CURRENT CONCEPTS AND METHODOLOGIES FOR ASSESSING AND COMMUNICATING RISK IN WASTE MANAGEMENT

Eugene J. Gardner, Aubrey E. Harvey, and John B. Mitchell
Management Systems Laboratories
Department of Industrial and Systems Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

ABSTRACT

As part of its research on improving the effectiveness of DOE information exhibits, Management Systems Laboratories (MSL) is reviewing current concepts and methodologies for assessing and communicating risk issues to the public.

There are three types of what is commonly called risk: 1) ordinary risk, such as the chance a turbine will fail; 2) behavioral risk, such as the chance a smoker will get lung cancer; and 3) uncertainty, such as the chance of an unforeseen effect of low-level radiation on the molecular structure of a particular containment structure after a thousand years. Each type requires different analytical tools. This paper is a brief survey of some of the tools particularly adaptable to risk communications.

In communicating risk, it is important for authorities to add information about the risk assessment approach and its inherent scientific uncertainties. Presenting the benefits as well as the risks also can help the audience balance the issues involved in making decisions about technological risk.

INTRODUCTION

The odds of winning a lottery are about one in 10 million, but many people buy tickets. The odds of being injured in an automobile accident are about 50% over one's lifetime, yet many motorists do not consistently wear seat belts. The likelihood of properly disposed nuclear wastes creating environmental or health problems are many times less than that incurred during temporary storage of wastes above ground, yet the public insists on zero risk, which may place unrealistic constraints on responsible waste management.

In general, public perceptions of risk are not founded on a scientific understanding of risk and uncertainty. Because the public as well as the media are not trained in mathematical tools, they both lack an objective framework to understand risk. Thus public opinion is vulnerable to being molded by sensationalistic and one-sided media portrayals exaggerating the risks associated with the nuclear industry (1). These portrayals help sell newspapers, magazines, and movies, but unfortunately create an environment of public hysteria surrounding the nuclear industry and suspicion of any program or spokesperson that could be construed to be "pro-nuclear."

Against this background of negative public opinion, waste managers must work with stakeholders to find ways to cooperatively address waste treatment, storage, and disposal issues, while addressing an ever-increasing regulatory burden. Some of these regulations and agreements may even be in conflict with each other. The more stringent reporting requirements and the proliferation of regulations are increasing the difficulty of finding feasible solutions to waste management problems. This is increasing the life cycle cost of waste storage sites.

Managers can improve their risk communication abilities by understanding scientific approaches to risk assessment and analysis. Informing the public about these approaches, and presenting the benefits as well as the risks involved in a proposed course of action, are ways managers can involve the public in the realistic management of technological risks associated with waste management.

RISK PARADOXES

Somewhere in space right now, rushing our way at 50,000 miles per hour, is a large chunk of rock, leftover from the formation of our solar system, on its way to a rendezvous with Earth and doomsday. This is the fear which is driving many in NASA and our defense establishment to propose a multi-billion dollar "star wars" - type solution to what is not even a quantifiable risk, but an unsolvable deterministic problem.

This problem is known in physics as the three body problem (2). There is a great deal of **uncertainty** as to what effect a collision or near miss with an asteroid might have. Depending on the interaction of several extremely precise variables, the result of intervention could be that the asteroid is safely deflected, an asteroid that would have missed collides with us, or that the Earth is knocked out of its orbit. Due to the uncertainty of this interaction, a space shield could be more dangerous than simply taking our chances with a cosmic collision (**status quo option**). These types of problems have become popularized under the term **chaos** (3), or more properly, **mathematical chaos** (4).

Even computer weather modeling has obvious limits to its accuracy. Ask anyone who has carried an unnecessary umbrella all day or wrung out his clothes in an airport terminal rest room when caught in an unexpected downpour. The problem with forecasting the weather is that uncertainty (chaos) can creep in to spoil the prediction. This is the public's most common encounter with uncertainty or what is known as **chaotic systems** (5).

UNCERTAINTY

Uncertainty of the type illustrated in the above examples can have one of two possible causes. The first cause is that the mathematical formulas which generate the forecast might represent a chaotic system. The impact of this is that a small numeric error can be greatly exaggerated as the solutions are iterated over time. Since such models can be solved only by computer approximation, they may appear to be random and unpredictable. The second cause is the simple lack of knowledge of the risk. Uncertainty from either of these causes is indistinguishable from the other.

When considering possible courses of action, risk managers must consider the status quo alternative. A case in point is the leaking HLW storage tanks at Hanford. At least one scientist (1) argues that no detrimental health effects can be expected from the leaking tanks, either now or in the future. All of the significant radioactive materials are absorbed in the soil within a few feet of the tank and the tank is more than 100 feet above the water table. Some radioactivity may be expected to eventually reach the water table after several hundred years. Only then can it move horizontally, toward the Columbia River, about 10 miles away. Best estimates of groundwater flow rates indicate 800 years would be required to cover that distance. The only significant radioactive material that would be left after that time would be a small amount of plutonium remaining after the filtration action of miles of travel through rock. Although plutonium, if inhaled, is one of the most toxic poisons known, the probability of any remaining plutonium becoming airborne is extremely remote.

It could be argued that the risks of a future leak at Hanford are minimal, and that present actions are adequate to avert risk to the environment and consequent health effects. Any cleanup alternative would generate additional risk factors associated with exposing unknown wastes to the air, the workers to the wastes, or moving wastes from one tank to another. These new risks could have negative consequences far greater than leaving well enough alone. Practically speaking, a rigorous monitoring program can identify problem areas such as leaking tanks that would require intervention.

Every technology has benefits and costs associated with it; its attractiveness depends on the probability and size of its possible gains and losses. Studies illustrate that people have difficulty thinking about and resolving the risks/payoffs involved even in simple gambles (6). When confronted with uncertainty, people often try to reduce the resulting anxiety by denying the uncertainty. This type of denial is illustrated by the case of people faced with the possibility of a severe flood at infrequent intervals. Some people deny (7) that a flood could recur in their area, despite experts' assessment of another flood being likely within a statistically probable period of time (e.g., a "100-year flood"). Unfortunately, many take this to mean a major flood cannot recur before many years have gone by; however, a second "100-year flood" is equally likely during any of the years in that 100-year period. The problem is compounded when people place confidence in flood control dams and reservoirs, building their homes in flood plains at higher densities, which makes likely even greater losses in a catastrophic failure of these systems than before the flood control was initiated.

The way some people deal with uncertainty is to attempt to outlaw the risk. Hence, we see "de minimus" standards for waste disposal systems, rather than objective approaches to the risks and benefits of all options under consideration. It must be remembered that risk can not be eliminated as a factor in technological decision-making. In trying to avoid a known, well-publicized risk, we may expose ourselves to a greater, lesser known risk. The only way to achieve maximum societal benefits is to make objective, scientifically-informed decisions about issues involving technological risk tradeoffs.

DECISION THEORY

Decision theory is one approach to try to objectify the human decision process. A way of dealing with uncertainty that does not use probabilities is to place the payoffs in an **action consequence matrix** (Fig. 1). Payoffs can be either positive (gain) or negative (loss) depending on the actions taken and the states of nature. For example, the action of purchasing shares of a given stock can result in a loss or a gain depending on the stock market.

	CONSEQUENCE 1	..	CONSEQUENCE m
ACTION 1	payoff 1,1	..	payoff 1,m
:	:		:
ACTION n	payoff n,1	..	payoff n,m

Fig. 1. Action-consequence matrix.

Once the considerable task of building the matrix is completed, the decision maker uses a pre-determined rule reflecting his/her or society's ethical values to select the "best" action. Two of the most commonly used rules are to choose the action that (1) minimizes the minimum loss (**mini-min**), or (2) maximizes the maximum gain (**maxi-max**) (8).

In general, Rule (1) is used by environmentalists on the basis of their perception of equity (i.e., spare no expense to achieve zero pollution and/or health risk). Rule (2) is the *perceived* stance of industry (i.e., wanting to maximize profitability of operations, often with little regard for the environment or public health).

A second approach, often ignored, is to use a **regret matrix** which includes factors such as the cost of a lost opportunity and lives shortened as well as potential profits. The regret can be negative (representing a gain) or positive (representing a loss). Then the decision rule is to choose the action that minimizes the maximum regret (**mini-max**). In this way, the decision more closely resembles the public's approach to everyday decisions, ("...gee, I could have had a V-8").

An example of regret can be found in long-range planning for nuclear energy production. Lacking a commitment to a breeder reactor program, our uranium reserves will be depleted in about fifty years. With breeder reactors we could have extended our nuclear fuel for thousands of years. This would have gained us the additional benefits of energy independence, as well as possible benefits affecting foreign policy in the mid-east (possible risk of war). A bonus would be the reduction of negative health effects from mining uranium since we have about a 200-year supply of U-238 that is already mined and in storage (1).

There is no *best* decision rule, since it depends on the values of the decision maker. The way decision theory reflects the values held by the decision maker is to use probabilities to develop what are called **utility functions**. These are fit to the decision maker's preferences by the employment of **lotteries**. An example of a lottery is a weekly pool of 100 people, each contributing a penny with one person winning the dollar. Each participant has a one per cent chance of winning a dollar versus a 99 per cent chance of losing one cent. The **expected value** of this lottery is therefore zero. This means that this lottery (a truly fair lottery), would allow one individual each week to have a whole dollar to spend at a minimal cost to the others. Eventually, everyone would be expected to win the dollar once. This would be represented symbolically by Fig. 2.

An interesting contrast of two lotteries that express different ethical approaches to the same practical value are represented by Fig. 3 (9).

For both approaches, we assume an even chance (50/50) of a positive outcome for each of two people. In the first lottery, called the **equity approach**, it is agreed that either both will win or neither will win. This approach is mirrored in public thinking about technological processes, reflecting the public's insistence that a technology under consideration endanger no one. No technology for generating power or managing wastes is risk-free; choices between alternatives require balancing trade-offs between groups. If an equity approach to energy production is adopted then the loss (minus L1, minus L2) could result in a major decrease in the standard of living for everyone (13).

In the **conservative** or "hedging" approach, it is agreed that one party will win and the other party will lose under either circumstance. This approach is reflected in the concept of hazardous duty pay. From the perspective of making decisions using expected value, both these approaches are equal. It is the ethical perception which influences decision makers to choose one over the other. It is therefore very important to consider the whole problem in the process of evaluation.

The view of the whole problem can be accomplished by using **vector valued utility functions** instead of single valued utility functions (10,11,12) in **decision trees**. The vector valued approach allows the risk assessor to make decisions based on the effects the decision will have on the **quality of life**. Another advantage is that the decision tree can be used as a communication tool showing the public the entire problem, not just an expected value result. An example of such a decision is depicted by the partial decision tree in Fig. 4.

A difficulty in solving and communicating complex problems is fully understanding the problem. The decision-theoretic tools presented above are methods for gaining this understanding (even if the formal solution techniques are never applied). Communicating this understanding to the public is one of the major challenges of the risk analyst.

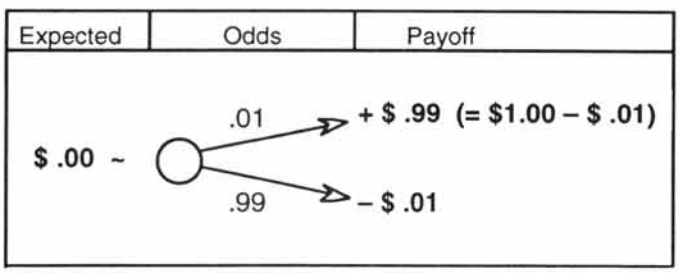

Fig. 2. A truly fair lottery.

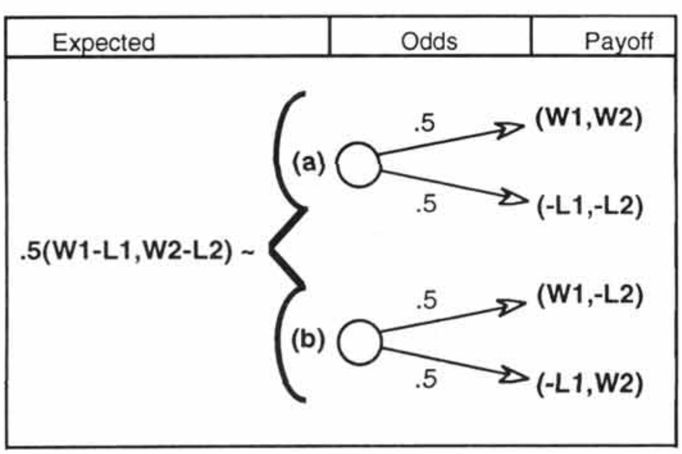

Fig. 3. Lotteries: a) equity; b) conservative.

RISK ASSESSMENT

The way to determine the probabilities needed in a decision tree is through risk analysis. Risk is defined as the expected frequency of undesirable effects resulting from exposure to an agent. Risk assessment is the process of assigning magnitudes and probabilities to the adverse effects resulting from human activities or natural events (13).

There are three steps in a risk assessment: 1. **hazard identification**, 2. **hazard evaluation**, and 3. **risk evaluation**. Before a risk can be assessed, someone must decide there is a risk. The domain of the risk communicator is the public perception of risk. The public perceives risk based on a number of factors that have been identified in risk communication literature (6,7). Among these are their personal experience, accounts of others' experiences, and what they most frequently hear about given risks. Further affecting public perception of risk is the public's desire for certainty.

An important factor in public perception of risk is that **technological risk** is perceived differently from an equivalent **natural risk**. For example, pesticide residues, representing a technological risk, are viewed to be more dangerous than the identical hazardous chemicals which may occur naturally in some foods. To illustrate, FDA requires "de minimus" residue levels in foods treated with pesticides containing cyanide, while sodium cyanide occurs naturally in almonds and lima beans at higher levels than those standards.

Figures 5 and 6 depict the relationship between the public perception of technologically-derived risks versus its perception of naturally-derived risks. As the actual risk (quantifiable by experts) increases or decreases, the perception of risk assessment experts tends to correlate with actual risk, while the public perception tends to exaggerate technological risks while ignoring natural risks. For example, many people would forego a diagnostic chest x-ray to avoid radiation exposure, but would not give a second thought to the "natural" radiation incurred during a transatlantic flight (6).

Another heuristic that helps explain differences in risk perception is called **availability** (7). The idea is that an event is judged as more likely if instances of it are easy to imagine or recall. Availability also can be affected by a recent disaster or a vivid film such as The China Syndrome.

In the public arena the availability heuristic may have several effects. The public bias due to memorability or imaginability may create barriers to open, objective discussions of risk. For example, a risk communicator may present information on an underground waste storage technology by using a fault tree depicting many low probability pathways that could lead to a system failure and environmental release. Despite the fact that compounded small probabilities further reduce overall risk, the public may come away with the perception, "I didn't realize there were so many things that could go wrong." The very discussion of any low-probability, high magnitude hazard may increase the public perception of its likelihood regardless of what the scientific evidence indicates (7). Figure 7 depicts the public misconception that high magnitude events are as likely to occur as low magnitude events, when in fact the opposite is true.

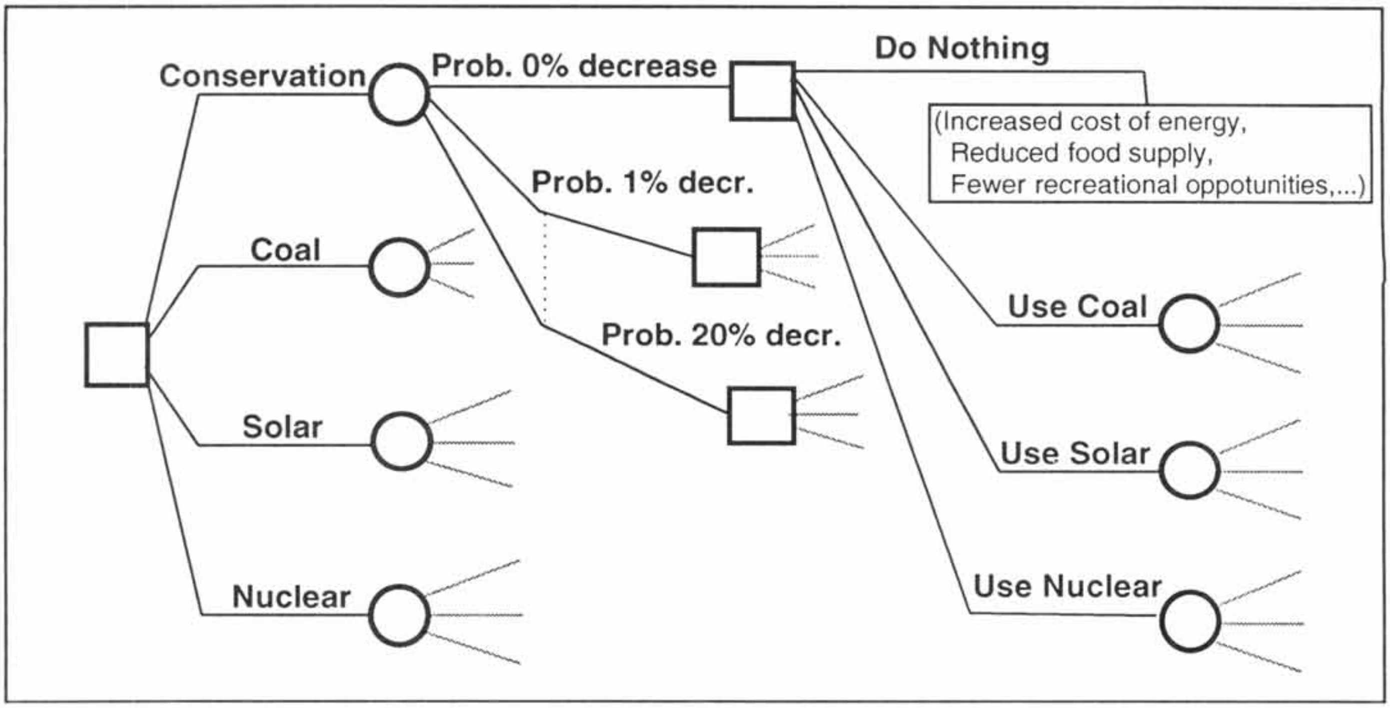

Fig. 4. Quality of life decision tree (Which source of energy to use to maintain current standard of living?).

In evaluating an identified hazard, risk assessors cannot identify the effects of low dose exposures to hazardous agents. They must use high dose animal experiments to determine the dose response curve as shown in Fig. 8. This is then extrapolated for low doses using one of three models. The risk assessor uses the concept of acceptable risk to determine the range for a **virtual safe dose** (VSD) as shown in Fig. 9. The risk assessor picks one of the models, frequently the **sublinear** curve (because the body can often repair minor damage resulting from exposure to an agent) and performs a curve fit to complete the high dose curve (see Fig. 10).

Figure 10 also depicts the public's perception of dose response. From news stories and observations it is obvious that the public generally believes that if a negative response can occur at a high dose level, then it is equally probable at a low dose level. In a natural defensive reaction, the public does not understand the need for risk managers to employ the concept of **acceptable risk** if they are to make objective and balanced decisions regarding technological risks.

To complete the risk assessment, the risk of the hazard must be evaluated and compared to the risks of other alternatives, including the status quo option, in order to allocate limited funds for courses of action which minimize the public's danger. Decision trees, although often overlooked by risk assessors, can be one of the most effective tools for presenting to the public a full understanding of the problem. The risk assessor can use such tools to see the problem more objectively and so obtain a better formulation. The challenge is to effectively communicate this formulation to the public.

One disadvantage of decision theoretic approaches is that the risk assessor and the public have different perceptions of the cost of risk reduction (see Fig. 11). While the public believes zero risk is obtainable at low cost, the risk assessor realizes that costs often increase astronomically in attempting to reach even acceptable risk levels.

Another disadvantage of decision theoretic approaches is that the public inherently distrusts risk comparisons that stress acceptability of risk (14). But risk comparisons are required to balance risk and opportunity objectively. There

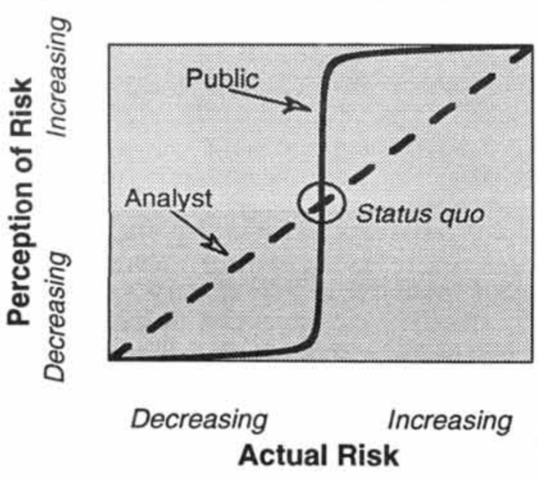

Fig. 5. Technological risk.

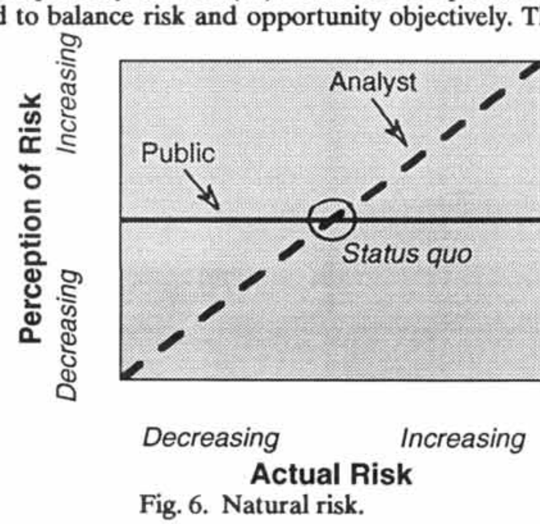

Fig. 6. Natural risk.

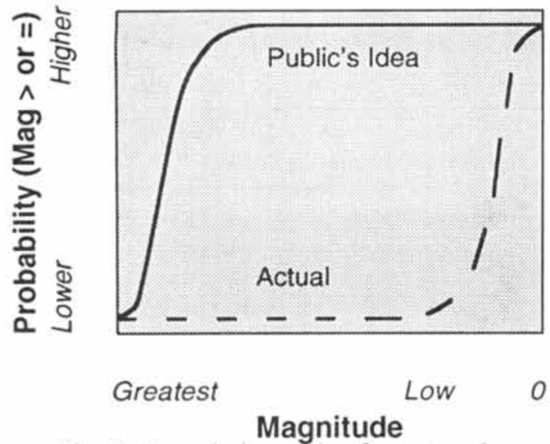

Fig. 7. Cumulative prob. of catastrophe.

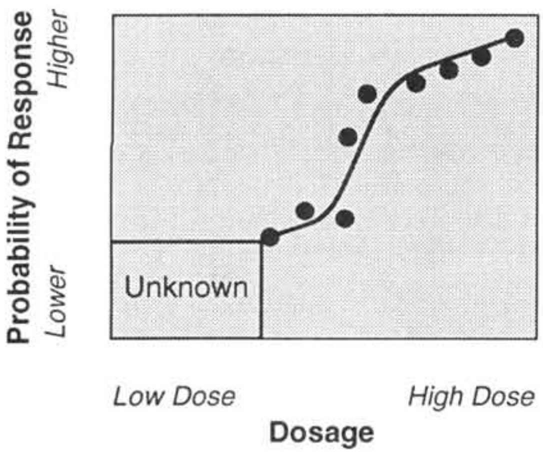

Fig. 8. Dose response curve.

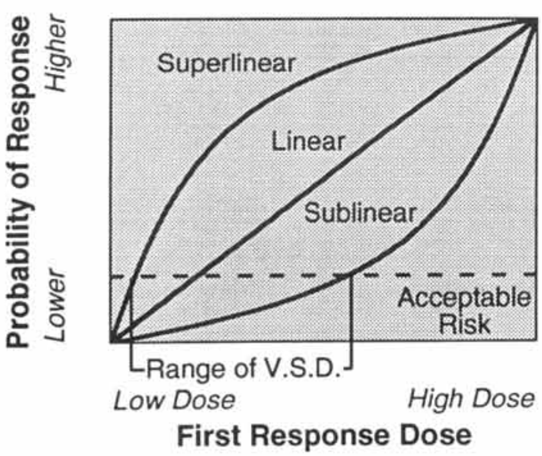

Fig. 9. Virtual safe dose.

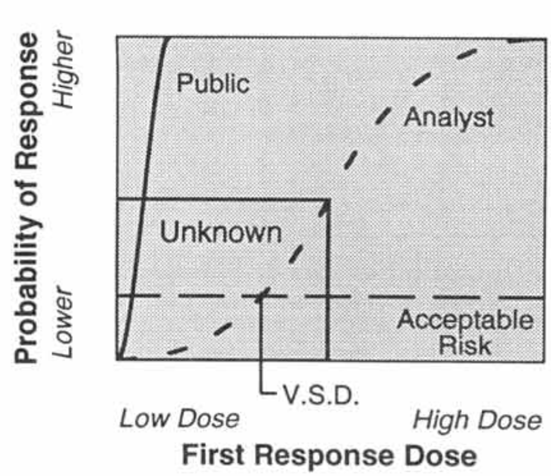

Fig. 10. View of hazard.

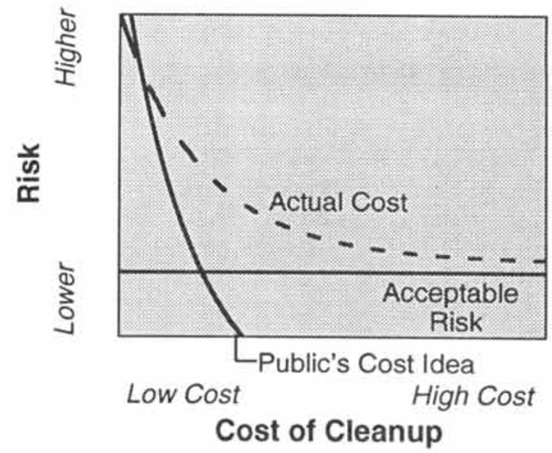

Fig. 11. Cost of cleanup.

are always trade-offs in choosing between technological risks. The risk assessor sees the trade-off between reducing potential risk to the public and increasing the actual risk to those who must handle hazardous substances (see Fig. 12). To resolve these conflicts, risk communicators should explain how cost approaches infinity as risk reduction is carried to "de minimus levels" and explain why appropriate risk comparisons (don't "compare oranges to apples") are essential to reach an objectively balanced decision.

The risk assessor combines the **probability** of an undesirable event with the **magnitude** of that event. To do this he obtains a **standard probability distribution**. Any statistical methodology can be used to obtain a probability distribution if sufficient data is available. If data is sparse, the **triangular distribution** may be useful (15). Here, the statistical analyst asks an expert to provide three points of likelihood: the minimum possible response, the maximum possible response, and the most likely response. Given these three points, there is only one triangular probability distribution which fits. In cases of great uncertainty, techniques such as **Bayesian methods** (16) have been used. These methods allow the statistical analyst to make a subjective guess of the distribution and iterate it through a series of empirical observations to obtain a valid distribution. Bayesian methods are the only statistical techniques which allow the analyst to use all previously gathered knowledge about the risks being studied.

Another family of statistical techniques for dealing with a known risk are **stochastic processes**. Stochastic processes are particularly well suited for deriving solutions to models of the reliability of technological systems. From these models, the analyst can determine the risk of failure of a system. If failure involves the loss of life, then the analyst can estimate the cost of saving a life (a typical measure of risk in current literature). As a demonstration of this technique, let's examine the following scenario.

There is an isolated tropical island which has sufficient rainfall to provide water for its current 200,000 inhabitants. Census projections indicate that the population could grow to 300,000 in the near future if sufficient water could be found. The government plans to purchase a de-salinization and water

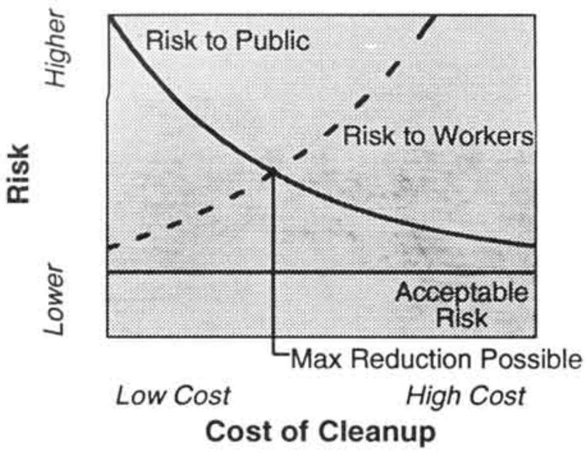

Fig.12. Overall risk.

purification system for $40,000,000 which will provide water for the additional 100,000 inhabitants.

This system can be in one of three states. It can be in full operation (state 0), under minor repair (state 1), or under major repair (state 2). Under state 1 (minor repair), the water purification system is degraded with the result that some inhabitants may get sick from dysentary. Under state 2 (major repair), no water is produced with the result that 100,000 inhabitants will die if repairs are not made in a few weeks. (This problem assumes total isolation of the island.)

The specifications of the system are that a minor failure is expected to occur twice in a year, and a major failure is expected to occur once in five years. If the system is in minor failure, then the chance of a major failure increases to once a year. A minor repair is expected to take 14 days and a major repair is expected to take 90 days. Therefore, the chance of a major failure must be minimized. An alternative is to buy a second "stand-by" system at a total cost of $80,000,000, reducing the risk by increasing the probability that one system will always be operating.

These problems can be modeled by what is known as a **Markov process** (17). The single system problem is expressed in the **transition matrix** shown in Table I.

From this transition matrix, a set of **differential equations** (measures of change) can be derived describing the probability of the system moving to a different state at any instant in time. Since the decision makers are interested in the long-range behavior of the system, the differential equations are solved in **steady state** (simply put, the change in the probabilities stops, that is, the differential equations equal zero) (18). The chance at any given moment in time of finding the system in each state is found in Table II.

This means that the expected number of deaths at any time is 6,472. (Note that the system is slightly more apt to be in state two than state one due to the longer repair time for complete failure and also the compounding of probabilities.) The alternative problem involving two systems has six states as shown in Table III.

State 5 is the only state that could involve fatalities. The problem is expressed by the transition matrix in Table IV.

Table V gives the steady state solution to the two machine problem. This means that the expected number of deaths in the dual system problem is 168. Therefore, the alternative system has an expected value of 6,304 lives saved. The total cost per life saved would be $6,345. Over the thirty year system life, this comes out to $212 per life saved, a very small investment in risk avoidance.

To put risk avoidance costs in perspective, contrast this example with industry plans to spend upwards of $1 billion to vitrify HLW at West Valley, New York to avert an estimated .01 deaths that could be eventually expected if the wastes stored there were simply converted to concrete in situ (at a cost of only $20 million). This corresponds to spending $100 billion per life saved. At the same time, our government is turning down other risk reduction projects that could save a life for every $100,000 invested (1). The public does not realize there are such inconsistencies in our public policies on technological risk. If the public receives objective and complete information on the true costs of risk reduction, they might well decide to pursue a very different course on issues involving energy production and waste management.

SUMMARY

This paper has attempted to present some of the statistical, decision theoretic, and modeling techniques which can enhance the objectivity of decision making affecting technological risk management. These techniques are not only recommended for analysis and assessment, but also have value as communication tools enhancing the public's understanding of complex issues. The public should be educated to understand mathematical approaches to balancing risks and benefits so that informed consent can be given to the policies of the nation. The challenge to risk communicators is to present these complexities in ways that are accessible to the average citizen. Only then, can the ideals of a democratic society find

TABLE I
Single System Transition Matrix

	State 0	State 1	State 2
State 0	1 - .00603	.00548	.00055
State 1	.07143	1 - .07417	.00274
State 2	.01111	0	1 - .01111

TABLE II
Chance of Finding Single System in a Particular State

State	Probability
0	.87596
1	.05932
2	.06472

TABLE III
State Definitions For Two Systems

State	Condition
0	1 unit working, 1 unit standby
1	1 unit working, 1 unit minor repair
2	1 unit working, 1 unit major repair
3	2 units minor repair
4	1 unit minor repair, 1 unit major repair
5	2 units major repair

TABLE IV
Two System Transition Matrix

	State 0	State 1	State 2	State 3	State 4	State 5
State 0	1 - .00603	.00548	.00055	0	0	0
State 1	.07143	1 - .07746	0	.00548	.00055	0
State 2	.01111	0	1 - .01714	0	.00548	.00055
State 3	0	.14286	0	1 - .14834	.00548	0
State 4	0	.01111	.07143	0	1 - .08528	.00274
State 5	0	0	.02222	0	0	1 - .02222

TABLE V
Chance of Finding Two Systems in a Particular State

State	Probability
0	.87959
1	.06735
2	.04530
3	.00250
4	.00358
5	.00168

their true expression in a realized national policy which ensures the most equitable and efficient use of national resources.

ACKNOWLEDGEMENT

The preparation of this paper was funded by U.S. Department of Energy (DOE) Grant No. DE-FG02-88DP48058. Management Systems Laboratories thanks DOE's Office of Environmental Restoration and Waste Management for providing us a real-world laboratory for the research, development, and testing of state-of-the-art management tools and the frameworks for understanding how to make them successful.

REFERENCES

1. B. COHEN, "Before It's Too Late - A Scientist's Case FOR Nuclear Energy," Plenum (1983)
2. M. SCHROEDER, "Fractals, Chaos, Power Laws. Minutes from and Infinite Paradise," W.H. Freeman and Company, New York (1991)
3. J. GLIECK, "Chaos - Making a New Science," Penguin Books, New York (1987)
4. I. STEWART, "Does God Play Dice? The Mathematics of Chaos," Basil Blackwell, Inc., Cambridge, MA (1989)
5. R. DEVANEY, "An Introduction to Chaotic Dynamical Systems," Second Edition, Addison-Wesley Publishing Co., New York (1989)
6. B. FISCHHOFF, "Improving Risk Communications," Commission on Risk Perception and Communication, National Research Council, National Academy Press (1989)
7. P. SLOVIC, B. FISCHHOFF, S. LIECHTENSTEIN, "Rating the Risks: The Structure of Expert and Lay Perceptions," Risk in the Technological Society (ed. C. Hohenemser, J. Kasperson), American Association for the Advancement of Science Symposium 65, Westview Press (1982)
8. W. MORRIS, "The Analysis of Management Decisions," Revised Edition, Richard D. Irwin, Inc., Homewood, IL (1964)
9. R. KEENEY, "Siting Energy Facilities," Academic Press, New York (1980)
10. S. FRIEDMAN, A. HARVEY, "A Technique for the Selection of Hardware in Automatic Control Systems," Proceedings ISA International Conference, October 11-14, 1976, Houston, TX
11. S. FRIEDMAN, A. HARVEY, "Application of a Vector-Valued Decision Model," Proceedings of the First International Conference on Mathematical Modeling, August 29 - September 1, 1977, St. Louis, MO
12. R. BROCKWELL, S. FRIEDMAN, A. HARVEY, "Decision Analysis for Environmental Management, An Approach to Choices Among Multiattributed Alternatives with Intangible Cost of Benefits," Proceedings of the Second International Conference on Mathematical Modeling, July 11-13, 1979, St. Louis, MO
13. S. RAMAMOORTHY, E. BADDALOO, "Evaluation of Environmental Data for Regulatory and Impact Assessment," Elsevier, Amsterdam (1991)
14. E. ROTH, M. MORGAN, B. FISCHHOFF, L. LAVE, A. BOSTROM, "What Do We Know About Making Risk Comparisons?" Risk Analysis, Vol 10, No. 3, (1990)
15. R. MEGILL, "An Introduction to Risk Analysis," Petroleum Publishing Co., Tulsa, OK (1977)
16. G. IVERSON, "Bayesian Statistical Inference," SAGE Pub., CA (1984)
17. E. FRANKEL, "Systems Reliability and Risk Analysis," Martinus Nighoff Pub., Boston (1984)
18. H. TAHA, "Operations Research, An Introduction," Third Edition, MacMillan Pub. Co., Inc., (1982)