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CAUSAL STRUCTURE: A FRAMEWORK FOR POLICY FORMULATION

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Controlling hazard in our technological society has become a major industry. Despite the positive benefits of technology, an increasingly common view has it that the benefits of technology exact their toll in environmental degradation, anxiety, illness, injury, and premature death. Especially in the last 10 years the American public has experienced a relentless parade of threats arising in technology. Some of these threats occur on the familiar "macroscopic" scale of oil spills, gas explosions, dam breaks, and air crashes; others appear on the intrinsically "molecular" scale of pesticides, food additives, and drugs. A few cases, which tend to arouse maximum fear, combine macroscopic and molecular scale threats as in the near meltdown of the reactor at Three Mile Island, or recurrent accidents involving fire and the simultaneous release of toxic chemicals.

We define hazards as threats to humans and what they value, and we take risks to be measures of these threats. A review of the scientific literature shows that scientists prefer to express risks as conditional probabilities for experiencing harm and frequently seek to use these probabilities as bases for prescribing societal response. Lay people, in contrast, judge risk on more complex scales, including such qualities as catastrophic potential, voluntary/involuntary character, and the degree to which risks are familiar and unfamiliar (Slovic et al, Chapter 10).

The degree of control that society achieves over particular hazards depends strongly on the character of institutions and laws, as well as perceptions of individuals. Consequently, a narrow definition of risk as a conditional probability is unlikely to predict individual or societal response. Instead, one finds that societal effort expended on risk control varies widely from case to case. Nevertheless, we believe that the generic problems of hazard control are rooted in the structure and the physical dimensions of hazards. As an introduction to this structure, we consider in this paper: (1) the magnitude of the technological hazard burden, as measured by hazard consequences; (2) the anatomy of hazards, as described by a generally applicable "causal model"; and (3) a taxonomy of technological hazard based on this causal model. Taken together, these three approaches lead to a first-order picture of technological hazard that may be useful in further illuminating research as well as in informing public policy.

1. The Burden of Technological Hazard

It is well to remember at the outset that technology is associated with both decrease and increase of risk. Age-adjusted mortality time trends (Figure 9.1) show that deaths from infectious disease, all accidents, and most intestinal diseases decreased during the last 80 years, whereas deaths from automobile accidents, cancer, and heart disease increased.

In approaching the risk of a technological society, it is also important to realize that as technology has grown, the last 80 years in America have witnessed a net increase of life expectancy of 20-30 years. This gain may be attributed to elimination of infectious disease, and as a necessary consequence, the "transfer" of mortality from infectious disease to causes of death that occur later in life.

In estimating today's burden of technological hazard, we have limited ourselves to mortality as hazard consequence, because data on it are most readily available. To determine the fraction of mortality associated with technology, we recognized at the outset three possible approaches, each widely described in the literature:

(1) Mechanistic models that provide a direct link between technological energy and materials releases and human harm, as in the saturation of blood with carboxyhemoglobin in the case of carbon monoxide exposure.

(2) Correlative exposure/consequence data relating specific energy and materials releases with specific expression of human harm, as in the link between exposure to ionizing radiation

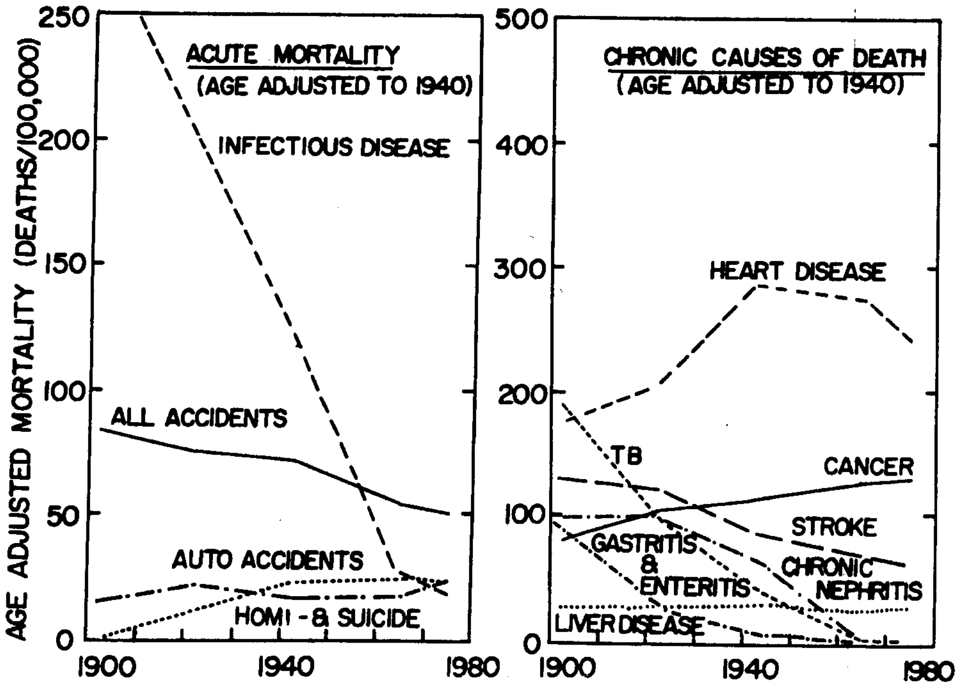

Figure 9.1. Historical variation of age-adjusted causes of death in the United States from 1900 to the present. Among acute causes, note the sharp decline of infectious disease and the rise in auto-accident mortality; among chronic causes of death, note the decline of most diseases except for cancer and cardiovascular disease.

and incidence of leukemia in humans.

(3) Definition of the fraction of exogenously "caused" chronic disease through a comparison of highest and lowest observed rates, as is done when 80-90% of cancer is assigned to "environmental causes."

Upon reflection we regarded each of these approaches inadequate. Approaches (1) and (2) require summing over a wide range of kinds of exposure, only a small fraction of which can be said to be defined through adequate data. It is thus a foregone conclusion that such summing cannot induce a complete answer. In contrast, approach (3) gives only an upper limit for the desired quantity and is likely to be a serious over-estimate.

To solve the problem at least in a rudimentary way, we took a fourth approach.[1] Starting with rates of "standard causes of death" as published by the World Health Organization[2] and the U. S. Department of Health, Education, and Welfare,[3] we correlated mortality rates with technological indicators such as percent employment in industry, per capita energy consumption, and per capita gross national product (GNP). In this way we learned that within the U. S. and internationally, age-adjusted cancer mortality rates are strongly related to level of technology whereas similar data for heart disease, stroke, respiratory and liver disease are not. Figure 9.2 illustrates our results for cancer in blacks and whites, both male and female.

We thus conclude that the mortality risk associated with technology may, at least in the case of cancer, be quite substantial, the overall beneficient time trends of Figure 9.1 notwithstanding. We drew three specific conclusions from our analysis of mortality:[1]

(1) Hazards of technology have in the industrial nations replaced ancient natural hazards of floods, pestilence, and disease (Table 9.1).

(2) In the United States, the death toll associated with technological hazards is 20-30% of all male mortality and 10-20% of all female mortality (Table 9.2).

(3) In the United States, the total value of medical costs and lost productivity was $50-75 billion in 1974, with about half of the total connected with accidents and violence and the other half

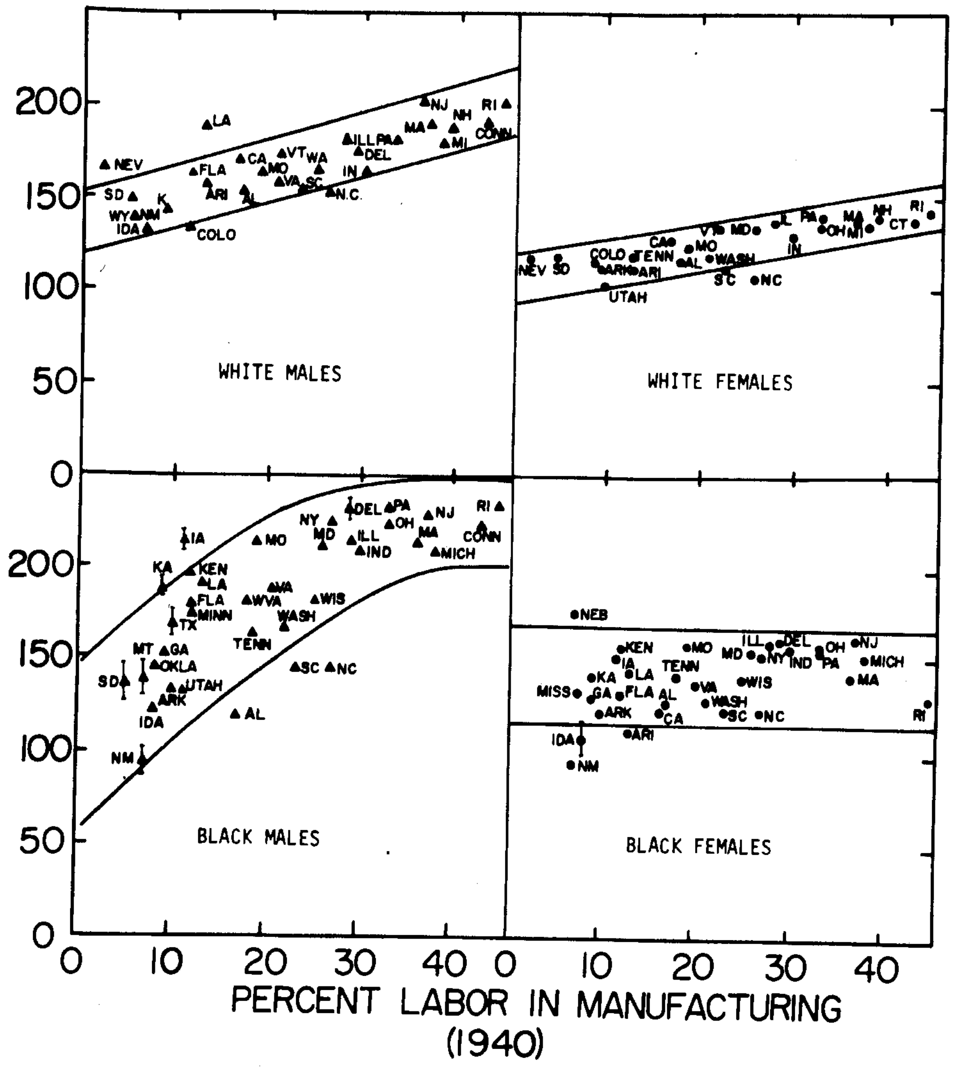

Figure 9.2. Correlation between average 1950-1969 age-adjusted cancer mortality and percent labor in manufacturing in 1940 for states within the United States. Note the pattern of increasing mortality with increasing industrial exposure except for black females.

Table 9.1. Comparative hazard sources in U.S. and developing countries

	PRINCIPAL CAUSAL AGENT[a]			
	NATURAL[b]		TECHNOLOGICAL[c]	
	Social cost[d] (% of GNP)	Mortality (% of total)	Social cost[d] (% of GNP)	Mortality (% of total)
United States	2-4	3-5	5-15	15-25
Developing countries	15-40[e]	10-25	n.a.[f]	n.a.[f]

a. Nature and technology are both implicated in most hazards. The division that is made here is made by the principal causal agent, which, particularly for natural hazards, can usually be identified unambiguously.

b. Consists of geophysical events (floods, drought, tropical cyclones, earthquakes, and soil erosion); organisms that attack crops, forests, livestock; and bacteria and viruses which infect humans. In the U.S. the social cost of each of these sources is roughly equal.

c. Based on a broad definition of technological causation, as discussed in the text.

d. Social costs include property damage, losses of productivity from illness or death, and the costs of control adjustments for preventing damage, mitigating consequences, or sharing losses.

e. Excludes estimates of productivity loss by illness, disablement, or death.

f. No systematic study of technological hazards in developing countries is known to us, but we expect them to approach or exceed U.S. levels in heavily urbanized areas.

Table 9.2. Estimates of technologically involved deaths in the United States

Cause of death	Percent male	Percent female	Annual deaths in thousands male	Annual deaths in thousands female
ACUTE MORTALITY				
Infectious disease	0	0	0	0
Deaths in infancy	5	5	1	1
Transportation accidents	90	90	39	15
Other accidents	70	50	28	11
Violence	30	30	10	3
Other acute deaths	70	50	8	5
CHRONIC MORTALITY				
Cardiovascular disease	0-40	0-40	0-217	0-132
Cancer	40	25	82	35
Chronic liver disease	0	0	0	0
Chronic respiratory disease	0-20	0-5	0-5	0
Other chronic disease	25	25	19	15
ALL MORTALITY	17-30	11-21	182-318	85-167

For a description of the methods used in obtaining the above results, see Harriss, et al.[1]

with chronic disease.

Although individuals enjoy some choice and control over the hazards they face, their responses are substantially constrained. Many risks are involuntary, involve difficult tradeoffs between benefit and risk, and are characterized by insufficient individual knowledge to permit sound individual decision making. To compensate society attempts to fill the gap. Hence, government and industry have increasingly usurped the individual's role in managing risk. Our study of this societal effort shows it to be extensive. Federal spending on hazard management and control was estimated to be $22-35 billion per year in 1979, whereas public and private damage costs totalled $80-150 billion. A detailed breakdown appears in Table 9.3.

2. The Causal Anatomy of Technological Hazard

If we are to understand hazards beyond the mortality they produce, it is essential to inquire into their structure. Accordingly, we present here a model of technological hazards that we believe is simple enough to serve as a framework for policy analysis and sufficiently detailed to provide an adequate representation of reality. As will be seen, our model characterizes the chain of causation that leads to human harm, while sidelining for the sake of simplicity any explicit reference to the benefits of technology.

Our way of thinking of hazard causation grew out of a number of years of work on natural hazards.[5] Put simply, our approach divides hazards into two components, events and consequences. In this characterization hazard events represent the potential for harm and hazard consequences the realization of harm. Consequences are measured in a variety of ways, including death, injury, economic and social loss. The separation of hazard into two components suggests three ways of coping or managing: (1) prevention of hazard events; (2) prevention of hazard consequences once events have occurred; and (3) mitigation of consequences once these have occurred.

A more versatile form of the model divides events into two parts, initiating events and outcomes. A further elaboration recognizes pathways connecting stages of hazard development. An illustration of the model in this form appears in Figure 9.3. Note the arrow of time, indicating the sequence of hazard development. Pathways connecting stages represent possible points for exercising hazard control, as indicated. Note further that for the case illustrated, several parallel events are required more or less

Table 9.3. Technological hazard control costs and damage for fiscal year 1979*

Description	Cost (Billions of $)
Federal control costs	$ 22-35
State and local control costs	11-17
All public (federal and state) control costs	32-52
Private control costs	67-80
Total government and private control	99-133
Public and private damage costs	80-150
Total control and damage costs	179-283

* For a description of the methods used in obtaining the results shown here, see the work of J. Tuller.[4]

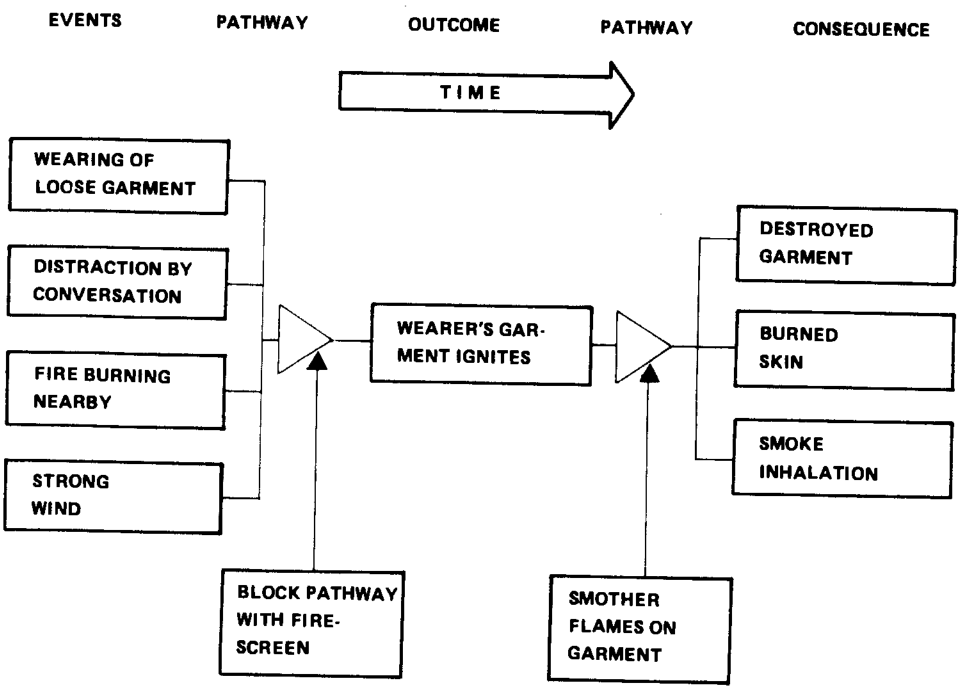

Figure 9.3. Three-stage model of hazard causation. The case illustrated involves a garment that accidentally ignites when the wearer stands too near an open fire.

simultaneously in order for initiating events to evolve to a subsequent outcome.

The model may be expanded further. For example, just as outcomes follow initiating events, higher order consequences may follow first order consequences, all appropriately linked by pathways. From a practical point of view, additional stages are introduced because they define additional meaningful management opportunities. Figure 9.4 provides two examples of expansion. In the first, several orders of consequences are indicated to show how a burn may lead to eventual death; in the second, several orders of outcomes are sketched to show how a corroded brake lining can lead to an auto crash.

Finally, to take the model to the origin of hazards, we add three stages upstream of initiating events. These we term choice of technology, human wants, and human needs. As illustrated in Figure 9.5 diagramming this full scope of hazard causality is particularly important in cases, such as pesticide use, for which downstream options for hazard management are poorly understood or unavailable.

For any given technology, full expansion of the model may be a major undertaking that can lead to baroque structures. Such structures may be fun to build, but they will have little use for decision makers. We think, therefore, that expansion should be restricted to 10 or fewer stages if policy analysis is intended. In that form, the model can be of use to decision makers in a number of ways. We consider these next.

Expanded understanding. The most immediate advantage of filling in the logical structure of a hazard is the fuller understanding that is gained. Thus, the model forces us to look at all logically possible management options. For example, the diagramming of pesticide use (Figure 9.5) led to our identification of a potential intervention--"to prevent cancer after ingestion of contaminated fish"--characterized as "method unknown." Indeed, this intervention remains, to our knowledge, impossible, but it is nonetheless worthy of research.

Mapping regulatory effort. The model may be used to map regulatory effort applied at each stage of control intervention. In most cases this immediately raises obvious questions about distribution of effort. A level-of-effort map requires convenient indicators, such as manpower, budget allocations, or the number of regulatory standards issued. To illustrate, we show in Figure 9.6 the distribution of

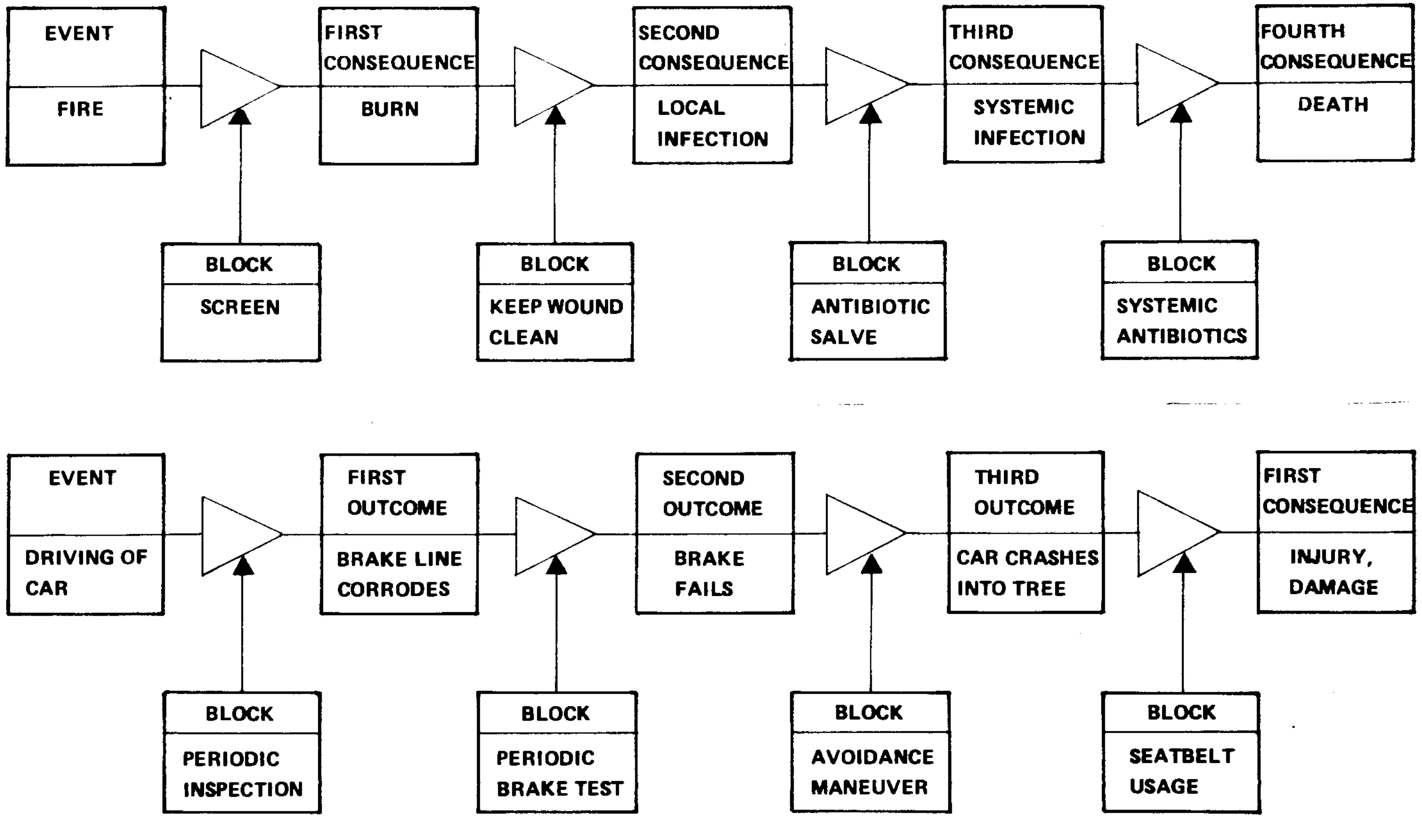

Figure 9.4. Top: Expansion of the model of hazard causation into several orders of consequences. The case illustrated concerns the potential medical developments that can occur following a burn. Bottom: Expansion of the model of hazard causation into several orders of outcomes. The case illustrated involves the evolution of a corroded brake lining into a car crash.

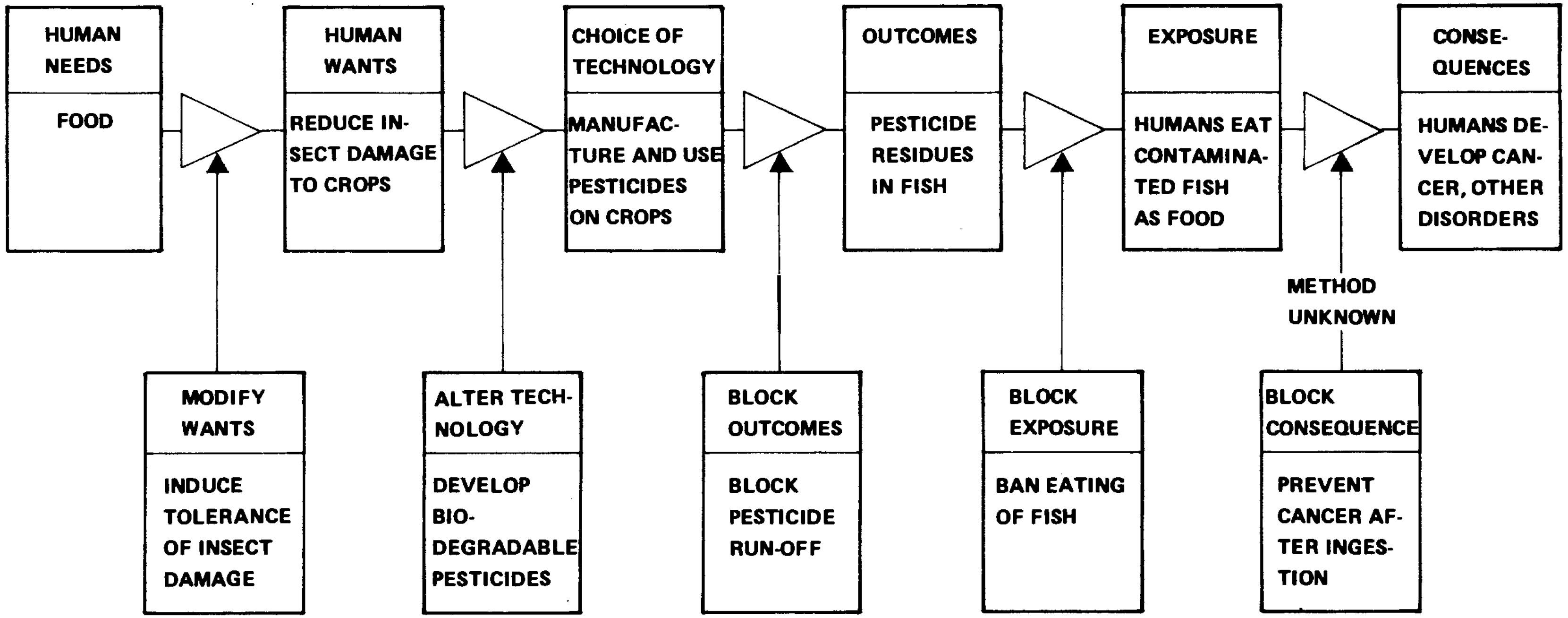

Figure 9.5. Expansion of the model of hazard causation into the full range of stages extending from human needs to consequences. The case illustrated involves the use of pesticides to suppress crop damage. It serves as a good example of the situation in which "downstream" management options involving events and consequences are not very promising or even possible, and "upstream" options involving human wants and choice of technology are most likely to succeed.

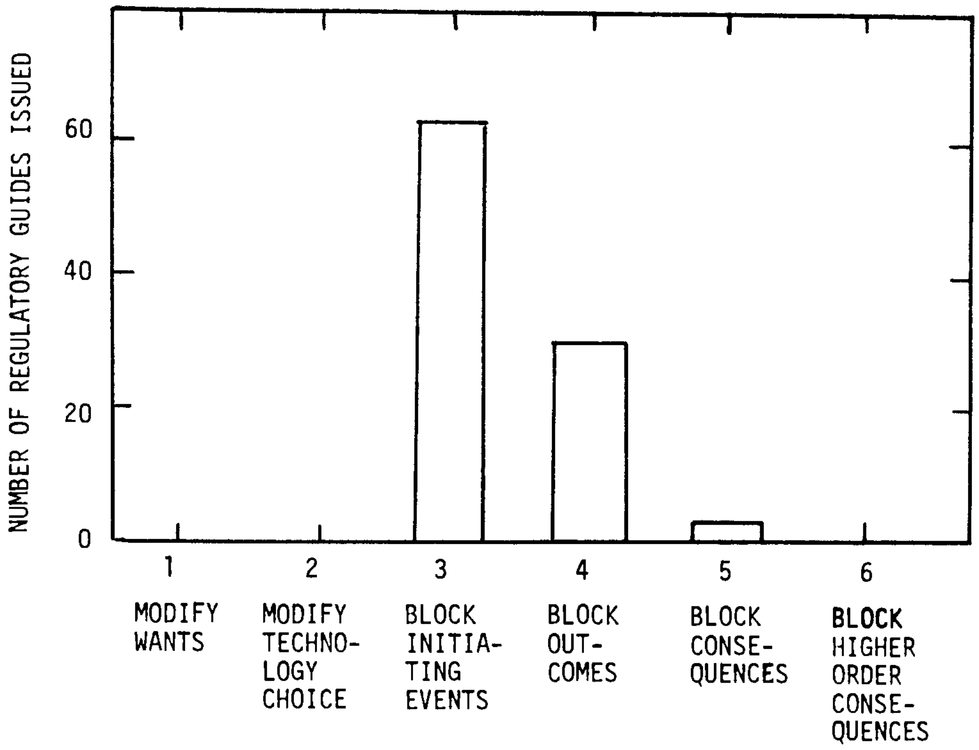

Figure 9.6. Number of regulatory guides by hazard stage issued by the Nuclear Regulatory Commission (Data through 1975).

regulatory guides issued by the Nuclear Regulatory Commission through 1975 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 consequence mitigation. A good example of consequence mitigation is evacuation to reduce radiation exposure. Since Three Mile Island, this has belatedly become a major priority, one which our model and the effort map in Figure 9.6 enabled us to recognize in 1976.

A similar level-of-effort map (Figure 9.7, top) categorizes highway safety standards issued by the U. S. Department of Transportation. It is readily apparent that 81% of the standards are classed as blocking initiating events, with little activity downstream. In contrast, a landmark highway safety report[6] analyzing 37 possible highway safety countermeasures places 40% of activity downstream from initiating events (Figure 9.7, bottom). Effort maps thus illuminate the difference between highway safety practice and highway safety theory and lead one to ask a number of questions. Is the distribution of effort appropriate for the physical nature of the hazard, the mandate and past history of the Department of Transportation, the perception of risk managers, or other factors? Is the distribution of effort optimal?

Classifying societal response. Societal response to hazard probably follows patterns in time that are structurally similar for similar hazards. To begin testing this hypothesis we have mapped control actions chronologically by hazard stage.

In the case of auto safety management, a schematic representation (Figure 9.8) shows that except for medical care administered to crash victims, the dominant early modes of management occurred far "upstream." The attempt to block injuries (first order consequences) once crashes have occurred is a rather recent development.

A diametrically opposite pattern emerges in the response of Japanese society to Minamata disease (Figure 9.9). Here control strategy begins downstream and in time moves steadily upstream, leading finally to the elimination of the technology, or what is the equivalent, its transfer to Thailand.[7]

Feedback analysis. In discussing the evolution of hazard from ultimate causes to final consequences, we have indicated control points without considering the details of the control processes. In many cases of hazard management, the simple flow of time from "upstream" to "downstream" is an inappropriate description. Instead, a hazard is first

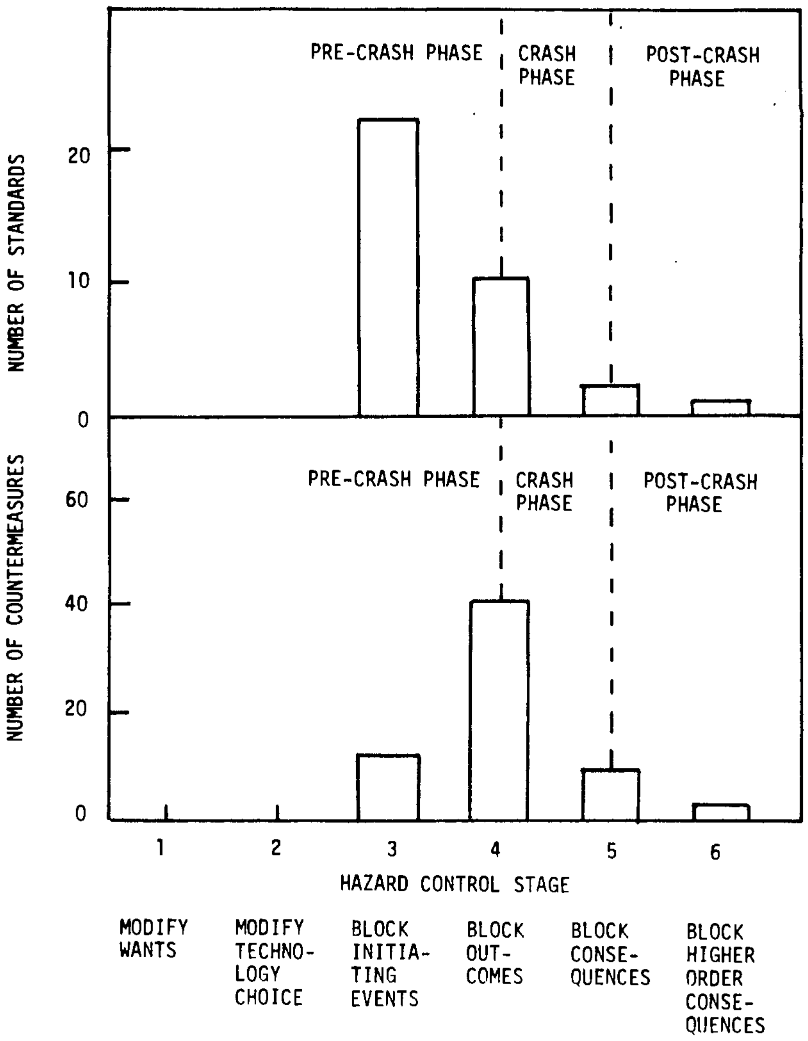

Figure 9.7. Top: Highway safety standards issued by the Department of Transportation by hazard control stage. Bottom: Highway safety "countermeasures" envisioned in the 1976 highway safety report published by the Department of Transportation.[6]

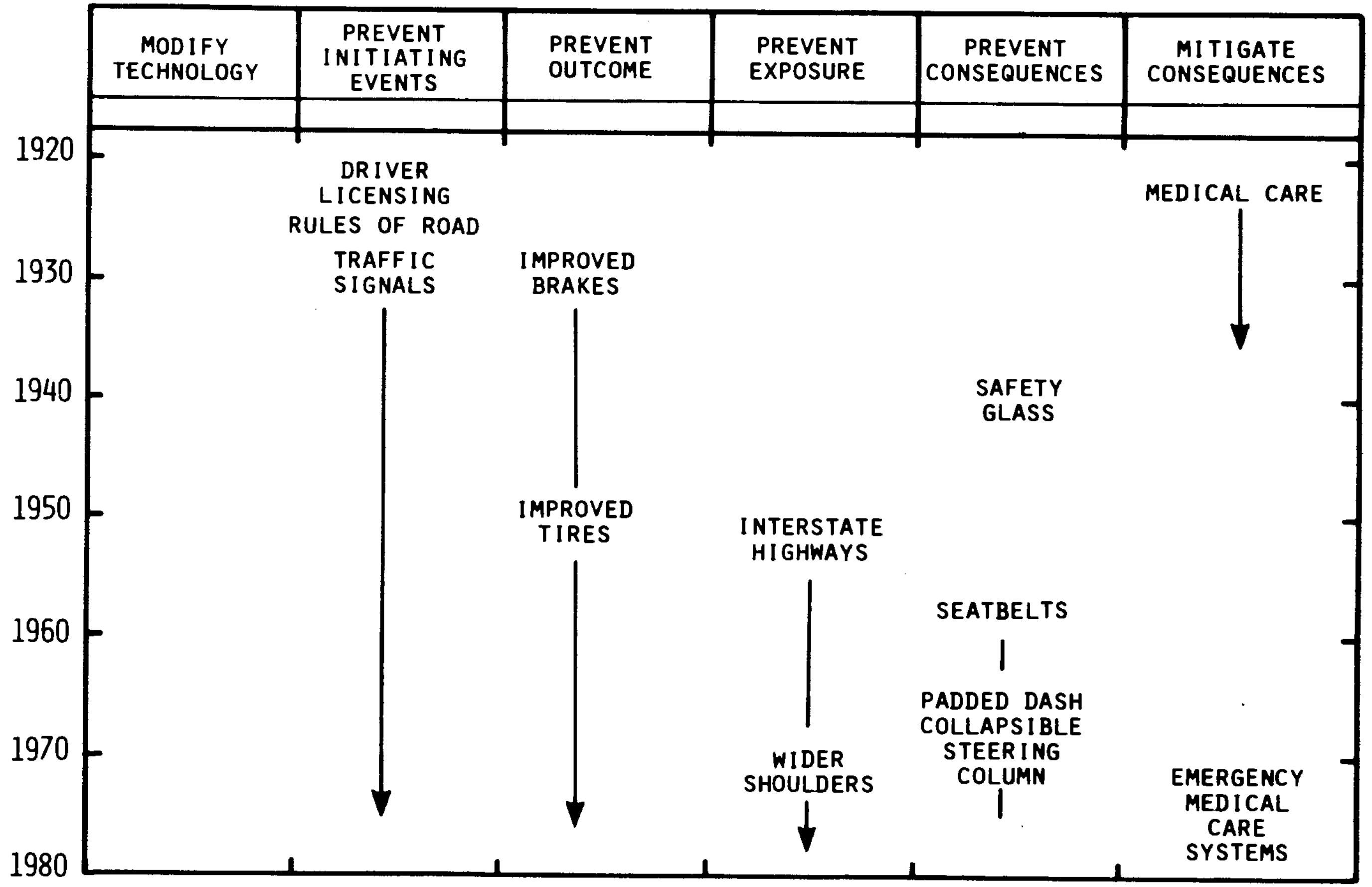

Figure 9.8. Chronological distribution of hazard control effort by hazard stage.

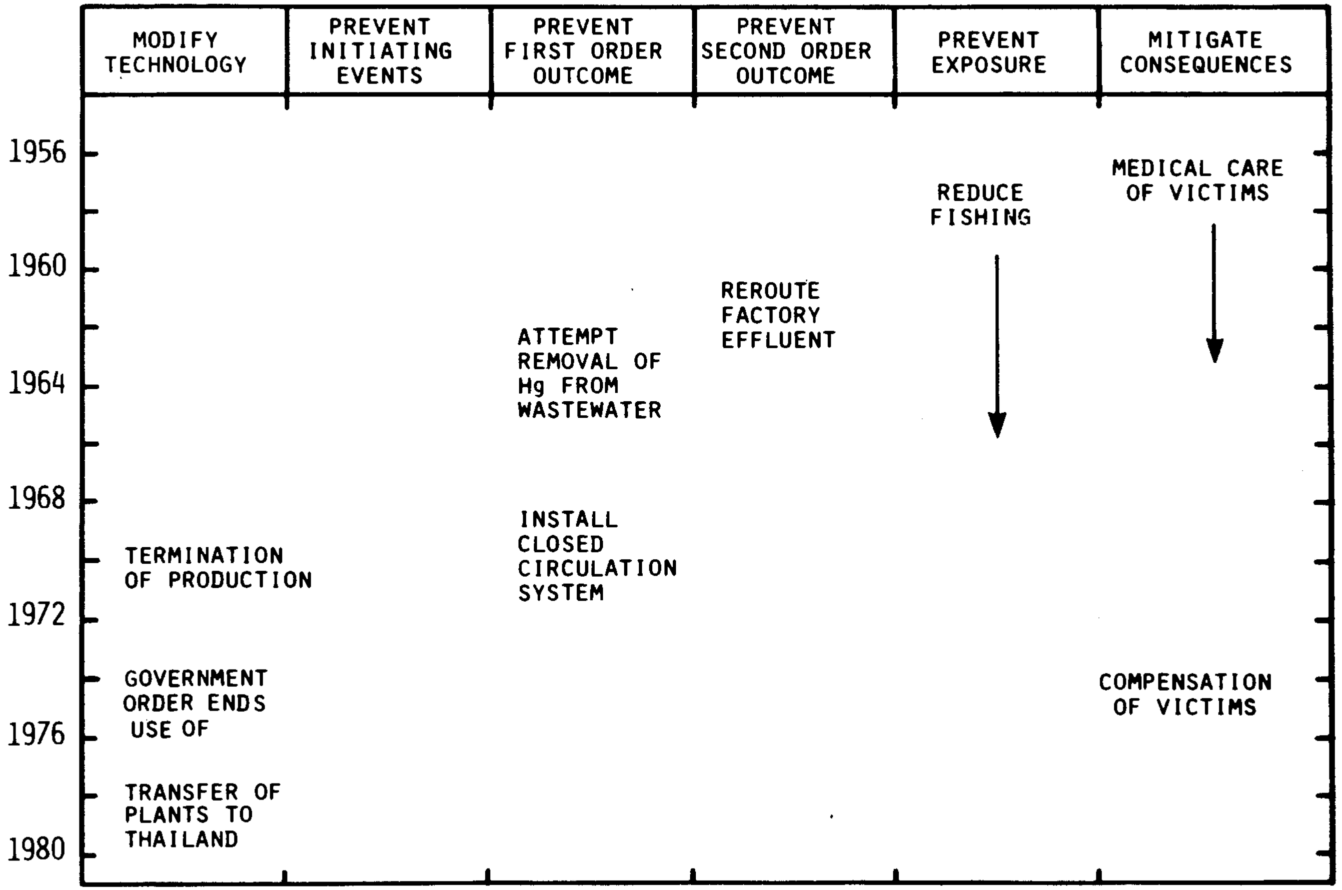

Figure 9.9. Chronological distribution of hazard control effort by hazard stage for Minamata disease.

recognized through an experienced outcome or consequence, and control action follows in time by inserting a block at appropriate upstream stages. In this sense, control intervention involves feedback, and information flows backward from downstream to upstream stages.

A great deal of feedback takes place in the way individuals strike a balance between hazard creation and reduction. Thus it is possible for effective feedback to occur through a "free market" mechanism, or through explicit regulatory actions.

Feedback may, in principle, be both positive or negative. For reducing hazard, we desire negative feedback; that is, we seek upstream control intervention that blocks or reduces consequences. Unfortunately, hazard management has in many cases produced unintended positive feedback, or processes through which upstream control interventions increase the level of consequences.

To illustrate both positive and negative feedback, we diagram in Figure 9.10 the case of flood damage control. The management sequence runs roughly as follows:

(a) Floods occur (consequences).

(b) Assessors prescribe flood protection in the form of dams and levees (initiation of feedback loop).

(c) Engineers build dams and levees (implementation of feedback).

(d) The dams prevent a number of floods (intended negative feedback achieved by blocking outcomes).

(e) Unanticipated by the assessors and engineers, individuals perceive increased safety in the newly protected floodplains and settle there (initiation of positive feedback).

(f) Eventual flood damage is greater than before building of dams because infrequent, but nevertheless possible, overtopping leads to catastrophic flood damage in built-up flood plains (positive feedback overwhelms negative feedback).

A more recent and equally important case of unintended positive feedback has emerged from the Kemeny Commission report on the accident at Three Mile Island.[8] A diagram appears in Figure 9.11. The corresponding sequence of events

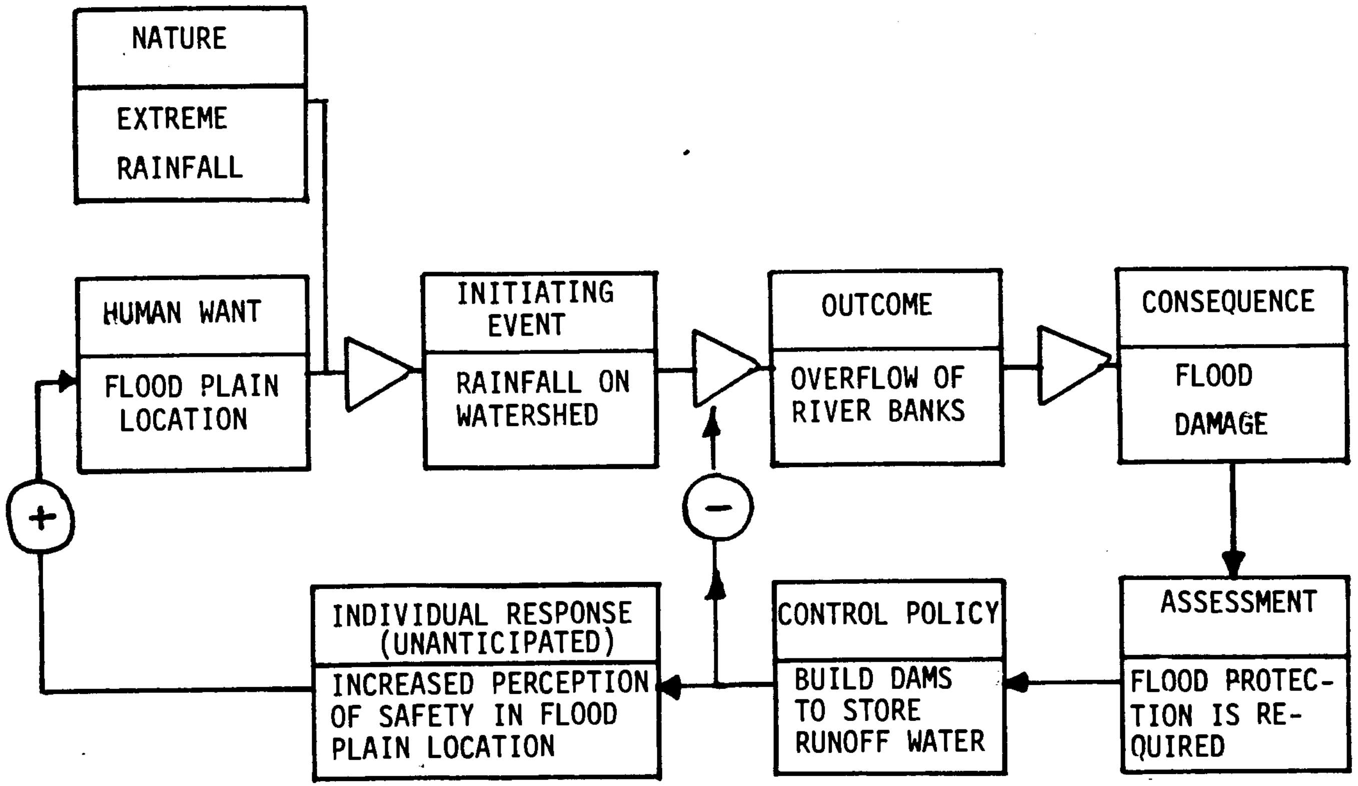

Figure 9.10. Feedback diagram for flood damage control. The unanticipated individual response of increased perceived safety in floodplain locations acts as a positive feedback and defeats the control policy.

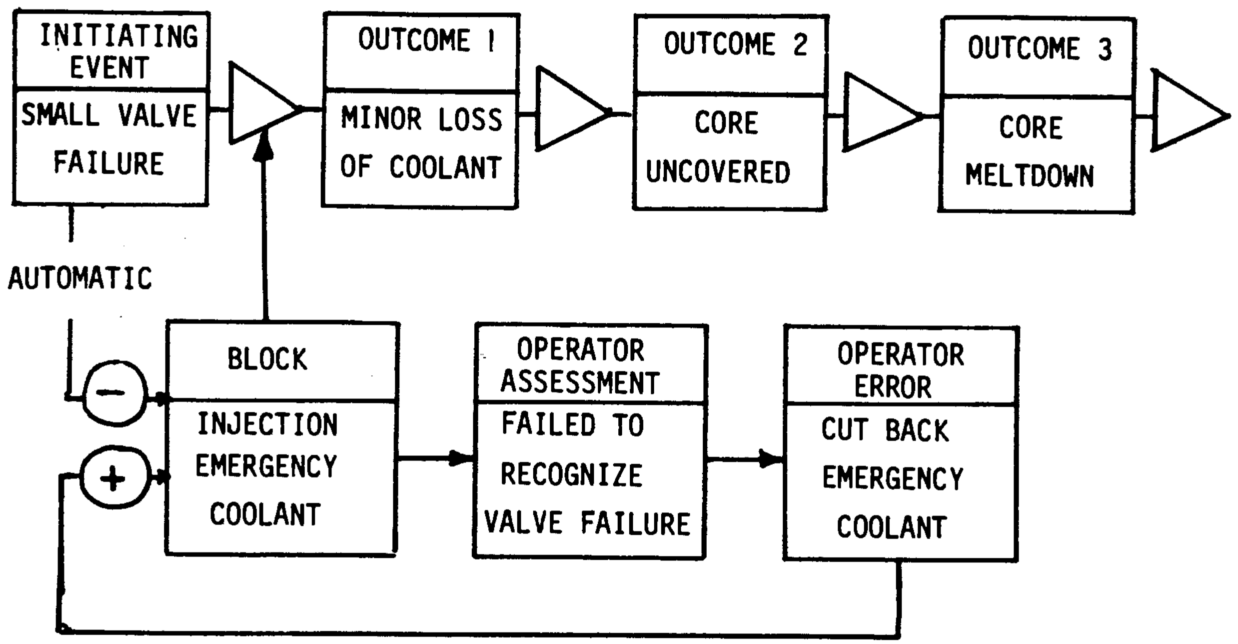

Figure 9.11. Partial feedback diagram for the accident at Three Mile Island. Negative feedback in the form of emergency core coolant was automatically triggered by the failure of a small valve in the primary cooling system. This was followed by an improper operator assessment and led to cutback of emergency coolant through operator action. The result was that the automatically triggered feedback was cancelled, and the initiating event progressed unchecked to a partial core meltdown.

may be described as follows:

(a) A minor valve in the primary coolant system accidentally remains stuck open (initiating event).

(b) Through an automatic process, this initiates injection of emergency coolant (automatic block: negative feedback).

(c) The operators, unaware of the stuck valve, but observing the injection of the coolant, misinterpret the situation and cut back on the coolant (unintended positive feedback).

(d) The automatic process which initiated injection of the emergency coolant is cancelled, and over a period of hours the stuck valve leads to an uncovered core and a partial meltdown (positive feedback overwhelms negative feedback).

We regard feedback analyses as indicated in these examples as extremely useful and powerful tools for making explicit the structure of hazards and the methods of hazard control. We expect, further, that a few kinds of feedback diagrams apply to all hazards, and that it makes sense to construct a feedback catalogue that can serve as a checklist and guide for hazard managers. The challenge is, of course, to predict the future and not merely to explain the past.

3. Toward a Causal Taxonomy of Hazard

Currently, technological hazards are classified in a variety of apparently inconsistent ways, ranging from technological source, to function or purpose, to exposed population, to environmental pathway, to any or all varieties of consequences. Which hazards fall into what category is a function of historical or professional as well as regulatory organization. Any given chemical might be classified as a toxic substance, a threat to worker health, or a prescription drug. Integration of widely varying hazard classifications has been slow.

For the purpose of optimum management, it may be helpful to classify hazards in a more logical manner. Such a classification should allow use of similar managerial tools for all hazards of a given class. A successful classification will also facilitate more effective comparative assessment than is now possible. One should be able to answer such questions as: what do saccharin, skateboards, and the collapse of the

Grand Teton Dam have in common? How do they differ?

Dimensions of causal structure. Recently we have used the causal model described in Section 2 to construct a taxonomy of technological hazards. On the basis of information derived from the scientific literature, we have coded 93 technological hazards on 16 dimensions. Each stage of the causal structure of hazard is characterized by one or more dimensions, as indicated in Figure 9.12. The scales used to define each dimension are given in Table 9.4. Wherever possible, we used numerical scales of logarithmic character: scale increments of unity were defined to correspond to multiplicative factors of 10 or 100. In this sense our scales are similar to other sociophysical scales in which physical events of human interest cover many orders of magnitude in physical "intensity." In the field of hazard analysis, a well-known example of such a scale is the Richter scale for earthquake intensity, on which increments of one correspond to a factor of 10 in energy release. Beyond the wide range of the physical dimensions underlying causal structure, we chose logarithmic scales for two additional and independent reasons: (1) given the paucity of information for many hazards, it is unrealistic in general to differentiate among hazards to any greater accuracy than a factor of 10; (2) in many cases, individual events in a given hazard structure involve a range of values that may cover a factor of 10 or more. Whether such crude scaling could capture interesting differences between hazards was a question we sought to answer by trying the method. At the outset we had no a priori insight that "factor-of-10 scaling" would be successful.

Hazard codification. Our initial selection of 66 hazards drew upon an existing library of case studies at Clark University's Center for Technology, Environment, and Development (CENTED), the caselist employed by Slovic and his collaborators (Chapter 10), and informal discussion within our group. Our early choices, then, were not supported by a systematic selection method, but they did include a large fraction of the cases that had received public attention. After scoring the initial set of 66, we plotted their distribution on each of the scales and noted the extent of population imbalances. In selecting further hazards to round out our sample, we made a special effort to correct such imbalances. Our final sample of 93 is therefore reasonably well distributed on most scales, though it can but reflect the fact that there are few hazards in the extreme regions of most scales, and many at the low end. Though our interest is technological risk and hazard, we included in our sample several "marker" cases related to smoking and alcohol use.

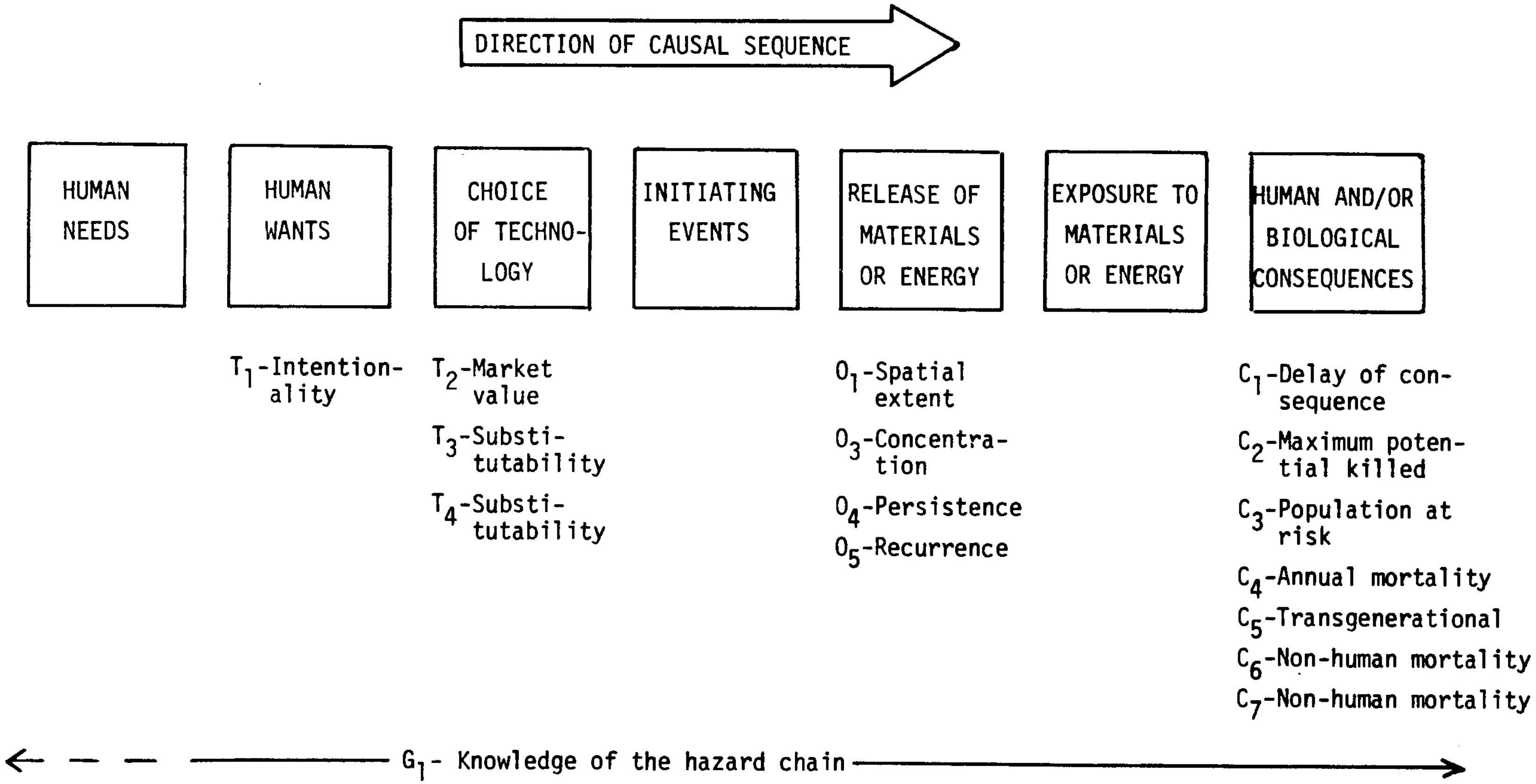

Figure 9.12. Causal model of hazard, with approximate location of variables. T-variables describe human wants and choice of technology. O-variables describe outcomes or releases. C-variables describe exposure-consequence relations and consequences. G_1 describes the state of knowledge of the whole chain.

Table 9.4. Elementary variables

Symbol	Name	Variable Range	Variable Scale
G_1	Knowledge	poor to excellent	1 - 9
T_1*	Intentionality	"not intended to harm organisms" to "intended to harm humans."	3, 6, 8
T_2	Market value	$\$10^1 - 10^{12}$	1 - 7
T_3	Substitutability: broad	"no known substitutes" to "two or more"	1, 3, 5, 7, 9
T_4	Substitutability: specialized	"No known substitutes" to "two or more"	1, 3, 5, 7, 9
O_2*	Spatial extent	$1 - 10^{14}$ m^2	1 - 9
O_3*	Concentration	energy: acceleration from 0 - 80 g. materials: concentration relative to background from 0 - 10,000+	1 - 9
O_4*	Persistence	1 min. - 20+ yrs.	1 - 9
O_5*	Frequency of recurrence	1 min. - 20+ yrs.	1 - 9
C_1*	Delay of conseq.	1 min. - 20+ yrs	1 - 9
C_2*	Maximum potential killed (U.S.)	$0 - 10^8$+	1 - 9
C_3*	Population of risk (U.S.)	$0 - 10^8$+	1 - 9
C_4*	Annual mortality (U.S.)	$0 - 10^8$+	1 - 9
C_5*	Transgenerational	"no effect" to "several generations affected"	3, 6, 9

Table 9.4 continued

Symbol	Name	Variable Range	Variable Scale
C_6*	Non-human species mortality-max. potential	"none" to "significant mortality" to "species extinction"	3, 6, 9
C_7*	Non-human species mortality-experienced	"none" to "significant mortality" to "species extinction"	3, 6, 9

* Variables used in factor analysis

Most hazards were scored by two or more individuals. Many cases were discussed in order to clarify the meaning of the available literature. After all scoring was complete, one individual made a series of checks for inconsistent scoring and thereby altered 20% of the scores by one scale point and a handful by as many as 2 or 3 scale points.

Composite Dimensions. Through factor analysis we have extracted from the 12 causal structure variables that describe hazard anatomy downstream from "choice of technology" five composite, orthogonal dimensions. The composite dimensions (factors) "explain" 82% of the variance of the sample. To good approximation this means that the causal structure of each of 93 hazards, and any others to be scored in the future, may be described by values of just five composite variables. Table 9.5 summarizes the relation of the composite variables to the original 12 variables.

The principal virtue of the analysis illustrated in Table 9.5 is that it simplifies thinking about hazards in a systematic way. The five composite variables are simpler to comprehend than the original 12. At the same time they constitute a considerable extension of the concept of technological risk frequently used by analysts. Only one of the five qualities--"annual mortality"--is normally included in quantitative discussions of risk; the other four--"intentionality," "persistence-delay," "catastrophic," and "global threat"--are dimensions that are normally omitted, or left as incidental remarks about risk.

A Taxonomy of Extremes. The factor analysis by itself is not a taxonomy of hazards, but it does offer several possible ways of constructing one. One such taxonomy may be derived from the factor analysis by identifying extreme scorers on each of the five composite scales as five hazard classes; multiple extremes as a sixth; and all others as a seventh and eighth class. The resulting grouping of hazards, illustrated in Table 9.6, has the effect of emphasizing the extremities of hazard space, on the assumption that it is these cases that merit special societal attention. In this sense, the present taxonomy defines in a systematic manner a partial list of society's "worry beads." Assuming that our methodology is found workable, this should remove some of the ad hoc character from much of the discussion of hazard identification, evaluation, and prioritization.

At present, society's struggle to deal with extreme scoring hazards is incomplete, though a well-identifiable policy exists for three classes. Thus, society prescribes prior approval, demonstrated safety, and restricted access

Table 9.5. Factor structure for combined energy and materials hazards: 93 cases

FACTOR			CAUSAL DIMENSIONS		
No.	Name	Variance explained		Name	factor loading
1.	Intentional	.32	C_7	non-human species mortality (experienced)	.87
			C_6	non-human species mortality (potential)	.79
			T_1	intentional design of technology	.81
2.	Persistence/ delay	.19	O_4	persistence of release	.81
			C_1	delay of consequences	.85
			C_5	transgenerational effects	.84
3.	Catastrophic	.11	O_5	rarity of occurence	.91
			C_2	maximum potential killed	.89
4.	Annual mortality	.10	C_4	annual mortality	.85
5.	Global threat	.09	C_3	population at risk	.73
				Concentration above background	.73

Table 9.6. Proposed taxonomy

Classes	Examples
1. Multiple Extremes	Nuclear war, Recombinant DNA, Deforestation
2. Intentional Biocides	Pesticides, Nerve gas, Antibiotics
3. Persistent Teratogens	Uranium mining, Radioactive Waste, Mercury
4. Rare Catastrophes	Recombinant DNA, LNG, Satellites
5. Common Killers	Automobiles, Handguns, Medical x-rays
6. Diffuse Global Threats	Fossil fuel (CO_2), SST (NO_x), Coal Burning
7. Macro Materials, Energy	Skateboards, SST (noise), Underwater Construction
8. Micro Materials, Energy	Saccharin, Laetrile, Microwave Appliances

and use for intentional biocides; prior approval, event prevention and engineered safety for major catastrophic hazards; and educational efforts, behavior modification, technical fixes, and diffuse responsibility for common killers. Society is seeking a policy for persistent, delayed teratogens--through debates on cancer principles, burden of proof, validity of animal experiments, and liability. And society is still assessing the risks for diffuse global hazards such as atmospheric CO_2 buildup and acid rain.

From its structure, it is clear that our codification of technological hazards via quantitative measures of causal structure will permit a number of alternative interpretations. The present, brief report on our hazard classification efforts must therefore be regarded as a preliminary view of a still developing story. Current and future work is concerned with validation of scoring procedures; with more suitable classification of routine, non-extreme hazards; with the relation between hazard dimensions and benefits; and with a detailed comparison of our codification to perception.

4. Summary and Prognosis

We have estimated the magnitude of the technological hazard problem and shown it to be substantial; described a model of technological hazard that makes explicit the causal structure; suggested several ways in which the model can be useful in clarifying issues of hazard control; and described how a taxonomy of hazard may be constructed.

The remaining question is: can our model of hazard, its application to mapping effort and classifying hazards, improve hazard control? Our hope is that the answer is yes. But at this stage proof of this is not yet in, nor will it be until the causal model and the applications we have suggested are adopted by people who must make decisions about hazards in their roles as citizens, managers of private industry, and government regulators.

References and Notes

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