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COGNITIVE PROCESSES AND SOCIETAL RISK TAKING

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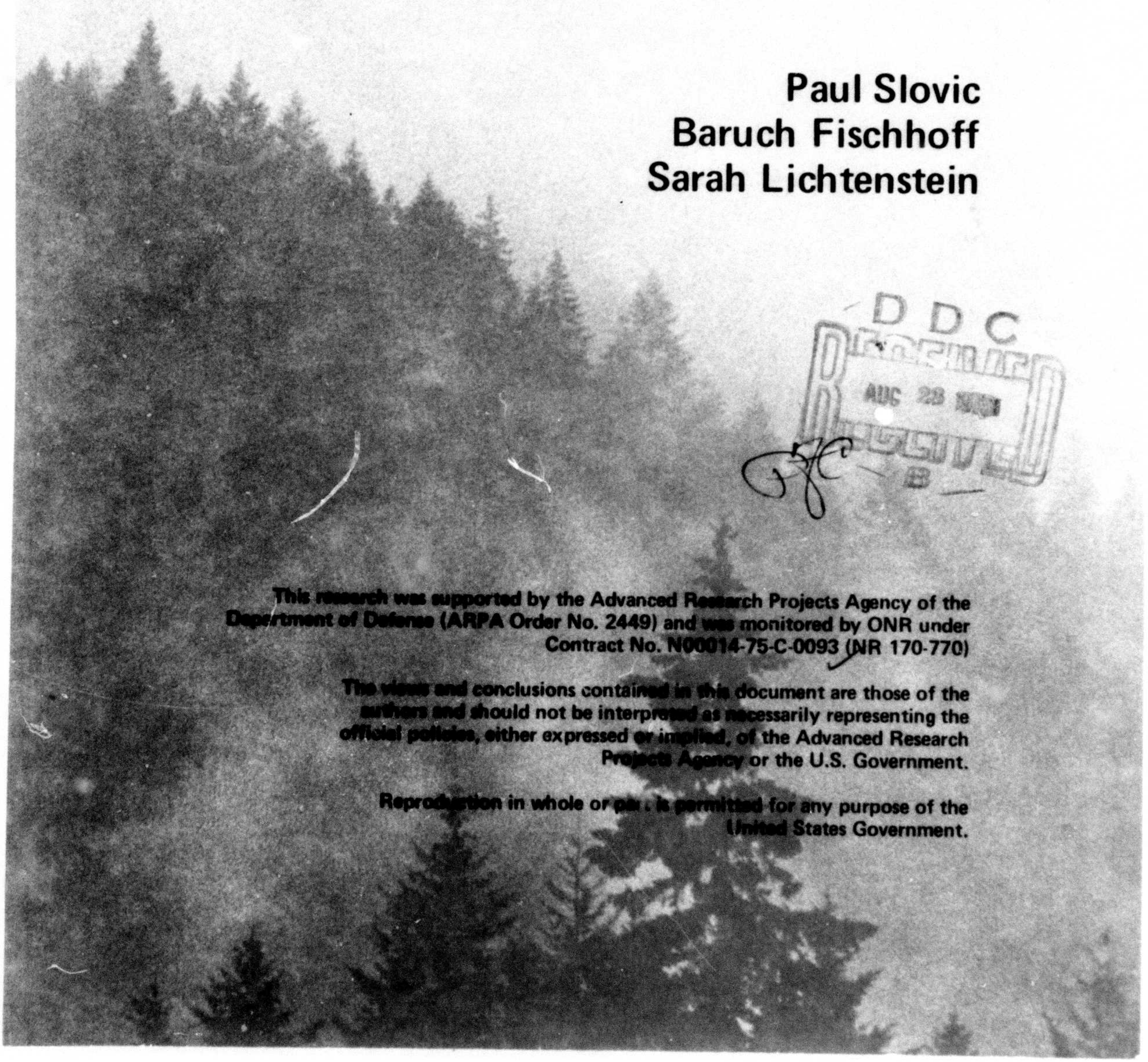

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13. ABSTRACT

This paper explores how the psychological study of decision processes might help those who seek to understand and improve societal decisions involving risk. The discussion is organized around three questions: (a) What are some of the basic policy issues regarding societal risk? (b) What knowledge has 25 years of empirical and theoretical research produced that is relevant to these issues? (c) What more do we need to know and how might we acquire that knowledge?

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Cognitive Processes and Societal Risk Taking

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Our world is so constructed that the physical and material benefits we most desire are sprinkled with the seeds of disaster. For example, the search for fertile fields often leads us to floodplains and our attempt to make less fertile fields productive forces us to rely, at some risk, on fertilizers, pesticides, and fungicides. The wonder drugs that maintain our health carry side effects proportional to their potency, and the comforts and conveniences of energy are enjoyed at the risk of damage from a host of pollutants. Modern man has some control over the level of risk he faces, but reduction of risk often entails reduction of benefit as well.

The regulation of risk poses serious dilemmas for society. Policy makers are being asked, with increasing frequency, to "weigh the benefits against the risks" when making decisions about social and technological programs. These individuals often have highly sophisticated methods at their disposal for gathering information about problems or constructing technological solutions. When it comes to making decisions, however, they typically fall back upon the technique which has been relied upon since

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We are indebted to Berndt Brehmer, Daniel Kahneman, Howard Kunreuther, and Amos Tversky for stimulating our thinking on many of the issues discussed here.

antiquity--intuition. The quality of their intuitions sets an upper limit on the quality of the entire decision-making process and, perhaps, the quality of our lives.

The purpose of this paper is to explore the role that the psychological study of decision processes can play in facilitating societal risk taking. Over the past 25 years, empirical and theoretical research on decision making under risk has produced a body of knowledge that should be of value to those who seek to understand and improve societal decisions. After reviewing aspects of this research that we believe particularly relevant, we will focus on some of the many important questions that remain unanswered, even unstudied. There is an urgent need to link the study of man's judgmental and decision-making capabilities to the making of decisions that affect the health and safety of the public. We are not suggesting that the researcher abandon the laboratory completely, but it seems time for him to look out the window, and even foray occasionally into the real world. Fortuitously, it seems likely that, while commuting between the real world and the laboratory, he will uncover many stimulating basic problems lurking in applied guise.

The paper is organized around three questions: (a) What are some of the basic policy issues regarding societal risk? (b) What do we already know that is relevant? (c) What more do we need to know and how might we acquire that knowledge?

Basic Issues

The issues involved in policy making for societal risks can best be discussed within the contexts of specific problem areas. Two such areas are presented in this section.

Natural Hazards

Natural hazards constitute an enormous problem. For example, the mean annual cost of natural disasters in the U.S. is approaching $10 billion (Wiggins, 1974). A major earthquake in an urban area could cause $20 billion in property damage (Gillette & Walsh, 1971), not to mention the accompanying human misery, anguish, and death.

The question facing public policy makers is: What sorts of measures should be employed to maximize the benefits of one's natural environment, while, at the same time, minimizing the social and economic disruption due to disasters? In the case of floods, the policy options that have been tried or considered include compulsory insurance, flood control systems, strict regulation of land usage, and massive public relief to victims.

Not surprisingly, technologically advanced countries have opted for technological solutions such as dams. It is now recognized that, ironically, these well-intended programs have often exacerbated, the problem. Although the U.S. government has spent more than $10 billion since 1936 on flood control structures, the mean annual toll of flood losses has risen steadily (White, 1964). The damage inflicted upon Pennsylvania in 1972 by flooding associated with Hurricane Agnes exceeded $3 billion despite the fact that the area was protected by some 66 dams. Apparently, the partial protection offered by dams gives residents a false sense of security and promotes overdevelopment of the flood plain. As a result of this over-development, when a rare flood does exceed the capacity of the dam, the damage is catastrophic. Perpetuating the problem, the victims of such disasters typically return and rebuild on the same site (Burton, Kates, & White, 1968). Thus, flood control dams have been called technological man's ultimate folly. The lesson to be learned is that technological solutions are likely to be inadequate without knowledge of how they will affect the decision making of individuals at risk.

The current focus of debate over public policy is the question of compulsory disaster insurance. Kunreuther (1973) noted that, whereas few individuals protect themselves voluntarily against the consequences of natural disasters, many turn to the federal government after suffering losses. Federal relief funds have been ample enough to leave many individuals better off financially after the disaster than before. As a result, the taxpayer is burdened with financing the recovery for those who could have financed much of their own recovery by purchasing insurance. Kunreuther and others have argued that both property owners and the federal government would be better off financially under an insurance program than under a disaster relief program. They recommend federal flood-insurance policies which both shift the burden of disasters from the general taxpayer to individuals living in hazard-prone areas and promote wiser decisions regarding use of flood plains. One possible option would allow individuals to qualify for federally subsidized insurance only after their communities had taken steps towards reducing losses by enforcing land use measures and building codes. Another would make eligibility for federal disaster relief loans contingent upon the individual's having had at least some hazard insurance. A third would set insurance rates proportional to the magnitude of risk in order to inform residents of those risks and deter development of high risk areas.

Without a better understanding of how people perceive and react to risks, however, there is no way of knowing whether any of these options would have the desired effect. For example, although there is evidence that people will not voluntarily insure themselves even if the rates are highly subsidized, the reasons for this are unknown. Knowledge of the interplay between psychological, economic, and environmental factors as they determine insurance purchasing might suggest ways to increase voluntary purchases--or indicate the need for a compulsory insurance program.

Nuclear Power

The problem of deciding society's level of dependence upon nuclear energy is so well known as to require little introduction. Policy makers in this area face not only the problems of guessing how the public will react to various plans, but also the question of weighing the risks and benefits of a technology for which relevant operating experience is so limited that they must extrapolate far beyond available data.

One major issue in the nuclear power controversy is determining the locus of decision-making authority and the nature and amount of public input. At one extreme are those who argue that decisions about nuclear development should be left to technical experts and to policy makers trained in sophisticated decision analytic techniques. Resistance to this view is exemplified by Denenberg (1974) who insisted that "Nuclear safety is too important to be left to the experts. It is an issue that should be resolved from the point of view of the public interest, which requires a broader perspective than that of tunnel-visioned technicians."

At present, weighing of benefits vs. risks has degenerated into a heated controversy over the magnitude of the risks from loss-of-coolant accidents, sabotage, theft of weapon's grade materials, and long-term storage of wastes. Some experts argue that nuclear power is extraordinarily safe; others vigorously dissent and have mobilized numerous public interest groups in opposition to the nuclear menace. The development of nuclear power has been brought to near standstill by adverse public opinion. Ralph Nader's battlecry portends one likely result of public participation:

> "Let me make a prediction here. I don't think that there will be another nuclear plant built in this country. . . after five years. I think that there is going to be the biggest environmental, legal, legislative, executive branch, citizen, consumer battle in the history of the country. And what happened to the SST will be a spring picnic compared to the struggles that are going to come forward on nuclear fission power" (Nader, 1974).

If the opponents of nuclear power are right about the risks, every reactor built is a catastrophe. If they are wrong, following their advice may be equally costly to society.

What contributions can cognitive psychologists make towards resolution of this controversy? Several possibilities exist. First, they can help develop judgmental techniques to assist engineers in assessing probabilities of failure for systems in which relevant frequentistic experience is lacking. Second, they can attempt to clarify, from a psychological standpoint, the advantages and disadvantages of various methods of performing risk-benefit evaluations and determining acceptable levels of risk. Third, they can assist the layman trying to understand what the professionals' analyses mean. Even the most astute technical analysis will be of little value if its assumptions and results cannot be communicated accurately to the individuals who bear ultimate decision-making responsibility. Fourth, psychological study of man's ability to think rationally about probabilities and risks will be essential in determining the appropriate roles of expert and layman in the decision-making process.

Psychological Knowledge Relevant to Societal Risk Taking

Early Work

The classic view of man's higher mental processes assumes him to be an intellectually gifted creature. A statement typical of this esteem was expressed by economist Frank Knight: "We are so built that what seems reasonable to us is likely to be confirmed by experience or we could not live in the world at all" (Knight, 1921, p. 227).

With the dawn of the computer era and its concern for information processing by man and machine, a new picture of man began to emerge. Miller (1956) in his famous study of classification and coding, showed that there are severe limitations on our ability to process sensory signals. About the same time, the close observation of performance in concept formation tasks led Bruner, Goodnow, and Austin (1956) to conclude that the task imposed a condition of "cognitive strain" that their subjects tried to reduce by means of simplification strategies. The processing of conceptual information is currently viewed as a serial process, constrained by limited short-term memory and a slow storage in long-term memory (Newell & Simon, 1972). With regard to symbol manipulation, we are certainly no match for a computer.

But what of the more direct forms of decision-making activities we humans use to attain our objectives? Here, too, classic assumptions of rationality have been challenged on psychological grounds. A leading challenger has been Simon (1957) whose theory of "bounded rationality" asserts that the cognitive limitations of the decision maker force him to construct a simplified model of the world in order to deal with it. Simon argued that the decision maker

> ". . . behaves rationally with respect to this [simplified] model, and such behavior is not even approximately optimal with respect to the real world. To predict his behavior, we must understand the way in which this simplified model is constructed, and its construction will certainly be related to his psychological properties as a perceiving, thinking, and learning animal" (Simon, 1957, p. 198).

Recent Studies of Probabilistic Information Processing

Because of the importance of probabilistic reasoning to decision making, a great deal of recent experimental effort has been devoted to understanding how people perceive and use the probabilities of uncertain events. By and large, this research provides dramatic support for Simon's concept of bounded rationality. The experimental results indicate that people systematically violate the principles of rational decision making when judging probabilities, making predictions, or otherwise attempting to cope with probabilistic tasks. Frequently these violations can be traced to the use of judgmental heuristics or simplification strategies. These heuristics may be valid in some circumstances but in others they lead to biases that are large, persistent, and serious in their implications for decision making. Because much of this research has been summarized elsewhere (Slovic, Kunreuther & White, 1974; Tversky & Kahneman, 1974), coverage here will be brief.

Misjudging sample implications. After questioning a large number of psychologists about their research practices and studying the designs of experiments reported in psychological journals, Tversky and Kahneman (1971) concluded that these scientists seriously underestimated the amount of error and unreliability inherent in small samples of data. They expected samples drawn from a given population to be more similar to one another and to the population than sampling theory predicts. As a result, these scientists (a) had unreasonably high expectations about the replicability of results from a single sample; (b) had undue confidence in early results from a few subjects; (c) gambled their research hypotheses on small samples without realizing the extremely high odds against detecting the effects being studied; and (d) rarely attributed any unexpected results to sampling variability because they found a causal explanation for every discrepancy. Results similar to these in quite different contexts have been obtained by Berkson, Magath and Hurn (1939) and Brehmer (1974). However, people are not always incautious when drawing inferences from samples of data. Under certain circumstances they become quite conservative, responding as though data are much less diagnostic than they truly are (Edwards, 1968).

In a study using Stanford undergraduates as subjects, Kahneman and Tversky (1972) found that many of these subjects did not understand the fundamental principle of sampling--that the validity of a sample increases as the sample size gets larger. They concluded that "For anyone who would wish to view man as a reasonable intuitive statistician, such results are discouraging" (p. 445).

Errors of prediction. Kahneman and Tversky (1973) contrasted the rules that determined peoples' intuitive predictions with the normative principles of statistical prediction. According to the normative theory, prior probabilities or base rates, which summarize what we knew before receiving evidence specific to the case at hand, should remain relevant even after such evidence is obtained. People were found to behave differently. They relied almost exclusively on the specific information and neglected the prior probabilities. Similar results have been obtained by Hammerton (1974) and by Lyon and Slovic (1975).

Another normative principle is that the variance of one's predictions should be sensitive to the validity of the information on which the predictions are based. If validity is not perfect, predictions should be regressed towards some central value. Furthermore, the lower the validity of the information on which predictions are based, the greater the regression should be. Kahneman and Tversky (1973) observed that otherwise intelligent people have little or no intuitive understanding of the concept of regression. They fail to expect regression in many situations when it is bound to occur and, when they observe it, they typically invent complex but spurious explanations. People fail to regress their predictions towards a central value even when they are using information that they themselves consider of low validity.

Kahneman and Tversky also found that the internal consistency of a pattern of predictive cues is a major determiner of confidence in one's predictions based on these cues. The normative model asserts that, given input variables of stated validity, accuracy of prediction decreases as redundancy increases, However, people tend to have greater confidence in predictions based upon highly redundant or correlated predictor variables. Thus, the effect of redundancy on confidence is opposite what it should be.

Availability bias. Another form of judgmental bias occurs from the use of the "availability" heuristic, (Tversky and Kahneman, 1973). This heuristic involves judging the probability or frequency of an event by the ease with which relevant instances are imagined or by the number of such instances that are readily retrieved from memory. In life, instances of frequent events are typically easier to recall than instances of less frequent events and likely occurrences are usually easier to imagine than unlikely ones; thus mental availability will often be a valid cue for the assessment of frequency and probability. However, availability is also affected by many subtle factors which are unrelated to actual frequency, such as recency and emotional saliency. If the availability heuristic is applied, then factors that increase the availability of instances should correspondingly increase the perceived frequency and subjective probability of the events under consideration. Thus, reliance on availability may result in serious and predictable biases in judgment as the experiments by Tversky and Kahneman demonstrate.

Anchoring biases. Bias also occurs when a judge attempts to ease the strain of processing information by following a process of anchoring and adjustment. In this process, a natural starting point is used as a first approximation to the judgment, an anchor, so to speak. This anchor is then adjusted to accommodate the implications of the additional information. Typically, the adjustment is a crude and imprecise one which fails to do justice to the importance of additional information. Recent work by Tversky and Kahneman (1974) demonstrates the fact that adjustments tend to be insufficient. They asked subjects questions such as "What is the percentage of people in the U. S. today who are age 55 or older?" They gave the subjects starting percentages that were randomly chosen and asked the subjects to adjust these starting points until they reached their best estimate. Because of insufficient adjustment, those whose starting points were too high ended up with higher estimates than those who started with a value that was too low.

Application of the anchoring and adjustment heuristic is also hypothesized to produce the serious bias that occurs when people attempt to express the degree to which they are uncertain about an estimate or prediction. Specifically, in studies by Alpert and Raiffa (1968) and Schaefer and Borcherding (1973), subjects were given almanac questions such as the following:

How many foreign cars were imported into the U.S. in 1968?

a) Make a high estimate such that you feel there is only a 1%

probability the true answer would exceed your estimate.

b) Make a low estimate such that you feel there is only a 1% probability the true answer would be below this estimate.

If subjects' answers were unbiased, we should expect the true answers to such questions to fall between the upper and lower bounds 98% of the time. What is typically found, however, is that subjects set the bounds much too narrowly. The true value exceeds the bounds as much as 40% of the time across many subjects answering many questions. Subjects appear to use a computational algorithm to devise a best guess which serves as an anchor. Their boundary estimates are then determined by adjusting this best estimate. These adjustments tend to be insufficient in magnitude, failing to do justice to the many ways in which the initial estimate can be in error.

Lichtenstein and Slovic (1971, 1973) observed that anchoring and adjustment leads people to make judgments about the attractiveness of gambles that are inconsistent with their choices among those same gambles. When confronted with a pair of gambles, one offering a high probability to win a modest amount and the other offering a modest probability to win a large amount, subjects tend to choose the high probability gamble as most attractive but state higher selling or buying prices for the high payoff gambles. This inconsistency derives from the fact that people who find a gamble attractive use the amount to win as a natural starting point for attaching a monetary price to it. When they adjust the amount to win downward, to take probability and amount to lose into account, the adjustment tends to be rather small, leaving their final price rather close to the amount to win. Thus gambles with large winning payoffs are overvalued by this monetary index of attractiveness.

Hindsight biases. A series of experiments by Fischhoff (1974, 1975; Fischhoff & Beyth, 1975) has examined the phenomenon of hindsight. Fischhoff found that being told some event has happened increases our feeling that it was inevitable. We are unaware, however, of this effect of knowing how the outcome turned out, and tend to believe that this inevitability was apparent in foresight, before we knew what happened. In retrospect, we tend to believe that we (and others) had a much better idea of what was going to happen than we actually did have. Fischhoff (1974) shows how such misperceptions can seriously prejudice the evaluation of decisions made in the past and limit what is learned from experience.

Comment

Since these experimental results greatly contradict our traditional image of man, it is reasonable to question whether the observed inadequacies of probabilistic thinking would persist outside the laboratory in situations where decision makers use familiar sources of information to make decisions that are personally important to them.

Much evidence suggests that the laboratory results will generalize. These cognitive limitations appear to pervade a wide variety of tasks where intelligent individuals served as decision makers, often under conditions that maximized motivation and involvement. For example, the subjects studied by Tversky and Kahneman (1971) were scientists, highly trained in statistics, evaluating problems similar to those they faced in their own research. Overdependence on specific evidence and neglect of base rates has been observed among psychometricians responsible for the development and use of psychological tests (Meehl & Rosen, 1955).

When Lichtenstein and Slovic (1971) observed anchoring bias in subjects' evaluations of gambles, they repeated the study, with identical results, on the floor of a Las Vegas casino (Lichtenstein & Slovic, 1973).

Particularly relevant to the present paper is evidence illustrating these sorts of biases in individuals attempting to cope with natural disasters. For example, availability biases are apparent in the behavior of residents on the flood plain. Kates (1962, p. 140) writes:

> "A major limitation to human ability to use improved flood hazard information is a basic reliance on experience. Men on flood plains appear very much to be prisoners of their experience. . . Recently experienced floods appear to set an upward bound to the size of loss with which managers believe they ought to be concerned."

Kates further attributes much of the difficulty in achieving better flood control to the "inability of individuals to conceptualize floods that have never occurred" (p. 88). He observes that, in making forecasts of future flood potential, individuals "are strongly conditioned by their immediate past and limit their extrapolation to simplified constructs, seeing the future as a mirror of that past" (p. 88). A more detailed linkage between psychological research, bounded rationality, and behavior in the face of natural hazards is provided by Slovic, Kunreuther, and White (1974).

One additional implication of the research on man's limited ability to process probabilistic information deserves comment. Most of the discussions of "cognitive strain" and "limited capacity" that are derived from the study of problem solving and concept formation depict man as a computer which has the right programs but cannot execute them properly because its central processor is too small. The biases due to availability and anchoring certainly are congruent with this analogy. But the misjudgment of sampling variability and the errors of prediction illustrate more serious deficiencies. Here we see that man's judgments of important probabilistic phenomena are not merely biased but are fundamentally wrong. Returning to the computer analogy, it appears that man lacks the correct programs for many important judgmental tasks.

How could it be that we lack adequate programs for probabilistic thinking? Sinsheimer (1971) argues that man's brain has been designed by evolution to cope with certain very real problems in the immediate, external world and thus lacks the conceptual framework with which to encompass many phenomena. He comments on how much more difficult it is to teach a 17-year-old a few laws of physics than to teach him or her to drive a car:

> "To drive a car, a 17-year-old makes use of a set of routines long since programmed into the primate brain. To gauge the speed of an approaching car and maneuver accordingly is not that different from [gauging] the speed of an approaching branch and [reacting] accordingly as one swings through the trees . . . . Whereas to solve a problem in diffraction imposes an intricate and entirely unfamiliar task upon a set of neurons" (Sinsheimer, 1971, p. 21).

In the past as in the present, man's decision making has largely ignored uncertainty, relying either on habit (tradition) or simple deterministic rules. Following Sinsheimer's reasoning, it might be argued that man has not had the opportunity to evolve an intellect capable of dealing conceptually with uncertainty. He is essentially a trial-and-error learner and it remains to be seen whether he can change his ways in the nuclear age when errors may be catastrophic.

Where Do We Go From Here?

Suppose that individuals and society are unfit to think rationally about uncertainty. What are they to do? A traditional solution has been to defer to technical experts, trained in dealing with uncertainty. To some extent, this strategy may work. Adopting it, however, incurs a societal risk of quite another sort, the creation of a technocratic state. In addition, as both the evidence described above suggests and the consumer advocates loudly claim, experts, too, are prone to biases. Experts certainly are better than lay people at many tasks for which solution algorithms are available, such as building a dam or managing an inventory. When, however, they are confronted with a new or poorly defined problem for which their algorithms fail to apply, or for which they must supply subjective inputs to those algorithms, they may do no better than the rest of us.

Psychological research can contribute by identifying the major sources of error in societal risk-taking decisions and by devising techniques to minimize those errors. In the remainder of this paper we shall speculate about some of the directions this research could take.

Evaluating Low-Probability, High-Consequence Events

The most important public hazards are events with extremely low probabilities and extremely great consequences. For example, Holmes (1961) found that 50% of the damage due to major floods was caused by floods whose probability of occurrence in any year was less than .01. The city of Skopje, Yugoslavia was leveled by earthquakes in the years 518, 1555, and 1963, and the mudflow that took 25,000 lives in Yungay, Peru, had swept across the same valley between 1,000 and 10,000 years before. The probability of serious radiation release from a nuclear power reactor has been estimated at between 10^{-4} and 10^{-9} per reactor year. Despite the obvious significance of understanding how (and how well) experts and laymen estimate probabilities for such events, there has been little or no systematic study of this problem (for an important exception to this statement, see Selvidge, 1975). Some approaches to this research are illustrated below.

<u>Availability biases</u>. We have recently been studying people's perceptions of low-probability, high-consequence events. Our stimuli were 41 causes of death, including diseases, accidents, homicide, suicide, and natural hazards. The probability that a randomly selected U.S. resident would succumb to one of these events in a year ranges from about 1×10^{-8} (botulism) to 1.6×10^{-3} (cancer) and 8.5×10^{-3} (heart disease). We constructed 106 pairs of these events and asked a large sample of college students to indicate, for each pair, the more likely cause of death and the ratio of the greater frequency to the lesser frequency.

We found that (a) our subjects had a consistent subjective ordering of relative frequency for causes of death; (b) this subjective ordering often deviated markedly from the true ordering; (c) with a few notable exceptions, the subjects could accurately discriminate the pairwise relative frequencies of causes of death when the true ratio of greater to lesser frequency was 5:1 or more. At true ratios of 2:1 or below, discrimination was poor. A subset of the detailed results is presented in Table 1.

Insert Table 1 about here

Kates' (1962) research suggests that evaluations of low-probability, high-consequence events are likely to be influenced greatly by factors such as personal experience, imaginability, and memorability. To determine the extent that the misperceptions we observed can be accounted for by "availability factors", we had a separate group of subjects rate each event in terms of their exposure to it via the media and via their own personal experiences with the event as a cause of suffering and death. From these ratings, an availability score was given to each event, a high score indicating a high degree of exposure to the event, across subjects. The difference in

TABLE 1

Judgments of Relative Frequency for Selected Pairs of Lethal Events

Less Likely	More Likely	True Ratio	% Correct Discrimination	Geometric Mean of Judged Ratios [a]
Asthma	Firearm Accident	1.20	80	11.00
Breast Cancer	Diabetes	1.25	23	.13
Lung Cancer	Stomach Cancer	1.25	25	.31
Leukemia	Emphysema	1.49	47	.58
Stroke	All Cancer	1.57	83	21.00
All Accidents	Stroke	1.85	20	.04
Pregnancy	Appendicitis	2.00	17	.10
Tuberculosis	Fire & Flames	2.00	81	10.50
Emphysema	All Accidents	5.19	88	269.00
Polio	Tornado	5.30	71	4.26
Drowning	Suicide	9.60	70	5.50
All Accidents	All Diseases	15.50	57	1.62
Diabetes	Heart Disease	18.90	97	127.00
Tornado	Asthma	20.90	42	.36
Syphilis	Homicide	46.00	86	31.70
Botulism	Lightning	52.00	37	.30
Flood	Homicide	92.00	91	81.70
Syphilis	Diabetes	95.00	64	2.36
Botulism	Asthma	920.00	59	1.50
Excess Cold	All Cancer	982.00	95	1490.00
Botulism	Emphysema	10,600.00	86	24.00

[a] Geometric means less than 1.00 indicate that the mean ratio was higher for the less likely event. A geometric mean of .20 implies the mean was 5:1 in the wrong direction.

these scores for paired events was found to correlate .57 with a "misperception" index for each pair. Consideration of the specific events that appear most overestimated (botulism, tornadoes, accidents) with those most underestimated (asthma, emphysema, diabetes) further strengthens our belief regarding the importance of differential media publicity and imaginability in probability assessment. Further indirect support for the availability hypothesis is that accuracy increases somewhat with increasing absolute frequency (and thus exposure) for the events in question. At present, we are studying whether subjects informed about the nature of availability bias will perform better than the subjects in our first experiment.

Many other questions remain to be asked. For example, will the results of the first study vary across subject populations? Perhaps older people will have different perceptions of the risks for events to which they are most susceptible. Do men and women differ in their judgments? Are people more accurate in gauging higher-probability chronic hazards such as drowning or automobile accidents than rarer, but more spectacular catastrophes such as floods and tornadoes? Economists such as Bergstrom (1974) have hypothesized that there will be greater divergence of opinion about the probability of catastrophes than about the probability of death from chronic sources and that this, in turn, will lead to more disagreement on how much it is worth to attempt to prevent a catastrophe. These hypotheses can and should be put to empirical test.

The important implication of this exploratory study is that, contrary to the assumptions of many policy makers, intelligent individuals may not have valid perceptions about hazardous events to which they are exposed.

<u>Fault-tree analysis</u>. The previous section illustrates the manner in which the psychological construct of availability might influence the intuitive assessment of low-probability, high-consequence events. The present section considers the manner in which psychological analysis, again using availability along with other considerations, might help technical experts in their use of sophisticated techniques such as fault-tree analysis to assess the probabilities of rare hazards.

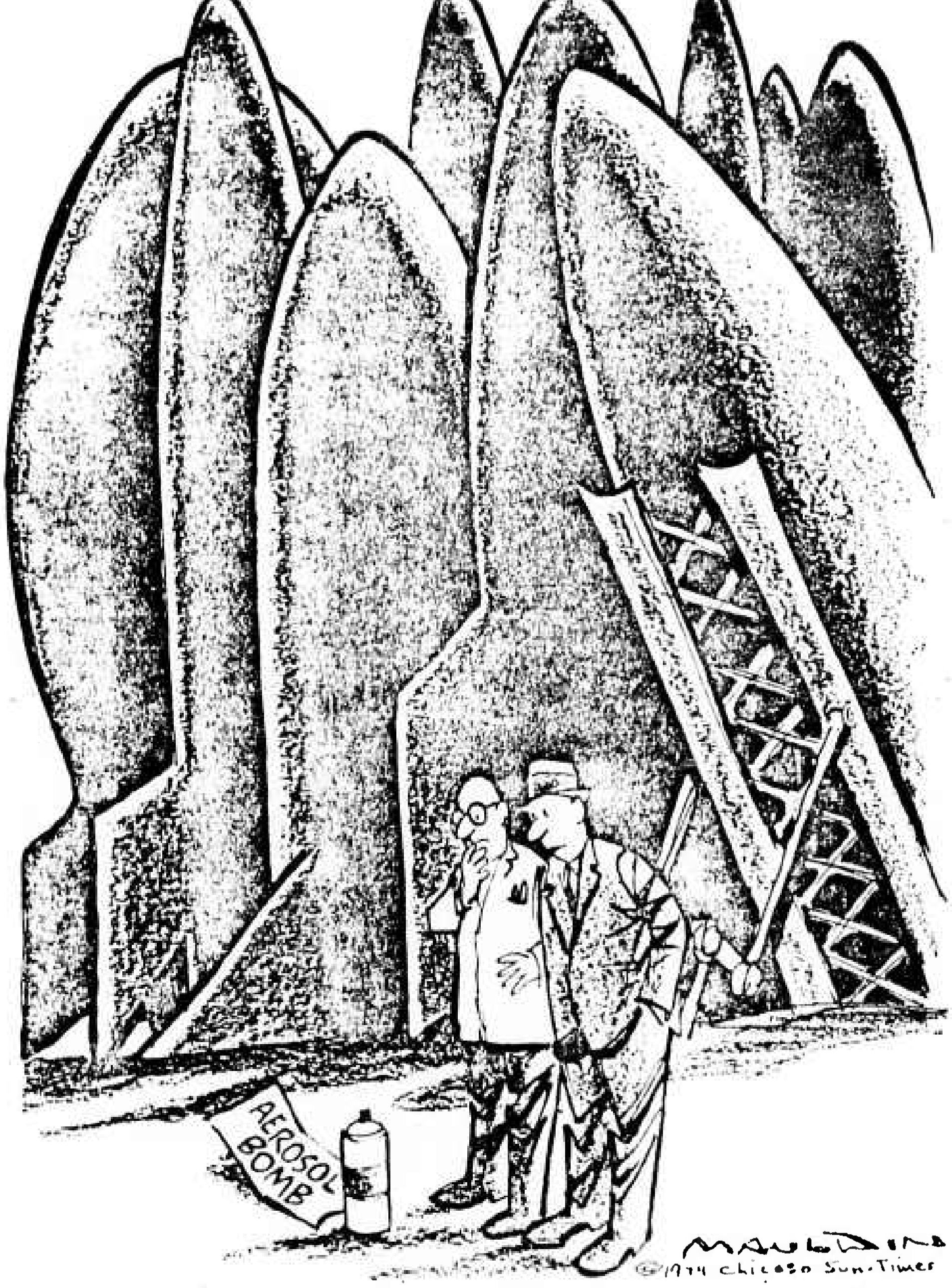
When frequentistic data for failure rates of a complex system are unavailable, many technical experts believe that an analytic estimate can be obtained by constructing a fault tree. Construction begins by listing all important pathways to failure, then listing all possible pathways to these pathways, and so on. When the desired degree of detail is obtained, probabilities are assigned to each of the component pathways--and then combined to provide an overall failure rate. For example, major pathways in a fault tree designed to calculate the probability of a car failing to start would include defects in the battery, starting system, fuel system, ignition system, etc. Battery deficiency could, then, be traced to loose terminals or weak battery charge. The latter could be further analyzed into its component causes, such as lights left on, cold weather, defective generator, etc. The likelihoods of these separate events would be combined to produce an estimate of the overall probability of starting failure.

The importance of fault-tree analysis is demonstrated by its role as the primary methodological tool in a recently completed study assessing the probability of a catastrophic loss of coolant accident in a nuclear power reactor (Rasmussen, 1974). The study, sponsored by the Atomic Energy Commission at a cost of $2 million, concluded that the likelihood of such an accident ranged between 10^{-5} (for an accident causing 10 deaths) to 10^{-9} (for a 1,000-death accident) per reactor-year. Fault-tree analysis has, however, recently come under attack from critics who question whether it is valid enough to be used as a basis for decisions of great consequence (e.g., Bryan, 1974).

Psychologists may be able to improve the effectiveness of fault trees by identifying biases which may afflict fault tree users and by shoring up the methodology. One methodological problem which psychologists surely could address is deciding by what technique (e.g., direct estimation, paired comparisons, Delphi methods) failure rates for component parts should be estimated. One possible source of bias worth investigating arises from the fact that one rarely has complete failure rates on all the component parts of a complex system. Such rates are typically estimated from slightly different parts or parts that were developed for a different purpose. Anchoring and adjustment may well play a role here, possibly leading to estimates more suitable for the original part or original context than for the one in question.

Another possible bias would be the omission of relevant pathways to failure or disaster. A tree used to estimate starting failure in an automobile could, for example, be seriously deficient if it failed to include problems with the seat belt system (for 1974 models), theft of vital parts, or other vandalism.

The dangers of omitting relevant pathways to disaster should not be underestimated. The cartoon by Mauldin dramatizes this problem, reflecting the recent reports that the ozone layer, which protects the earth from solar radiation, may be damaged by the fluorocarbons released by aerosol products. In the innumerable scenarios which have been created to evaluate the major risks of technology to mankind, who would have thought prior to this discovery to include hair sprays and deodorants as lethal agents?



'So THAT'S the one most likely to get us'

Insert Cartoon about here

We suspect that, in general, experts will not be adequately sensitive to those avenues to disaster that, due to lack of knowledge, forgetting, or lack of imagination, they have failed to consider. We would assume the expert to be unaware of his omissions and, therefore, to be unduly confident in the completeness of his analysis and the validity of his estimate. Experts who are unaware of their own omissions are likely to seriously underestimate the true failure rate. This hypothesis can surely be tested experimentally.

Even if technical experts can be helped to produce better estimates, problems with the fault tree would not be over. With most societal decisions, ultimate decision-making responsibility lies with either the general public or political policy makers. The finest analysis will be of little value if it cannot be communicated to these people. Considerations of availability suggest that fault-tree analysis is a technique whose results are particularly prone to creating misconceptions. For example, naive observers of a fault tree may be startled by the variety of possible pathways to disaster, some of which will be new and surprising to them. Unless they combat the increased imaginability of disaster pathways by properly discounting the less probable paths, they are likely to overreact, perceiving the risk to be greater than it is. Furthermore, the larger and bushier a tree is--in the detail with which specific components of each major pathway are presented--the greater the misperception may be. Thus, analyses intended to clarify decision makers' perceptions may, instead, distort them.

Critics of nuclear power often appear to be playing on these proclivities. Consider this message from Alfven (1972): "Fission energy is safe only if a number of critical devices work as they should, if a number of people in key positions all follow their instructions, if there is no sabotage, no hijacking of the transports, . . . No acts of God can be permitted" (p. 6).

Although Alfven's statement is an extreme position, availability effects may make it difficult even to engage in unbiased attempts at discussing low probability hazards without, at the same time, increasing the perceived probability of those hazards. This may explain, in part, why continued discussions of nuclear power risks have led to increased resistance to this technology. Ultimately, public acceptance of new, high risk technologies may be determined more by psychological considerations than by the opinions of technical experts.

Coherence and the judged probability of scenarios. Forecasts and predictions of high consequence events are often developed within the context of scenarios. Some recent examples are "The Day They Blew Up San Onofre" (Schleimer, 1974), describing the sabotage of a nuclear reactor and its consequences, and "The Oil War of 1976" (Erdmann, 1975) describing how the world as we know it comes to an end when the Shah of Iran decides to take it over with Western arms. A scenario consists of a series of events linked together in a narrative form. Normatively, the probability that a multi-event scenario will happen is a multiplicative function of the probabilities of the individual links. The more links there are in the scenario, the lower the probability that the entire scenario will occur. The probability of the weakest link sets an upper limit on the probability of the entire narrative.

Human judges don't appear to evaluate scenarios logically. We have begun collecting data that suggest that the probability of a multi-link scenario is judged according to its overall coherence, where coherence represents a global impression based on the average likelihood of all linkages. Subsequent strong links appear to "even out" or compensate earlier weak links, making it possible to construct scenarios whose perceived probability <u>increases</u> as they become longer, more detailed, and <u>normatively less probable</u>. Consider the following example of such a scenario:

> "Tom is of high intelligence, although lacking in true creativity. He has a need for order and clarity, and for neat and tidy systems in which every detail finds its appropriate place. His writing is rather dull and mechanical, occasionally enlivened by somewhat corny puns and by flashes of imagination of the sci-fi type. He has a strong drive for competence. He seems to have little feel and little sympathy for other people and does not enjoy interacting with others.
>
> In the light of these data, what is the probability that (a) Tom W. will select Journalism as his college major (b) but quickly become unhappy with his choice and (c) switch to Engineering?"

When subjects were given the initial conditions contained in the first paragraph and asked to estimate the probability of subsequent event <u>a</u>, Tom's selection of journalism as his college major, their mean estimate was .21. When they were asked to estimate the compound probability of statements <u>a</u> and <u>b</u>, given the same initial conditions, the mean probability rose to .39. When they were asked to estimate the compound event consisting of statements <u>a</u>, <u>b</u> and <u>c</u>, the mean probability rose to .41.

These startling results suggest that scenarios are really quite difficult to evaluate properly. Specifically, well constructed scenarios, ones which tell a "good story", may be accorded much more credibility than they deserve.

Experiments are needed to clarify the cognitive processes used in the evaluation of scenarios and the biases to which these processes are susceptible. It is important to determine the qualities of scenarios that lead them to appear feasible or not feasible. We suspect that scenarios mislead by burying weak links in masses of coherent, appealing details and by giving no hint of alternative scenarios or no indication of how the proposed scenario could go wrong. Writers of scenarios may be deceiving themselves as well as others by failing to incorporate probabilistic considerations into their narratives.

Debiasing Procedures

Much of the research described above focuses on identifying judgmental biases and understanding their cognitive underpinnings. Once disseminated to individuals in non-technical form, this knowledge can alert them to biases in their own judgments as well as in the information and recommendations they receive from others. Full utilization of this knowledge, however, requires the development of specific procedures to circumvent and/or correct biases.

Work on formulating and testing debiasing procedures needs to be undertaken, and will depend, of course, upon further developments in our understanding of the biases themselves. An obvious first step is simply to educate or warn the judge about the bias. If this fails, more sophisticated techniques will have to be devised. For example, to combat coherence biases in the evaluation of scenarios, it may be necessary to decompose the scenario into its component events, estimate conditional probabilities for individual events given preceding developments, and then combine these conditional probabilities mathematically to produce an overall evaluation (see Edwards & Phillips, 1964, for details of a similar approach to combat a different bias). Alternatively, one could insist on the production of multiple alternative scenarios on any given topic and use an adversary approach to evaluation in which the merits and disadvantages of each are debated. The whole area of debiasing is open for development and in need of creative research.

Psychological Considerations in Risk-Benefit Analysis

The application of scientific methods and formal analyses to problems of decision making originated during World War II from the need to solve strategic and tactical problems in situations where experience was either costly or impossible to acquire. One of the offshoots of this work is the technique called "cost-benefit analysis", which attempts to quantify the prospective gains and losses from some proposed action, usually in monetary terms.

If the calculated gain from an act or project is positive, it is said that the benefits outweigh the costs and its acceptance is recommended, providing no other alternative affords a better cost-benefit ratio. A good example of this is the analysis of auto-safety features by Lave and Weber (1970). Risk-benefit analysis is a special case in which explicit attention is given to quantifying costs due to loss of life or limb, pain, and anguish.

Risk-benefit analysis, still in its early stages of development, is being counted on to provide the basic methodological tools for societal risk-taking decisions. This nascent methodology clearly has important political, economic, social, and technical components. In this section, we shall explore the manner in which certain of these components interact with various psychological considerations as risks and benefits are assessed and evaluated.

<u>How safe is safe enough</u>? Any risk-benefit analysis must ultimately answer the question "How safe is safe enough?" Starr (1969) has proposed a quantitative technique for answering this question based on the assumption that society learns by trial, error, and subsequent corrective actions to arrive at a reasonably optimal balance between the risks and benefits associated with any activity. This leads to the use of historical accident and fatality records to reveal patterns of "acceptable" risk-benefit ratios. Acceptable risk for a new technology becomes that level of safety associated with ongoing activities having similar benefit to society.

Starr illustrates his technique by examining the relationship between risk and benefit across a number of common activities. His measure of risk for these hazardous activities is the statistical expectation of fatalities per hour of exposure to the activity under consideration. Regarding benefits, Starr distinguishes between voluntary risk-taking activities (e.g., sports, smoking, flying in private aircraft), which the individual can engage in or not according to his own value system, and involuntary activities (e.g., commercial aviation, energy production systems). For voluntary activities, benefit is assumed to be approximately equal to the average amount of money spent on an activity by an individual participant. For involuntary activities, benefit is assumed proportional to the contribution that activity makes to an individual's annual income.

Insert Figure 1 about here

The result of this analysis is shown in Figure 1. From this figure and related analyses, Starr concludes that (1) the public seems willing to accept voluntary risks roughly 1,000 times greater than involuntary risks at a given level of benefit; (2) the acceptability of a risk is roughly proportional to the real and perceived benefits; and (3) the acceptable level of risk is inversely related to the number of persons participating in an activity. Noting the similarity between risks accepted voluntarily and the risks of disease, Starr (1969, p. 1235) conjectures that: "The rate of death from disease appears to play, psychologically, a yardstick role in determining the acceptability of risk on a voluntary basis."

The Starr approach provides an intuitively appealing solution to a problem facing all risk-benefit analyses and, in fact, a similar approach has already been used to develop a building code regulating earthquake risk in Long Beach, California (Wiggins, 1972). There are, however, a number of serious drawbacks to this method. First, it assumes that past behavior is a valid indicator of present preferences. Second, it ignores recent psychological research which has revealed systematic biases which may prevent an individual from making decisions which accurately reflect his "true preferences"

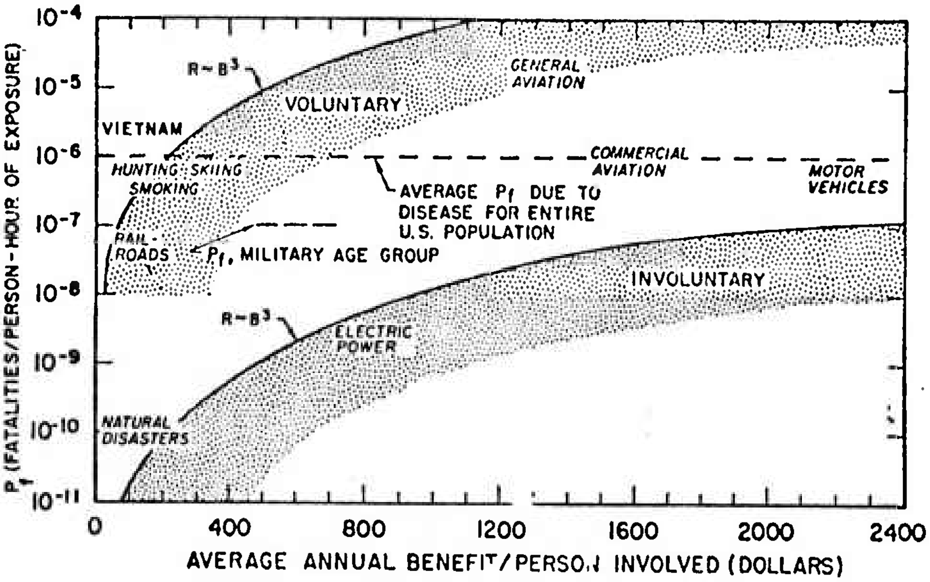


Figure 1. Risk (R) plotted relative to benefit (B) for various kinds of voluntary and involuntary exposure (from Starr, 1969).

(e.g., Lichtenstein & Slovic, 1971, 1973; Slovic & MacPhillamy, 1974). Third, misperception of risks as observed in the "causes of death" study described above could reduce the validity of historical preferences and certainly casts doubt upon Starr's interpretation regarding the "yardstick role" of disease rates. Fourth, the Starr approach assumes that the public has available a wide selection of alternatives from which to choose. Is it reasonable to assume, for example, that the public's automobile-buying behavior accurately reflects their preferences concerning the trade-off between safety and other benefits? Unless the public really knows what is possible from a design standpoint, and unless the automobile industry cooperates in making available information that may not necessarily serve its own profit maximation interests, the answer is likely to be no.

One avenue of research that might help circumvent these difficulties would be to examine risk-benefit trade-offs via judgmental techniques. Psychological measures of perceived risk and perceived benefit could be developed for major classes of activities. A judgmental space analogous to Starr's could then be constructed. Judgments of desired risk could be elicited in addition to judgments of actual risk. Analysis of these data would focus on the degree to which judged risk and benefit correlated with empirical calculations of these factors. In addition, Starr's results regarding voluntary vs. involuntary activities, level of perceived benefit, and number of persons participating in an activity could be validated by repeating his analyses within the judgmental risk-benefit space.

Perceived risk. It is surprising that, with the exception of a few studies using simple gambles as stimuli (see, for example, Coombs & Huang, 1970; Payne, 1975), the determinants of perceived risk remain unexplored.

Yet, there is anecdotal and empirical evidence of a number of phenomena meriting serious psychological study. One such phenomenon is society's apparent willingness to spend more to save a known life in danger than to save a statistical life. Is this true, and, if so, why? Second is the speculation that familiarity with a hazard reduces its perceived risk. Study of this question may provide insight into why the public tolerates levels of risk from some hazards (e.g., radiation from medical x-rays) that they would never tolerate from nuclear power plants. A third is the notion that hazards whose consequences are delayed (e.g., smoking) are discounted. Such time effects have rarely been studied. Fourth, it has been suggested that perceived risk is influenced by whether the locus of uncertainty lies in the probability that the hazardous event will occur or in the consequences when it does occur. Finally, it is almost certain to be true that perceived risk depends greatly upon the mode of presenting the relevant information. For example, risks from radiation may appear negligible when described in terms of average reduction in life expectancy for the population within a given radius of a nuclear power plant. However, when this figure is translated into number of additional cancer deaths per year, the risk may take on quite a different perspective.

Research on these phenomena may answer questions concerning the determinants of societal response to scientific information about risk. Growing concern over threats to our environment has led to expanded programs of scientific research on the effects of such hazards as herbicides, fertilizers, pesticides, pollution, radiation, etc. It has been assumed that publication of scientific information about these hazards would be sufficient to elicit appropriate public action. For reasons which are inadequately understood, this assumption seems not to be valid. Scientific information leads in some cases to hasty public action; in other cases, information goes unheeded (Lawless, 1975). While the determinants of societal response are undoubtedly complex, it seems likely that cognitive factors related to communication of information and perception of risk will play an important role.

Value of a life. Although the economic costs stemming from property damage, disruption of production, medical expenses, or loss of earnings can be estimated, we have no suitable scheme for evaluating the worth of a human life to society. Despite a certain aversiveness to thinking about life in economic terms, the fact is inescapable that by our actions we put a finite value on our lives. Decisions to install safety features, to buy life insurance, or to seek extra salary for a hazardous job all carry implicit values for a life.

Economists have debated for years the question of how to best quantify the value of a life (see, for example, Hirshleifer, Bergstrom & Rappaport, 1974; Mishan, 1971; Rice & Cooper, 1967; Schelling, 1968). The traditional economic approach has been to equate the value of a life with the value of a person's expected future earnings. Many problems with this index are readily apparent. For one, it fails to place a value on people in non-income earning positions. In addition, it ignores interpersonal effects wherein the loss suffered by the death of another bears no relation to the financial loss caused by the death. A second approach, equating the value of life with court awards (Holmes, 1970; Kidner & Richards, 1974) is hardly more satisfactory.

Bergstrom (1974) argues that the question "What is a life worth?" is ill-formed and what we really want to know is "What is the value placed upon a specified change in survival probability?" As with the Starr approach to assessing risk-benefit trade-offs, Bergstrom argues that the best way to answer this second question is by observing the actual market behavior of people trading risks for economic benefits. Thus, Thaler and Rosen (1973) studied salary as a function of occupational risk and found that a premium of about $200 per year was required to induce men in risky occupations to accept an annual probability of .001 of accidental death. From this, they inferred that the value of life, at the margin, is equivalent to about $200,000. Certainly, the same criticisms leveled earlier at the Starr approach apply to this method. It assumes that individuals have enough freedom of choice and perceptiveness of risks so that their preferences are valid indicators of their values.

We believe this question is too important for psychologists to ignore. They can contribute by testing the cognitive assumptions upon which the economic measures rest and by providing alternative methods of assessing the value of a life, such as direct questions or other psychophysical techniques. Preliminary attempts at this by Acton (1973) and Torrance (1970) have been downgraded by economists on the grounds that "Time and again, action has been found to contradict assertion. Since surveys always elicit some degree of _strategic_ behavior ("What do they want me to say?"), we would be better advised to observe what people choose under actual conditions" (Rappaport, 1974, p. 4). Whether attitudes or behaviors provide a more accurate reflection of people's values needs to be examined utilizing the broader perspective and expertise that psychology can provide.

Amalgamating economic and non-economic costs and benefits. One of the most common criticisms of risk-benefit analysis is that it has failed to incorporate the many components of risk and benefit that are not easily translated into a dollar amount.

The methodological technique presently being advocated for amalgamating economic and non-economic risks and benefits into an overall index of value suitable for guiding decisions is "multi-attribute utility analysis" (Huber, 1974). One version of this method proposed by Edwards (1971) uses a 10-step procedure for combining multiple outcomes into an overall utility. This procedure begins with structuring the problem by detailing decision alternatives and their attributes. Next the attributes are ranked in importance and then relative weights are assigned to them. Following this, the levels for each attribute are quantified, judgmentally, on a common scale of utility. The next-to-last step is calculation of utility for each alternative by multiplying scale values x weights and summing this over attributes. The final step, decision, involves selecting the alternative with the maximum sum. Thus far, multi-attribute procedures such as this have not been validated and some would argue that they are unvalidatable--a strong statement that bears scrutiny.

Justification. Decision makers will employ the new tools of risk-benefit analysis and multi-attribute utility theory to the extent that they believe that such tools lead to good decisions. What are the perceived characteristics of a good decision? Tversky (1972) and Slovic (1975, in press) have found evidence that decision makers rely on procedures that are easy to explain and easy to justify to themselves and others. If this is generally true, it may be that pre-decisional cognitive processes consist essentially of searching for or constructing a good justification, one that minimizes lingering doubts and can be defended no matter what outcome occurs. For people accustomed to relying upon such justifications, the validity of risk-benefit and multi-attribute utility techniques must be questioned. The early steps of such techniques, which involve structuring the problem and detailing alternatives and their attributes may be useful devices for helping the decision maker think deeply and in relevant ways about his problem. However, we have serious reservations about the quantification steps in which we may be forcing people to produce information at a level of precision that does not exist.

An alternative conceptualization, possibly more in tune with people's natural predilections, would have decision makers act like debaters, marshalling thorough and convincing arguments relevant to the decision at hand, rather than like computers making decisions on the basis of arithmetic (for a similar argument, see Mason, 1969).

These speculations lead naturally to the questions: "What are the components of justifiability? What makes a good justification?" Although we don't have any firm answers, we do have some hypotheses about factors that might _not_ be viewed favorably. We think subjective factors, such as subjective trade-off functions or opinions about probability not well supported by frequentistic data will be perceived as weak justifications for decisions in the face of risk. Subjective probabilities leave one vulnerable to second guessing--remember the designers of the Edsel explaining in 1961 that their carefully constructed opinions about the market indicated that it was likely to be a big seller. Expected value computations, another basic tool of the analytic approach to decision, may also make weak justifications because of their dependence on "long run" estimates; such estimates may not appear relevant for decisions viewed as one-shot affairs.

Will people view decisions based on shallow but nice-sounding, rationales (cliches, universal truths, adages) as better than decisions based upon complex, thorough decision-analytic techniques? The answer to this question obviously has important implications for understanding and predicting public decision makers' responses to information bearing upon technological risk. Roback (1972, p. 133) in discussing the defeat of the Supersonic Transport (SST) subsidy, provides anecdotal evidence in support of this conjecture.

> "There was not . . . a nice weighing of risk and benefit. . .. What counted most in the balance, I daresay, was the question that enough congressmen put to themselves before casting a vote: 'How will I explain to my constituents, the majority of whom have never even been on an airplane or traveled far from home, why we need an SST to save two or three hours' travel time between New York and Paris?'"

If these hypotheses are true, the risk-benefit analyst could be preparing analyses merely for his own edification, since few others would be likely to use them. In this event, research would be vital to teach us how to communicate risk-benefit and other valuable analytic concepts in a way that would enable such material to be woven into the fabric of convincing justifications.

Concluding Remarks

Our aims have been to summarize, from our own perspective, the state of psychological knowledge regarding decision making under risk and to attempt to convey our sense of excitement regarding the potential contributions of this branch of cognitive psychology to basic knowledge and societal well-being.

Our knowledge of the psychological processes involved in risk-taking decisions has increased greatly in recent years. However, we still have only a rudimentary understanding of the ways in which bounded rationality manifests itself. We know much about certain types of deficiencies and biases, but we don't know the full extent of their generality across tasks and across individuals of varying expertise. Nor do we know how to combat these biases. We still do not understand the psychological components of value and how they determine, or depend upon, decisions. We know little about perceived risk, the determinants of societal response to threat, modes of communicating information about risk, or the role of justifications in decision processes. Research in these problem areas is vital to the development of methodologies for societal decision making that can accomodate the limitations and exploit the specialties of the people who must perform and consume these analyses.

H. G. Wells once commented: "Statistical thinking will one day be as important for good citizenship as the ability to read and write." That day has arrived. Our discussion points to the need for educating both the technical experts and the public regarding the subtleties of statistical thinking. Such education should be incorporated into the curriculum of the schools, perhaps as early as in the lower grades. We need to teach people to recognize explicitly the existence of uncertainty and how to deal rationally with it. We must become accustomed to monitoring our decisions for consistency. We need to understand that the quality of a decision cannot be gauged solely by the quality of its outcome. We must recognize the distortions of hindsight when we evaluate the past.

Although the concept of bounded rationality arose within the mainstream of cognitive psychology (e.g., Miller's and Simon's work), research on decision processes has made little subsequent contact even with such closely related fields as the study of non-probabilistic information processing. It should. Certainly the phenomena described here cannot be fully understood without considerations of their underlying cognitive mechanisms. Likewise, some of these phenomena may provide stimulating inputs for general theories of cognition. The hindsight results, for example, indicate one way in which semantic memory is reorganized to accommodate new information. The bias here called availability suggests a need to better understand the process of constrained associates production. No theory of cognitive development appears to relate to the acquisition of judgmental biases and heuristics as conceptualized here. Without such knowledge, we have no idea when it is best, or when it is even possible, to begin teaching children to think probabilistically.

While this article has emphasized what psychologists can do to facilitate societal decision making, clearly a multidisciplinary approach, involving cooperative efforts with physicists, economists, engineers, geographers, and, perhaps most important, decision makers, is called for. Only by working hand in hand with decision makers can we learn what their problems are--both those they perceive and those they do not. Only continual multidisciplinary interaction will alert us to the narrowness of our own perspective and enable us to develop practical tools for decision makers.

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