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Andrew J. Van Horn and Richard Wilson

ENERGY AND ENVIRONMENTAL POLICY CENTER
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CAMBRIDGE, MASSACHUSETTS 02138

DECEMBER 1976

INFORMAL REPORT

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Introduction

Decision makers are faced to an ever increasing extent with evaluating uncertain risks and benefits to human health and to the environment. Without reliable knowledge of the implications and consequences of alternative projects or possible courses of action, their ability to make sound judgments is diminished. However, estimating the magnitude, probability, and distribution of risks and assessing the costs and benefits of projects are fraught with the difficulties of science, the uncertainties of technological and economic forecasting, and the pitfalls of public policy. How then can risks, costs, and benefits be explicitly compared? How should pertinent information be ordered and assimilated to assist in achieving acceptable balances between benefits and risks, both in the short term and in the long run?

The methodologies which are used in "risk-benefit analysis" attempt to make explicit the often hidden tradeoffs between lives lost and dollars spent, or between pollution and environmental quality. No magic formulae have been evolved for grappling with these seemingly incommensurable attributes. Nevertheless, the growing difficulties of regulation, standard setting, legislation, and technological choice have necessitated improved methods for answering risk-benefit questions. The purpose of this paper is to review the status and identify the common problems of this developing art which is beginning to be applied in numerous subject areas.

Description and Limitations

Risk-benefit analysis is a generic term for techniques encompassing risk assessment and the inclusive evaluation of risks, costs, and benefits of alternative projects or policies. The risk-benefit analyst attempts to measure risks and benefits, to identify uncertainties and potential tradeoffs, and to present this information coherently to decision makers. Like other forms of policy analysis the steps in risk-benefit analysis include specifying objectives and goals for the project options, identifying constraints, defining the scope and limits for the analysis itself, and developing measures of the effectiveness of feasible alternatives. Ideally, these steps should be completed in conjunction with an accountable decision-maker, but in many cases the decision-maker is unknown to the analyst. In such cases poorly defined decision options or the selection of alternatives which are too limited to meet proposed objectives may result. These faults are shared by all forms of policy analysis, but because risk-benefit analyses are frequently controversial, the risk-benefit analyst must be particularly careful to state the assumptions and limitations of each assessment.

The principal task of the risk-benefit analyst is to express numerically, insofar as possible, the risks and benefits which are likely to result from project outcomes. Calculating these outcomes may require scientific procedures or simulation models to estimate the likelihood of an accident and its probable consequences. These consequences are first measured in the most appropriate units (e.g. injuries, deaths, tons of emissions, dollars of damage) and their uncertainties indicated. Finally, an inclusive assessment is carried out which aggregates the disparate measures of the alternative outcomes. The conclusions should incorporate the results of a sensitivity analysis, which varies each significant assumption or parameter in turn to judge its effect on the aggregated risks, costs, and benefits.

The economic methods of cost-benefit analysis are most commonly used to assess the overall merits (net benefits) of proposed alternatives.[1,2] The extension to include risks is, however, not trivial. A principal problem is that risks and benefits may be measured in different units and therefore are not strictly additive. By definition risk-cost-benefit analysis will attempt to express all quantities in a common unit, usually dollars, so that tradeoffs are between comparable quantities and a net benefit can be calculated. This may require estimating a producer's or consumer's surplus where economic markets exist or determining a "willingness to pay" in cases where no markets exist (e.g. for goods like clean air, salt marshes, or human lives). If fatalities are potential consequences, we might wish to assign a cost by estimating the willingness to pay for reducing the probability of death or injury. This has somewhat misleadingly been described as determining "the value of human life." We would like to avoid this overly dramatic description. For actual decisions the cost of decreasing a risk is nonetheless a concept which cannot be avoided. Many of the difficult issues related to society's willingness to pay to prolong life have been discussed in References 3-6.

Recognizing that subjective value judgments are required in order to assign monetary values to costs and benefits, the risk-benefit analyst will not always attempt to arrive at a calculation of "net" benefits, but may choose to present risks and benefits in their respective units or categories. This leaves the decision-maker free to impose his own values or a range of values in aggregating risks, costs, and benefits. Thus risk-benefit analysis, in contrast to risk-cost-benefit analysis, will not necessarily arrive at a single number to represent the value of a project. Instead, a matrix of effects may be given including such disparate costs and benefits as lives lost, property damage, kilowatt-hours of electricity, and aesthetic losses. A "meticulous accounting" of like effects may avoid some of the obfuscation inherent in dealing with issues such as the identifiability of the life at risk or the voluntary/involuntary nature of a risk.[7]

Most of the disagreement over the usefulness of risk-benefit analyses derives from disputes over the methods used to aggregate risks and benefits. The most widely used measure for aggregating cost and benefit streams is the net present value:

$$NPV = \sum_{T=0}^{T} \frac{(B_t - C_t)}{(1 + r)^t}$$

where B_t and C_t are the benefit and cost in year t, respectively, r is the appropriate discount or interest rate, and T is the time horizon for the project. In most cases it is appropriate to discount equally costs and benefits if future opportunities (e.g. to prevent premature death) are likely to be the same or greater than today's. Questions of intertemporal equity become most important for evaluating long term effects like those resulting from persistent chemicals in the environment, increasing global CO_2 concentrations from fossil fuel combustion, or long-lived radioactive wastes from nuclear power generation, just to name a few examples. Relative net present values and the ranking of alternative projects with substantially different timing of the relative costs and benefits can be dependent upon the choice of a discount rate.

The idea of a different discount rate for risks and for economic costs has been widely mooted but is only beginning to be discussed logically.[7,8] If the cost of saving a life in the future is expected to be the same as the cost today, the discount rate for risks should be the same as for other costs. If, however, the cost of saving a life is expected to go down in the future, one might account for this by taking a higher discount rate. Arrow has shown that this is incorrect.[8] Instead one should explicitly take the expected cost change into account in the cost or benefit stream, C_t or B_t. For some cases of environmental and health hazards the costs of cleanup might increase with time. If, for example, toxic chemicals in the biosphere increase over time, costs attributed to their effect should rise more rapidly than the discount rate. It is for these cases that a negative discount rate has been suggested, but an explicit accounting in C_t is to be preferred. Uncertainties in these costs should also be handled in the numerator of the NPV formula, not in the discount rate itself. Economists inevitably dispute the choice of the specific discount rate to be used, e.g. the social rate of time preference or the prevailing interest rate. Except when a particular discount rate is specified by the decision maker, the NPV calculation should be repeated using several discount rates to ascertain the sensitivity of results.

The difficulty in agreeing on a discount rate is usually secondary to the problem of determining future cost and benefit streams. Uncertainties in long term costs and benefits may be large for time horizons up to T years, although frequently all alternatives will suffer from similar uncertainties. Because of uncertainty it has been suggested that we should not discount potentially large effects more than a generation in the future.[9] We believe these uncertainties should be reflected in the benefit and cost streams and not masked in the discount rate. Investigating questions of intertemporal equity and methods for dealing with uncertain outcomes are central problems of research, and their logic must be relentlessly pursued. Moreover, all forms of decision making must resolve these questions whether or not they are explicitly dealt with.

Risk-benefit analysis has been slow to develop, partly because of its multi-disciplinary nature and partly because its objective and subjective components can never be wholly separated. Although it has bases in scientific and economic techniques, it is an art with limitations. These limitations have arisen because the ultimate criteria for any decision must reside in exogenously determined values and goals specified by society or by an accountable decision maker. So long as the limitations are recognized, risk-benefit analysis can establish a basis for the explicit comparison of alternatives, indicate significant uncertainties, and point out aspects of the decision which are outside the scope of formal analysis.

Development and Usage

Many methods of risk assessment and cost-benefit analysis have been used. In an attempt to promote interdisciplinary communication and increase awareness of these methodologies, the Committee on Public Engineering Policy of the National Academy of Engineering and the Engineering Foundation have sponsored two conferences: "Benefit-Risk Decision Making"[10] and "Risk-Benefit Methodology and Application."[11] The first of these was held in 1971 in order: (1) to help make the issues of benefit-risk decision making explicit enough for public discussion; (2) to ascertain the current status of benefit-risk decision making as a field of study and in terms of current practice; and (3) to identify promising lines of inquiry that might lead to improvements in methodology and implementation."[10] The colloquium succeeded in asking a number of important questions and discussed risk-related issues in fields like architecture, decision analysis, economics, physics, engineering, chemistry, law, government, and medicine. Few questions were answered, but the hope was engendered that interdisciplinary approaches would lead to improvements in risk-benefit decision making.

Four years later a second conference was held at Asilomar, California to examine the state of the art. In the intervening years considerable work had been performed in diverse areas such as the reliability analysis of engineering systems, health effects assessment, economic approaches to life-saving, insurance protection for natural hazards, and the psychological perception of risks. From the 1975 conference[11] and from a survey of literature[12] it is evident that no coherent definition of risk-benefit analysis has emerged, owing to the breadth of subjects under study. Most recent effort has been in the area of risk assessment, less attention has been given to benefit assessment, and even less attention has been devoted to how decision makers should integrate this information into the political process.

Risk assessment can require expertise in several disciplines, since risks may originate from causes such as disease or natural hazards, from human errors or sabotage, or from hardware or equipment failures. For frequent risks the expected rate of occurrence may be calculated statistically from similar experience or predicted from models. Failure and reliability analyses for engineered systems may employ sophisticated event tree and fault tree methods such as those used on the widely publicized Rasmussen study of nuclear reactor risks.[13] However, for low probability risks it may be difficult to apply present knowledge to accurately predict the probabilities of accidents. There is always the lingering doubt that possible failure modes may have been overlooked, especially common mode or simultaneous failures. In estimating probabilities for particular events the influence of design failures and of deliberate actions like sabotage must also be considered. Scenarios are usually constructed in order to envision rare potential accident sequences. Each of the analysis methods now in use has limitations in its applicability to new circumstances, particularly in estimating absolute probabilities of very infrequent events. Despite their short-comings, these methods have proven to be powerful techniques for finding the most prominent failure modes and for identifying potential weak spots in technological systems.[14]

The consequence of an accident determines the magnitude of the risk. For many risks models must be developed to predict the damage to humans or to the environment. For example, estimating the effects of air pollution can involve dispersion models for transport of the pollutants from the source to the individual, including atmospheric chemical conversions. Such models permit estimation of the dose received. Additional studies in experimental toxicology and epidemiology are then needed to characterize the dose-response relations. Here synergistic effects and the problems of competing risks must be sorted out. Population distributions must then be folded in to estimate the overall magnitude of the risk. Although vast amounts of information are required and there are uncertainties in our current knowledge, consequence models can roughly estimate these risks. Refinements of our scientific understanding and of our ability to estimate such risks are needed to ensure that decisions and regulations are indeed reducing the most severe risks.

While decision makers readily appreciate the significance of mortality or morbidity estimates, it can be difficult to develop good measures for environmental losses such as damage to vegetation, recreational losses, and ecological or biosphere contamination. Indeed, it is not always necessary to assign dollar values to aesthetic or environmental losses, so long as the losses can be identified in appropriate categories. (The National Environmental Policy Act requires the consideration of alternatives in a cost-benefit framework, but Environmental Impact Statements usually only categorize like effects. Their major failing is that differences between the proposed alternatives are usually so small that the decision maker has no real choice. In addition, the voluminous amounts of information are often not adequately summarized so that meaningful comparisons can be made.)

Latent effects, which may not appear until 20 years after exposure in the case of some cancers or until the next generation in the case of mutations, pose severe problems. For example, if the depletion of atmospheric ozone continues, how should we assess the risk to succeeding generations? How do we measure low level chronic effects or account for risks which are not yet identified? These are unanswered questions which exacerbate the previously mentioned difficulties of specifying an appropriate discount rate and dealing with uncertainties.

Although risk assessment is improving, relatively little work has gone towards assessing the benefits of those technologies or activities which generate risks. Research on benefit assessment for earlier cost-benefit analyses is relevant, but in many cases these benefit calculations have been hotly disputed. (The Corps of Engineers has become adept at measuring benefits but not always successfully.) Cost-benefit analyses have been extensively applied to water resource problems.[15,16] In a number of cases these have been incomplete or wrong. Many lessons on the limitations of cost-benefit methods which were applied in the Delaware River Basin have been discussed in Reference 17.

In instances where the benefit is common to all alternatives under consideration, it may be possible to examine the cost-effectiveness of alternatives for producing a given unit of benefit. However, a principal limitation of analyses which distinguish among alternatives on the basis of cost-effectiveness is their inability to determine the overall scale or size for a program. One risk-benefit study of alternative methods for generating electricity compared only the risks, claiming the benefits of equivalent amounts of electricity are equal.[18] This might be true for one additional power plant but it is not necessarily so for substantial additions to a generating system. Further, highly aggregated data is needed in many instances to measure health and other risks reliably. There can be difficulties in using these average costs in choosing among alternative technologies, especially when the geographic locations can be different. Economic theory makes a distinction between average and marginal costs, and analyses should properly utilize marginal costs. In studies evaluating energy technologies with common benefits the separation of the risk-benefit analysis into two separate parts, one national in scope and another regional or local, might well be appropriate. Otherwise it is hard to see where to bring in such important factors as the advantages of diversifying methods of electricity generation or advantages to the nation of energy independence. Ideally the benefit of an action should exceed the risk both for the nation as whole and for each significant region or political jurisdiction. Transfer payments, including taxes and the like, may be necessary to ensure that this is true. In the case of energy supply the separation of risk-benefit analyses into national considerations of the level of supply and regional considerations of particular sources might clarify present debates.

The literature on risk-benefit analysis is largely dominated by articles on how to perform aspects of an analysis or determine acceptable levels of risk, largely without reference to the benefits. Apparently it is easier to suggest how one might proceed in theory than it is to carry out practical analyses. In 1973 C.O. Muehlhause of the National Bureau of Standards was asked whether he could cite some quantitative success at risk-benefit analysis, and he replied "I know of no instance where the nonpecuniary aspect of the problem has been included in a proper quantitative manner."[19] He did state that such analyses had proven useful in cases where the risks were already accepted by the public. Obviously the most difficult area for risk-benefit analysis is in treating those future risks with the greatest uncertainties. In this area improved risk assessments and a better framework for considering these problems are sorely needed.

The most apparently straightforward risk-benefit studies are those which evaluate the costs of saving lives through the application of known medical technologies or safety equipment. Here the tradeoffs can be direct: years of life saved vs. the risk of losing a life in an operation. But the situation is quickly complicated by questions of disability, quality of life, and choices involving whose life to save. Determining the real costs of a program and evaluating the efficacy of medical treatments have posed severe difficulties to the use of risk-benefit analysis techniques in the medical area. Analyses have usually presented the decision-maker with a cost/life-saved (cost-effectiveness) comparison of several possible options, but at some stage a decision-maker might have to choose between a large program or a small one and in these cases net benefits become important. However, progress is being made in performing risk-cost-benefit comparisons.[20] Because of the limited resources which can be allocated for all medical treatments, risk-benefit analyses can aid decision makers by making explicit the relationships between lives saved and dollars spent.

In general risk-benefit analyses which succeed are those which have been constructed to provide information on well-defined decisions with specific options. The analysis of Acton[21] uses surveys and decision analysis methods to rank several programs for treating heart attacks, including mobile coronary care units, for a town of 100,000 people. Terrill[22] compares two major sources of radiation, nuclear power plants and medical x-ray machines, and estimates the costs and benefits of reducing radiation doses from each. Kitabatake et al.[23] estimate the number of lives saved from a program of mass chest x-rays in Japan and compare this to the induced cancers. In each case it is clear which questions the analyst is attempting to answer and the tradeoffs in each are of like risks.

In contrast a very comprehensive analysis by Klarman[24] which measured many potential economic benefits of syphillis control programs was not examining well-defined decision options and thus would have been difficult to apply to a particular decision. Typically, in situations where projects invest in the well-being of people rather than purchasing capital goods, it is difficult to define the benefits or develop comparable alternatives. The analysis by Klarman offered considerable insight into the ramifications of a syphilis control program but was not directed to guiding choices among possible program objectives.

The literature contains other analyses and reviews which examine the efficacy of various medical treatments and discuss cost-benefit applications.[25-27] When the alternatives and the tradeoffs are explicit, and where statistical data exist, these risk-benefit analyses are quite useful. It is interesting to note that those who claim that risk-benefit analyses should not quantify tradeoffs between lives and dollars often do not object to its use for the allocation of resources in the medical field, where lives and dollars are directly at stake.

Dealing With Uncertainty

We should distinguish between cases where the project outcomes are well-characterized and their probabilities reliably determined and those cases where the probabilities of individual consequences are not well-known. It is in the latter situation that the most vigorous objections to utilizing risk-benefit techniques have been made. Here new ground must be broken, although the risk-benefit framework can still illuminate these tradeoffs. Decision criteria which reflect our lesser degree of certainty and perhaps a greater risk aversion may need to be adopted in such circumstances.

Dealing with uncertainty is the central dilemma of all policy choice. Uncertainty occurs in predicting the consequences of actions as well as in valuing the particular outcomes of alternative policies. Reducing uncertainty, defining its bounds and its effects on policy preferences should be primary goals for risk-benefit analysts. Sensitivity analysis is most often used to supplement deterministic calculations, but new means of incorporating probability distributions for uncertain outcomes and for assessing relative preferences among multi-attributed choices are beginning to be applied to decisions involving hazards. The analytical methods of decision analysis are providing useful tools for exploring the effects of uncertainty on project outcomes.[28,29] While these are techniques with great promise, they too can deal successfully only with well-defined questions. For example, a decision analysis comparing coal and nuclear fuels for an additional power plant in New York can not be readily extended to a choice between energy systems on a larger scale.[30] (We have mentioned earlier that choices of policy can depend significantly on the geographic scale considered for the particular decision.) Important "costs" may lie outside the defined scope of a risk-benefit analysis; the potential costs of legal liability were excluded explicitly in an analysis of a hypothetical decision to seed hurricanes.[31] Decision analysis methods can be used to incorporate probability distributions and expert judgments, to develop hierarchies among attributes, to discriminate between alternate strategies, and to point out significant information gaps. These methods may also be utilized for performing sensitivity analyses on parameters subject to variation or uncertainty.

As a rule, all costs which might affect the balance between risks and benefits should be identified and included. Implementation costs should not be overlooked. Analyses of the federal attempt to control automobile air pollution suggest that the development of long-term alternative engine technologies would have achieved greater overall reductions in air pollution from 1975 to 1989 at lower implementation costs than the strategy which was actually followed by Detroit. In one analysis the costs of various programs were plotted against an index for weighted reductions in air pollution to indicate the most desirable policy outcomes.[32]

Sensitivity analyses which investigate the effect of varying parameters can provide important information for the decision maker. Changes in the discount rate or in societal risk aversion may change the net benefits of a project. If possible a range of values should be studied. One example where results were given for a range of differing assumptions was in the analysis of automobile safety features by Lave and Weber.[33] In this study the worth to the consumer of seat belts, dual braking, and other safety systems was calculated for several discount rates and for different consumer aversions to injury and death, allowing an individual to determine the value of safety features for his own assumptions.

Acceptability of Risks

Even if the risk-benefit analyst is able to quantify risks and benefits, how are we to judge the acceptability of a risk? What criteria should apply to our choice among alternatives? This judgment is, or course, not the role of the analyst, but of the decision maker. If a choice were solely between freezing to death or burning unclean coal in our hearths, we would elect the latter. However, if the choice is between higher prices for energy and reduced risks, how do we choose? How do uncertainty and other factors affect our perceptions of risk situations? Lowrance has dealt admirably with many risk-benefit issues in his book, "Of Acceptable Risk: Science and the Determination of Safety."[34] There are no hard rules for equating risk and benefit trade-offs, and when the numerous risk situations in society are considered the situation becomes most complex. Retrospective studies of the previously accepted levels of risk in our society may be a guide to understanding our past behavior,[35-37] but comparing predicted future risks to statistically determined past risks can be misleading, especially if the predicted risks are presented without corresponding information on their uncertainties.

Risk-benefit analyses usually calculate the probability of death per person exposed to a hazard. This omits from consideration one important feature of public concern: Whether an accident involving the potential death of 10,000 people at once is to be considered worse than 10,000 accidents involving one person.[37-39] In an extreme case society could not recover from 4 billion simultaneous deaths, even if such an accident occurred only once in 10,000 years. Such an event is clearly worse than the preventable deaths from cigarette smoking, which occur at the same average rate. Both the uncertainty of a risk and its magnitude increase the perceived risk, thus focusing public concern on low probability, high consequence risks. One of us[38] has suggested that the perceived importance of a large accident with N fatalities is proportional to N^2, rather than N. Slesin and Ferreira have investigated frequencies of multiple death accidents in the United States between 1956 and 1970 and conclude that the social impact of large accidents varies as N^3, implying that one 100-death accident has the impact of one thousand 10-death accidents.[37] Society apparently acts to reduce the anxiety and impact of severe risks more than the absolute risk might suggest.

Although comparing risks and understanding risk perception are important for the decision maker, it is not always helpful to include information about other risks to influence the acceptability of a particular project. Risk-benefit analysts who do may all too easily overstep their role as risk assessors and appear to try to usurp the decision maker's function. A decision maker must be made aware of current levels of risks, but it is always possible to demonstrate that some other activity is worse. Directly comparable examples with similar benefits are relevant, but comparing automobile fatalities to accidents in chemical plants may not be particularly useful to a decision maker whose sole authority is to decide upon the acceptable levels of risk in a chemical factory.

Various formula or criteria have been suggested for defining levels of acceptable risk and allocating resources to reduce risks.[39-43] The empirical basis for most of these formulae is very limited and their applicability has not been widely demonstrated. Empirical formulae may be useful for engineering design and as a basis for risk analyses,[44] but at present it is doubtful that rigorous formulae can be applied to public acceptability decisions.

Public perceptions of risks and benefits do not always coincide with the actual level of risk or benefit. People may choose to live on flood plains either because they misperceive the real risk of floods or because other constraints (job availability, family ties, etc.) make flood plains an acceptable place to live. Psychologists have suggested that people in groups are more willing to take uncertain and larger risks than individuals and that delayed or latent risks are more acceptable than immediate risks. Smoking is one good example. Studies of the many factors involved in risk taking may aid in understanding the implementation problems of risk-related programs.[45]

In many cases a risk may be acceptable if it is borne by the persons receiving the benefits and be unacceptable if those bearing most of the risk are not those receiving most of the benefits. We must emphasize that risk-benefit analysis is not equipped to judge the equity of the distribution of risks and benefits, but it can identify impacted groups. Many present risk-benefit analyses fail to clearly identify the groups who are to be impacted. Often in aggregating net costs and benefits this information is lost. Because some impacts are more certain and more important to the decision maker than others, the risks and benefits to each identifiable group should be distinguished. Ultimate decisions of equity rest with the political process, but comprehensive risk-benefit analysis should supply distributional data. If compensation to those bearing undue risk is politically desirable or feasible, risk-benefit analyses may have an additional role to play.

Assessing risk and judging the acceptability of a risk (i.e. determining safety) are independent processes. Much confusion has arisen in public policy disputes over the failure to separate the distinguishable questions:

1. What are the scientific and technological bases for assessing the expected risks and benefits?
2. What are the relative probabilities and uncertainties of particular consequences?
3. Can the risk be reduced and what will it cost?
4. Is the distribution of risks and benefits fair?
5. Is this risk acceptable?

Attempting to answer these questions simultaneously can often mean that none are adequately answered. The last two questions fall outside the domain of risk-benefit analysts and lie in the province of the decision maker.

Much of present day legislation, regulation, and standard setting is based on intuitive balancing of risks and benefits. One objector to risk-benefit analysis has said that my gut feeling is better than any of your analysis. Gut feelings will continue to serve us well in many instances, but society has to discover ways of going beyond them. Solutions need to be found, especially if two persons' gut feelings differ. Surely, it is incumbent on someone whose gut feeling differs from a careful analysis to try to understand and explain the reason for that difference, so that the analysis may be improved.

From the point of view of public policy it would be desirable to know if standards should be designed to minimize the probable level of risk (minimizing the expected value) or to minimize the maximum harm (protecting against the catastrophe). Depending on the risk spectrum (probability vs. level of damage), these two possible criteria will lead to different choices, which can be distinguished by risk-benefit analysis. It is likely that other criteria for choices among alternatives should be applied for decisions involving more uncertainty or greater potential risks. Differences in costs, including benefits foregone, which will result from applying different decision rules need to be more clearly presented. Increased attention must also be devoted to finding methods for developing feasible alternatives and for identifying ways in which proposed alternatives may be modified to achieve better outcomes.

The concepts embodied in the phrases "as low as practicable," "best available technology," and "factor of safety" require baselines for judgment. Improvements in risk assessment should suggest how well these concepts work in practice and enable us to judge whether other regulatory schemes may reduce cumulative damages.[46] These expectations will not be fulfilled immediately, but only over the course of time as our knowledge and experience increase.

Moral and Ethical Issues

Critics of risk-cost-benefit analysis have aptly and correctly pointed out that risk-benefit analysis cannot make equity or ethical judgments.[47] They further feel that benefit-cost analysis may act to obscure important issues,[48] presumably because such analyses can be used to justify difficult political decisions by persons avoiding their personal responsibilities. Risk-benefit analyses are not intended as substitutes for moral and political judgments or for holistic decision making which includes factors outside the scope of formal analysis. As we have already pointed out the quantitative assessment of risk may be objective, but choosing the scope and values of any analysis requires subjective judgments. These limitations should not dissuade us from analyzing as objectively as possible the consequences of possible courses of action. To fail to do so would be to deny the worth of better information and greater knowledge. Merely knowing the extent of our uncertainties may guide our choice of action more wisely than proceeding in ignorance of potential risks and benefits.

Moral, ethical, and political considerations may all properly take precedence in decisions in our democratic society. Nevertheless, in many situations where ethical or political arguments are not paramount, understanding risks and benefits may be crucial. Fears that risk-benefit analyses will obfuscate the issues seem to imply that decision makers or opponents of particular alternatives are not capable of pointing out the limitations of an analysis. Surely, if decision makers are capable of comprehending the complex scientific and technological decisions to be made, they are capable of recognizing the limitations of analytical methods. Holistic decision making is not precluded by using risk-benefit analysis. Careful risk-benefit studies subjected to open criticism are more likely to rationalize and clarify the decision process than they are to hinder or obscure it.

Conclusions

This has necessarily been a superficial survey of the developing field of risk-benefit analysis. In the past risk and benefit have usually been evaluated separately, and relatively few analyses have been presented in a format where risks have formally been balanced against benefits.

As we become aware of more and more sources of risk and of society's limited resources, the need for setting priorities, identifying constraints, and for preserving future options will increase. Inevitably decisions must be made, and therefore, refined tools for measuring and evaluating risks and benefits are needed. Thus far the techniques of risk-benefit analysis have had limited application and limited success, but the art is improving with experience. Further research is especially needed to improve our assessments of risks and benefits, to develop means for dealing with uncertainty, to identify feasible alternative options, and to select appropriate decision criteria.

Two points remain to be made. Even if accurate estimates of risks and benefits can be provided, the final problem is how to aggregate them. A decision maker should be free to weight the various risk and benefit categories and their uncertainties in order to explore questions of equity as well as efficiency. Most analysts currently fail to present their results in a fashion which will enable a decision maker to examine for himself the sensitivity of the results to the assumptions and the distributional effects of alternative policies.

Finally, if decision making involving risks and benefits is to improve, more attention must be paid to the clear presentation of the assumptions, values, and results. Reports need to present concise summaries which convey the uncertainties and limitations of the analysis in addition to the matrix of costs, risks, and benefits. As the field of risk-benefit analysis advances the estimation of risks and benefits will become more precise and implicit valuations will be made more explicit. Corresponding improvements must also be made to enhance communications between the risk-benefit analyst and the accountable decision maker.

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