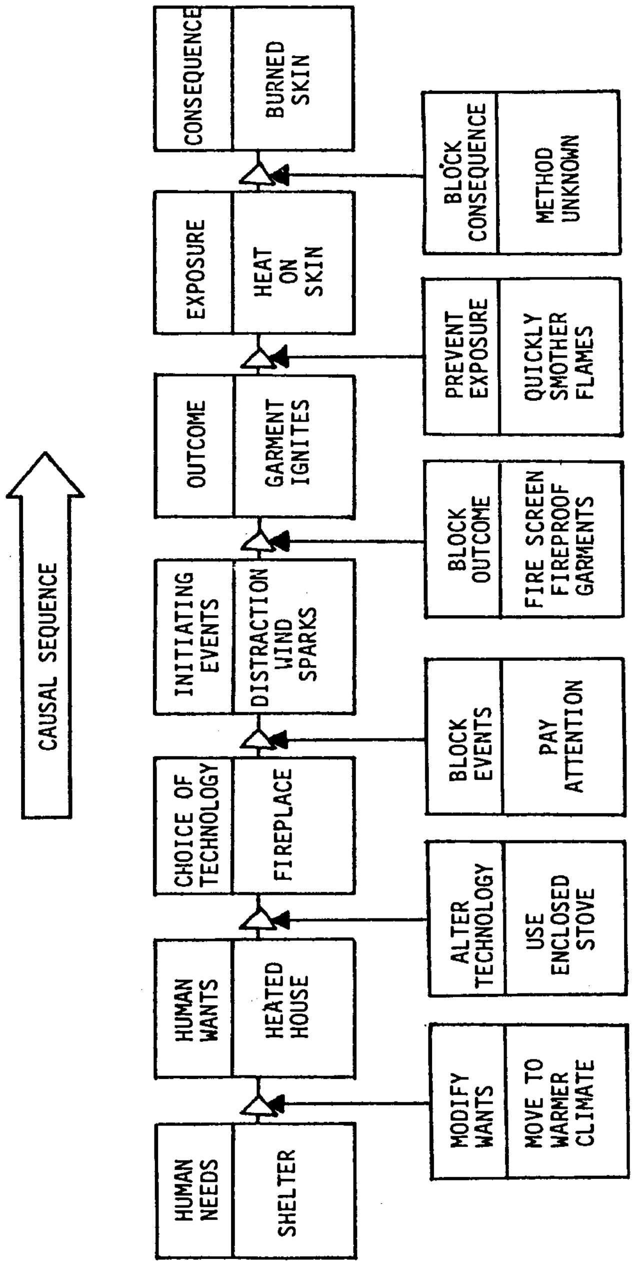

Figure 2. Seven-stage expansion of the hazard sequence, illustrated here for the case of the fireplace. Note the range of possible control interventions.

TABLE 2
Modes of implementation

MANDATE
Ban the product or process
Regulate the product or process (e.g., performance and design standards; use and dissemination restrictions)

ENCOURAGE

Seek voluntary compliance
Provide incentives (e.g., credits or subsidies)
Penalize through indemnifying those harmed
- via the market (wages)
- via the courts (award damages)
- via transfer payments (taxes)

Provide insurance

INFORM

Inform hazard-makers (by monitoring and screening)
Inform those at risk (e.g., by labeling, advertising campaigns)

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applied to the same hazard. Wilson (1975) for example, has estimated that the United States in 1975 expended $1,000 for avoiding a death in the liquefied natural gas industry, as compared to $750,000 for nuclear power. Similarly, as noted earlier, alternative control actions for highway safety in the United States had costs per fatality forestalled ranging from $500 to $7.6 million in 1976 (chapter 14).

Selecting a Management Strategy

Equipped with a hazard assessment and a control analysis, and assuming the risk has been judged intolerable and thus requiring action, the manager next must designate a hazard management strategy, consisting of an overall management goal and a package of control measures designed to achieve the goal. The control package will specifically include both control interventions (oriented toward the causal structure of hazards) and modes of implementation (oriented toward alternative institutional means for control). Four possible management goals—**risk acceptance**, **risk spreading**, **risk reduction**, and **risk mitigation**—can drive management strategy.

Risk acceptance may be achieved by providing compensation, as through higher wages for riskier work, or by seeking informed consent, as in informational or warning labels on hazardous products. The purpose of the latter is to make the risk more voluntary by enlarging information related to technology choice. It applies to a broad range of hazards, including hazards with very large numbers of associated fatalities. Thus, risk acceptance is the basic

strategy (however imperfect) for society's effort to manage the 300,000 cigarette-related deaths each year.

Risk spreading seeks to transform a maldistribution of risk into a more equitable one, through redistribution of the risk over social groups, regions, or generations. The new distribution may also seek to equalize experienced risk, to make risk concordant with benefits or with the ability to bear risk. An interesting example of risk spreading is the introduction of tall stacks to transform a local pollution problem into a regional one. Here, by all appearances, the principal regional hazard, acid rain, was initially unsuspected, and only at a later time became recognized as a serious ecological and health threat.

Risk reduction, in contrast to spreading and acceptance of risk, involves decisive intervention in the causal sequence of hazards. It is therefore a step that may in some circumstances curtail the benefits of technology. An extreme case of reduction is aversion, as exemplified by the total ban of a technology. Whereas risk reduction is widely regarded the dominant mode of risk management, aversion has been practiced only in a few cases, as in the banning of the domestic uses of DDT and carcinogenic food additives.

Risk mitigation includes a variety of ways of modifying hazard consequences once they have occurred. Typical actions include disaster relief, medical intervention, family assistance, and compensation through insurance or other means. Risk mitigation is often an initial societal response when risks have not been anticipated or when the causal chain of the hazard is poorly understood, as exemplified by the thousands of court cases now pending against asbestos manufacturers.

Although presented here as an integrated managerial approach, strategies usually develop piecemeal, frequently lack internal logic, and may appear only through trial and error over time. However they develop, they must eventually strike a balance between reaping technological benefits and reducing unwanted risks. Control actions will range along the causal chains of hazards, reflecting optimal points of intervention. Thus, for control of cigarette smoking, an addictive activity that society regards as tolerable, upstream intervention (banning the manufacture and/or sale of cigarettes) would be effective, yet unacceptable. In contrast, for preventing the disruption of the ozone layer, a feared and intolerable consequence caused in part by a minor technology (aerosol cans), upstream intervention based on banning is both reasonable and acceptable. For most hazards, midstream and downstream strategies of intervention are appropriate. They interfere less with benefits and can be directed at specific targets. Typical of such interventions are the use of filters on cigarettes and the wearing of seatbelts in cars. Neither strongly affects the benefits, and each reduces hazard consequences. When the causal structure is poorly understood and unpredictable, society by necessity concentrates on mitigating consequences. An example of this is the case of environmentally caused cancer, where both agents and mechanisms are to a large extent unknown, if not unknowable.

A **mature** hazard management strategy is one which over time steers an optimal path between realizing technological benefits and reducing unwanted risks. It will normally employ a complex set of interventions along the hazard chain and utilize a variety of managerial modes of implementation. Such a system evolves partly through improved knowledge and partly through trial and error.

This concludes the sequence diagrammed in Figure 1. But effective hazard management follows up these control efforts with determined implementation and retrospective evaluation. Such evaluation includes monitoring of the control actions for their effectiveness and vigilance for unexpected surprise impacts that may occur.

Implementation and Evaluation

Implementation. The sequential flow of hazard management, in the idealized form presented herein, concludes with the implementation of management strategies, the "packages" of selected control actions and implementation modes designed to advance a designated management goal. As indicated in Figure 1, each of these is intended to block or modify one of the pathway links that govern the evolution of a hazard.

Implementation is a crucial and oft-neglected stage of hazard management. The lengthy review by the National Research Council (1977,36-41) of the performance of the U.S. Environmental Protection Agency indicates why control actions often fail at the implementation stage. First, administrative resources are often inadequate, particularly in a decentralized system where lower administrative levels face large enforcement burdens. Thus, states often lack the necessary technical and financial resources for monitoring and testing pollution or even issuing permits. Second, as suggested in our initial discussion of major theoretical perspectives, those charged with implementing health and safety control actions are often reluctant to do so because implementation conflicts with their own organizational and political interests. Third, hazard management strategies always contain implicit notions as to how hazard makers can be induced to take control measures. If the assumptions as to inducements are incorrect (as occurred in delay of water pollution control efforts), implementation fails. Finally, where managers lack monitoring and surveillance resources in their intelligence function, implementation becomes dependent on reports furnished by hazard makers and compliance becomes unreliable.

A number of these problems are evident in the control of PCBs, as discussed in chapter 15. Three years after the passage of PCB control regulations, the EPA inspection program may be missing as much as 80 percent of PCB facilities and the inspection priorities program may be missing major users because the program lacks resources and sufficient regional sensitivity (U.S. General Accounting Office 1981). Further, the penalties for noncompliance have lacked adequate deterrent value and have failed to produce widespread voluntary compliance. Finally, EPA oversight and informational systems have been inadequate to target enforcement priorities. Quite similar problems pervade the efforts of the Occupational Safety and Health Administration (OSHA) to implement its enabling legislation, specifically to effect compliance with occupational health and safety regulations (Mendeloff 1980,151-167).

Evaluation. Hazard management is not complete even when controls are implemented. Effective management requires continued monitoring of control effects reviewing the adequacy of control intervention in light of evolving knowledge and checking for the creation of new hazards.

Following Levy, Meltsner, and Wildavsky (1974), we recognize two classes of results of management actions: **outputs** and **effects**.* The theory of public policy has viewed outputs as the goods and services produced by government. **Outputs** in our usage refer to the concrete results of management efforts; thus they comprise the various interventions into the causal sequence of hazard and the associated modes of implementation. **Effects**, by contrast, are the "so-whats" of hazard management. They refer to the results, wrought by these actions, as determined by the application of social values. Put another way, effects are the consequences of outputs, the overall impacts upon society's experience of the hazard. Output analysis, then, is primarily descriptive and empirical, whereas effect analysis is primarily normative.

Output Analysis

Using the causal chain of hazard, it is possible to map the distribution of managerial effort and thereby to evaluate the breadth and timing of control actions. A level-of-effort map requires output indicators, such as work-force or budget allocations, the number of regulatory standards issued, or, as in chapter 19, the number of laws enacted. Effort maps illuminate the differences between theory and practice, the imbalance between upstream and downstream control interventions, and the change of effort by hazard stage over time. Effort maps lead naturally to a number of evaluative questions: Is the distribution of effort appropriate for the physical nature of the hazard, the perception of managers, the mandate of history, and the evolving understanding of the hazard?

To illustrate, we show in Figure 3 the distribution of regulatory guides, issued through 1975 by the Nuclear Regulatory Commission, on the question of reactor safety. Of the 95 guides issued, 63 focussed on initiating events, 29 on outcomes, 3 on consequences, and none on mitigation. Since Three Mile Island, consequence mitigation (e.g., emergency-response plans) has belatedly become a major priority. Via our level-of-effort map, we were able to recognize this need in 1976 (see chapter 10). A similar management-effort map, shown in Figure 4 (top), which categorizes highway safety standards issued by the U.S. Department of Transportation (see chapter 14), shows that 81 percent of the standards fall into the class of blocking initiating events, with little activity downstream. In contrast, a landmark highway safety report (U.S. Dept. of Transportation 1976) places 40 percent of potential activity downstream from initiating events (Figure 4, bottom).

It is also possible to construct effort maps as a function of time. In the case of auto-safety management (Figure 5), except for medical care administered to crash victims, the dominant early modes of management occurred far "upstream" in the causal sequence of

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*Levy, Meltsner, and Wildavsky speak of outputs and **outcomes**. To avoid confusion with our usage of **outcomes** in the causal model (chapter 2), we substitute the term **effects**.

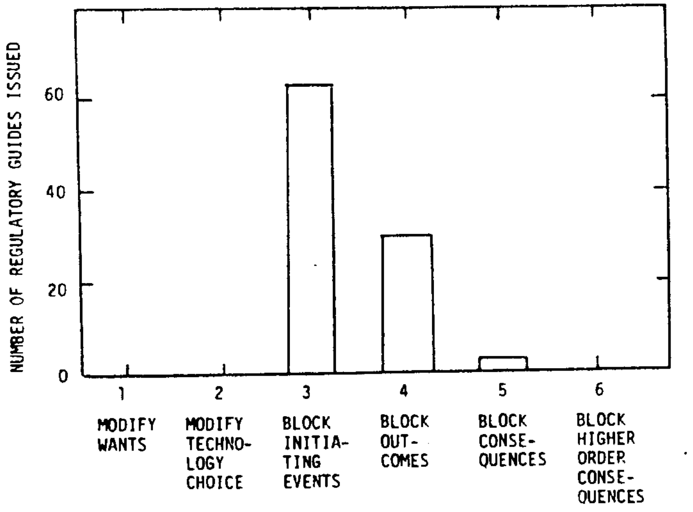

Figure 3. Number of Regulatory Guides by hazard stage, as issued by the Nuclear Regulatory Commission through 1975. Note the imbalance of regulation affecting upstream location and the near lack of regulation addressed to downstream stages.

hazard. The attempt to block injuries (that is, first-order consequences) once crashes have occurred is a rather recent development. In the case of Minamata disease (Figure 6) a diametrically opposite response pattern emerges. Control strategy begins downstream and in time moves steadily upward, leading finally to the elimination of the technology, or what is equivalent, its transfer to Thailand (chapter 9).

Recurring errors complicate the evaluation of hazard management. Characteristically, regulators overestimate the efficiency of their control actions, whereas technology sponsors often overstate the costs of those actions. As chapter 16 shows, safer products often become better products, and costs that are initially perceived as extremely high can be readily absorbed by design or engineering ingenuity. Control actions also produce **leveraged benefits,** those positive side-effects associated with industry's innovations to reduce the risks of products or the production process (Ashford 1980). Postaudits of the cost of control actions are equally needed.

Effects Analysis

Finally, there must be an overall social evaluation of what hazard management has accomplished, an assessment of the broad consequences of outputs. This involves the application of social criteria to determine whether managerial "success" has been achieved. Broadly defined, success is the skillful steering between the enlargement of technological benefit and the minimization of technological harm. We propose four criteria for evaluating how skillful the steering has been.

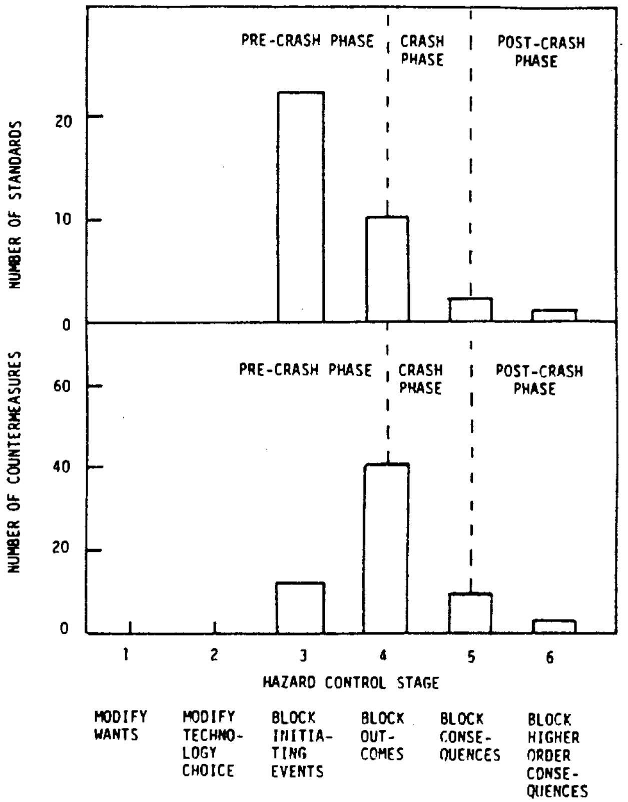

Figure 4. **Top:** Highway safety standards issued by the Department of Transportation, plotted by hazard control stage. **Bottom:** Highway safety countermeasures envisioned in the 1976 Highway Safety Needs Report. The distinctive shift toward more downstream intervention in the latter is noteworthy.

First, the management actions must be **effective:** that is, if a product is deemed to be unsafe, how much risk reduction actually occurs? Such effectiveness, of course, requires sound performance in the various stages of both intelligence and control functions. In particular, a full analysis of the causal chain and prospective feedback is required as well as the determined implementation of control actions chosen in the face of social conflict.

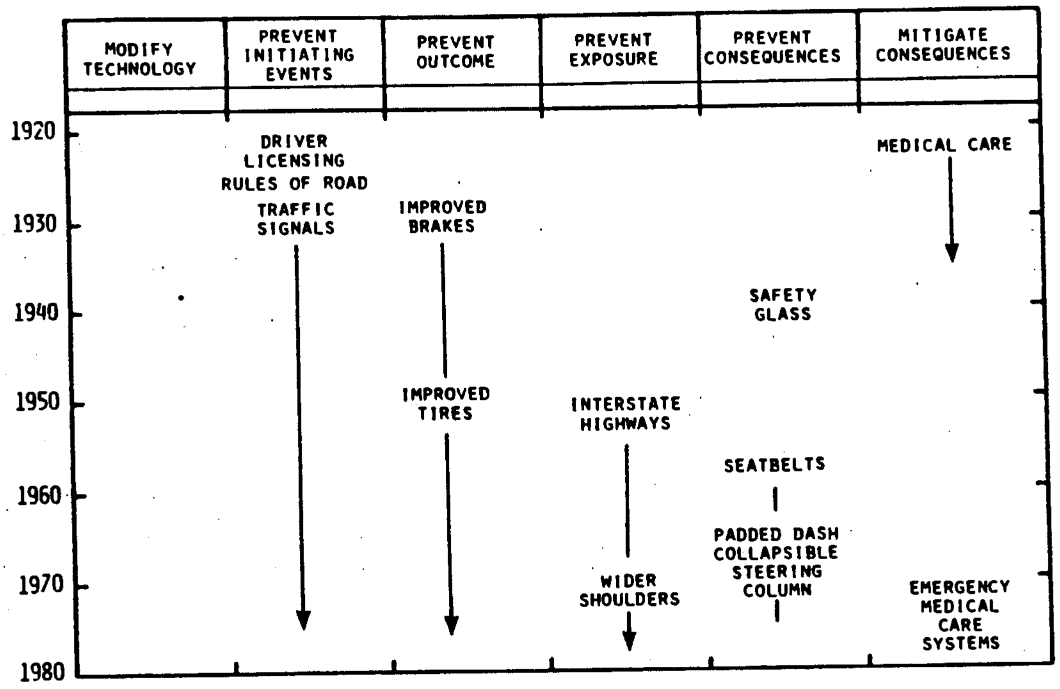

Figure 5. Chronological distribution of hazard control intervention by hazard stage for the case of automobile safety.

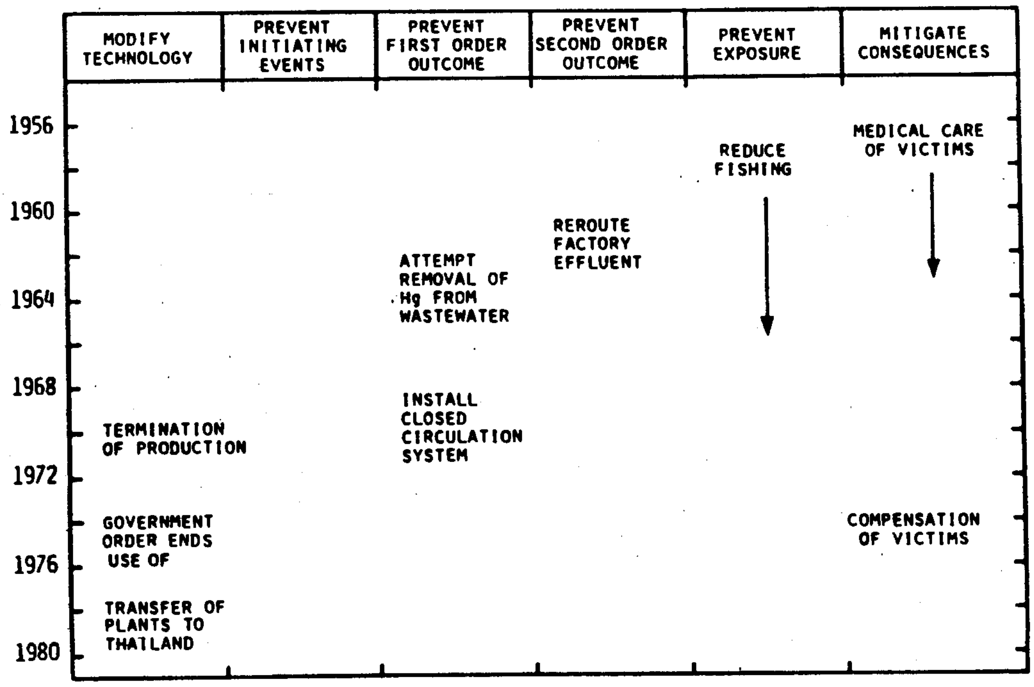

Figure 6. Chronological distribution of hazard control intervention by hazard stage for the case of Minamata disease.

Such risk reduction, at least for certain types of risk, should be amenable to quantitative statement.

Second, management must be efficient. There are two ways of viewing such efficiency, and both should be employed. One measure treats the simultaneous juggling of technological benefit and hazard. Clearly society does not seek risk reduction at any price and, as the energy/environment conflict makes clear, reasonable actions are needed that consider benefit and risk in tandem. The other measure is cost-effectiveness in risk reduction opportunity. Given a commitment to reduce risk, the most efficient measures, as measured in sociopolitical as well as economic terms, should be employed.

Third, management must be timely. Clearly, society's expectation, however unreasonable, is that those charged with responsibility for identifying and responding to hazards will do so promptly. Indeed, it is evident that managers, however large their domains of responsibility, are expected to identify prospective hazards and to take action before the hazard grows. As noted above, both previous research and our ongoing studies suggest that, despite public alarm over the hazard-of-the-week syndrome, society's hazard management appears to be improving over time on this criterion.

Finally, hazard management must be equitable. Unfortunately, although this criterion finds wide appeal, its application presents a formidable challenge often difficult to ascertain, because distributions of impacts are difficult to determine, and principles of social justice frequently conflict. Some forms of inequity—such as the more permissive standard for risk in the workplace—either remain quite concealed from the public view or are apparently tolerated. Only where equity issues attract social attention, as in compensation for black lung disease or exposure to atomic weapons testing, does action to reduce inequity usually occur. Management strategies that decrease inequities, however, are often deemed preferable.

Summary and Conclusion

The foregoing discussion provides a framework for analysis of society's management of technological hazards. Hazard management engages at least seven classes of major participants who make, influence, or match decisions. Our model of hazard management began with the causal chain of hazard and defined steps in the sequence of management, running from hazard assessment to control analysis, selection of management strategy, and implementation and evaluation. Throughout this management process (Figure 1), value-laden considerations, such as setting priorities, judging tolerable risk, and framing management goals, were important ingredients.

Of the participants responsible for hazard management, we know least about technology sponsors, little about individual citizens as hazard managers, and a great deal comparatively about public managers who are regulators and scientific risk assessors. Within the sequence of management activities we know most about hazard assessment, less about control analysis, little about how management strategies are formulated, and least about implementation. Meanwhile, comparative evaluation of managerial outputs and effects is just beginning.

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4

A Causal Taxonomy[1]

Christoph Hohenemser,
Robert W. Kates, and Paul Slovic

Despite the burden imposed by technological hazards and the broad regulatory effort devoted to their control, few studies have compared the nature of technological hazards in terms of generic characteristics. Existing studies are limited to case studies (Lawless 1977), comparative risk assessments of alternative technologies (Inhaber 1979;National Research Council 1980), lists of comparable hazards (Wilson 1979;Cohen and Lee 1979), and comparative costs of reducing loss (U.S. Dept. of Transportation 1976;Schwing 1979;Lave 1981).

A first step in ordering the domain of hazards should be classification. Today technological hazards are classified by the technology source (automotive emissions), use (medical x-rays), potentially harmful events (explosions), exposed populations (asbestos workers), environmental pathways (air pollution), or varied consequences (cancer, property damage). A single scheme is chosen, often as a function of historical or professional choice and regulatory organizations, although a given technology usually falls into several categories. For example, a specific chemical may be a toxic substance, a consumer product, an air or land pollutant, a threat to worker health, or a prescription drug. Indeed, a major recent achievement has been the cross-listing of several of these domains of hazardous substances by their environmental pathways (Greenwood, Kingsbury, and Cleland 1979).

In this chapter, we identify common differentiating characteristics of the domain of technological hazards in order to simplify hazard analysis and management. We conceptualize technological hazards as involving potentially harmful releases of energy or materials; characterize the stages of hazard causation via 12 physical biological, and social descriptors expressed on quantitative scales; score 93 technological hazards on these scales and analyze their correlative structure; and consider the implications of hazard structure for understanding hazards, their perception, and their management. The following is a highly condensed account of our detailed analysis (Hohenemser et al. 1983).

Measures of Hazardousness

We distinguish between **hazard** and **risk.** We define **hazards** as threats to humans and what they value and we define **risks**