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Risk analysis: scope and limitations

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Summary

Risk analysis is one of the key areas of expertise involved in regulating industrial hazards. Experts in the subject are frequently drawn into open debates (*see* Chapter 6), particularly because risk analysis itself has become a controversial issue (*see* Chapter 1). This chapter examines the major techniques and approaches of risk analysis, explaining what they can contribute to regulatory decision-making, as well as their limitations. It is organized as follows:

The development of risk analysis

Risk analysis has become of significance in policy-making because of the growing concern about technological and industrial hazards. It provides systematic methods to analyse and evaluate risks (*see* Chapter 1). This involves drawing together various disciplines, depending on the problem being addressed, such as engineering methodologies, ecology, physics, psychology, statistics, sociology, chemistry, economics and toxicology.

From this melange of expertise, four distinctive approaches to risk analysis have emerged:

(1) *The engineering approach* was the original basis for risk analysis. It is orientated towards the quantification of risk levels, based primarily on technological considerations.
(2) *Decision-analysis* techniques aim to take account of many risk dimensions, such as environmental degradation and economic losses and gains, as well as technical factors. These are analysed to help advise decision-makers on the best solution to meet their objectives, based on calculations made within formal mathematical models.
(3) *Risk-perception* studies seek to understand why people often allocate different priorities to risks than those which seem to be justified by theoretical and statistical analyses.
(4) *Policy-analysis* methods attempt to explain how a broad range of social and political influences affect the design and implementation of risk policies.

These approaches have evolved in response to varying national and international circumstances. Each has its own uses, advantages and disadvantages, as discussed in detail later in the chapter.

Modern risks in perspective

Any human action directed at changing future conditions of life, or altering the consequences of natural or man-made events, involves some notion of risk. Such risk-taking has helped to improve health and overcome natural hazards, but has also led to negative consequences. For example, life expectancy in the USA and Europe has increased by 20 to 30 years during the 20th century, largely due to the elimination of infectious diseases, but also because increased attention has been paid to safety[1]. At the same time, however, technological innovations have also generated hazardous, and sometimes disastrous, consequences.

These trends have led to an increasing awareness of, and anxiety about, new industrial risks during a period when technology was also helping to reduce other risks. The number of accidents affecting the public is kept down by the adoption of safety standards but the potential extent of damage that can be caused by accidents increases as technologies grow in scale. Safety demands for some dangerous technologies can also impose severe security measures that could even have potential impacts on social behaviour and, in some circumstances, shape the form of government and its institutions.

The science or art of risk analysis is a relatively new development. An article by Chauncey Starr published in 1969 by *Science*[2] is often cited as the beginning of the formal study of risk as a new discipline. Of course, there had also been a long history of theoretical research and practical application in the management of specific risks, such as in transportation and in actuarial techniques used by insurance companies. A substantial body of literature has been developed on risk analysis[3] (*see* Chapter 1 for further discussion on the emergence of risk analysis).

Central elements of risk analysis

Risk analysis is the identification of potential hazards to individuals and society and the estimation of the likelihood of any particular hazard occurring, using data, statistical analyses, systematic observation, experiments or intuition. These estimates are used to assess how and to what extent the environment, people, regulatory policies and other factors may be affected.

The four approaches to risk analysis defined earlier in the chapter vary in the amount of attention that each gives to these activities. For example, while the engineering concept concentrates mainly on the estimation and evaluation of risks, policy-science methods are more preoccupied with the risk-management problem. Superficially, it may even seem that the four approaches could be neatly matched to different risk-analysis phases: an engineering orientation for risk estimation, decision analysis and risk perception for evaluations of risk, and policy analysis for risk management. Each approach, however, brings its own perspective to all risk-analysis activities, enhancing and illuminating particular aspects.

The five main steps of risk analysis

Within overall risk analysis activities, the following are the main steps that are carried out.

(1) *Defining which outcomes could be labelled 'adverse' or 'beneficial'.* This involves a considerable degree of subjective social judgement in assessing various possible consequences, for example deciding whether the potential for a greater centralization of technologies is beneficial or harmful, or whether the improvements in health and agricultural efficiency resulting from new drugs and chemicals outweigh potential negative side-effects for individuals and the environment.

(2) *Choosing which factors are to be given priority in the analysis.* There are many possible health, ecological, economic, social and political dimensions to a particular hazardous development, and the analyst must choose which are to be considered. Even within a particular class of outcomes, such as health effects, which has been the focus of many one-dimensional analyses, there needs to be an aggregation of a number of factors, for example in making trade-offs between acute and delayed fatalities, chronic or transient diseases, and so on.

(3) *Assessing the magnitude of harm to which the public may be exposed.*

After identifying the hazards to be considered, the development of various risks needs to be traced and quantified, from the initial events which create them to their final effects. Mathematical and computerized models may often be used to determine the possible relationships between a harmful agent and the incidence of an adverse effect under varying conditions and dose-response relationship.

(4) *Calculating probabilities of various outcomes*. This has usually been accomplished using four general methodologies:

(a) collection of statistical data relating to the performance of a risk source in the past;
(b) collection of statistical data relating to the failure of particular components of a hazardous agent or technology, which can be synthesized to make probability judgements about overall system performance as well as subsystems within it;
(c) studies that seek to find statistically significant correlations between an exposure to a hazardous agent and an adverse effect in a defined population sample, for example through controlled experiments or by analysing the occurrence and distribution of diseases in society (*epidemiology*);
(d) estimation of probabilities by experts, lay people and decision-makers about events for which there is insufficient statistical data available and thus are intrinsically difficult, perhaps impossible, to quantify by more formal methods.

All these ways of calculating probabilities are limited by the fact that they are largely based on past and known performance of the same or similar risk sources. Many real problems are caused, however, by technological happenings and human behaviour resulting from the often unsystematic and unexpected way in which the circumstances affecting risk sources and the actions of people may vary over time. Trying to predict such unpredictable outcomes, which requires estimating the probability of a probability and is known as *probabilities of the second order*, cannot be covered adequately by risk analysis.

(5) *Determining who will be affected by the risk*. A hazard, such as pollution or the operation of a plant, can affect different people and groups in different ways, which has led to equity issues in the distribution of risks and benefits becoming key factors in regulation (*see* Chapters 2 and 4). The anonymity inherent in statistical approaches to risk analysis, however, has obscured these significant differential effects. Outcomes also vary over time, as well as between subjects, but risk analysis has not sufficiently differentiated between adverse effects that occur continuously and sudden disasters; thus, for example, a risk source that leads to one fatality each day is often treated as being equivalent to one that could cause to 365 deaths on a single day, once a year.

Subjectivity in risk analysis

However hard risk analysts try to be 'objective', their calculations are bound to be conditioned by subjective judgements in each of the analytic steps outlined above. For example, subjectivity is inherent in the definition of what effects are to be regarded as beneficial or harmful; the rule used to select which factors are to be included in analyses; the methods by which various effects, such as immediate deaths versus long-term illness and fatality from different causes, are combined into a one-dimensional scale used to compare risks; and the choice of which concept of 'probability' to use in calculating probability outcomes. Commonly-used risk-analysis techniques are open to a variety of interpretations, depending on which method is used and who carries it out. For example, the choice of which model to use in projecting future outcomes will determine how risks are assessed when, say, extrapolating the effects of high doses of a drug into situations where only low doses are to be expected, transfering results of experiments conducted with animals to possible human impacts, or deciding what are the most important factors in controlling the dispersion pathways of pollutants. Equity considerations involve a variety of complex social, economic and political judgements which cannot be calculated in scientific terms.

For all these reasons, risk analysis can be biased towards the values, attitudes and priorities of the analyst or the sponsoring organization or intervenor group. This does not discredit risk analysis as such, because all studies with policy implications are subject to similar influences. It is important, however, to understand its potential misuses so that the results of risk analysis can be treated with realistic caution and a careful investigation can be made of what judgements influenced the conclusions.

The engineering approach

The most common approach to risk analysis, and the one which formed its initial foundation, has a strong orientation towards the quantification of risks within a relatively narrow technical focus. It has the following general characteristics:

(1) 'Risk' is generally understood as the predicted size of a hazard multiplied by the probability of it occurring[4].

(2) The primary techniques used are the statistical analysis of past accidents and responses, systems analysis methods, epidemiological studies, and animal tests. Attempts are made to exclude overt personal judgements and other qualitative factors.

(3) Analyses are usually limited to one or two types of consequence, such as mortality risks or a narrow range of health effects and/or environmental deterioration, with information quantified and organized in a way that makes it suitable for processing using statistical analysis methods.

(4) Human errors, behavioural aspects of people exposed to hazards, and other interactions between people and risk agents, are regarded as incalculable and unsuitable for formal analysis; they are therefore ignored, although they are often accepted as being relevant factors.

(5) Little attempt is made to analyse in detail the different distributions

of costs and benefits to the exposed population, except in broad categories among those most directly affected, such as employees at a plant and the general public neighbouring the facility. Some implicit differentiation between risk characteristics is contained within analyses; for example, the notion of 'man days lost' at work due to the consequences of a hazard includes variations in effects according to the age of people and the time delay (latency) before ill-health or death occurs.

(6) Priority is given to techniques of hazard identification, estimation and measurement that use data which can be verified and which avoid personal or social judgements.

I have called this an 'engineering' approach because it is the one that attracts mainly engineers and other natural scientists. It does not mean to imply that this is either intrinsically more 'objective' than other methods or, conversely, too technocratic to be given credence in a topic affected by broader social and political forces. Its strength lies in the concreteness of its calculations, which can provide valuable design inputs and information relevant to regulatory decision-making. Its disadvantage is that this emphasis on quantifiable factors and relatively simplistic relationships and interactions leads it to neglect important non-technical, non-quantified sources of knowledge and to a restricted definition of risk.

The engineering approach in action

The techniques used by the engineering approach can be illustrated in more detail through an example of their use at a petrochemical facility between 1979 and 1981 in Rijnmond, Netherlands[5]. Initially, a systematic model was developed to determine the different ways in which accidents could occur as the result of component failures in the plant, with particular attention paid to examining the effects of varying critical operational parameters, such as material flow, pressure, and pumping direction. In addition, a straightforward checklist method was used to identify what experts considered to be the probable sequences of events that could lead to an accident. Interestingly, about 95 per cent of all possible conditions that were suggested could lead to failure were common to both methods of analysis.

A total of 14 000 failure scenarios were identified. This was too many to be handled by detailed probability analysis, so a smaller number of scenario classes were developed, each of which summarized a number of similar possibilities, refined to identify only the shortest paths that could lead to failure. Two main methods of analysis, *fault tree* and *event tree*, were then used to assign probabilities to each failure path. A 'tree' is a network of paths connected by relationships developed from mathematical logic, for example that one branch in the tree will be reached only if conditions represented by all the branches leading to it are 'true' (this is known as a logical AND operation). A fault-tree analysis starts with the assumption that a particular fault has occurred and traces the pathways back to find the roots of its initiating event. Event-tree analysis takes the opposite route, starting with events that could initiate failure and then moving forwards through possible subsequent sequences of events to see what the outcomes could be.

Once these analyses had assigned probability values to each potential failure path, the magnitudes of possible health and environmental effects of the release of hazardous material were calculated using a *consequence model*. This required, firstly, that attempts were made to determine the *dose-response relationship* using tests conducted on animals, to see how they reacted to materials similar to those that might be released in an accident, and epidemiological studies, which compared the reactions of populations exposed to a low dose of hazardous material or to unexposed groups. The dose-response relationship specifies how probabilities of adverse health vary with the size of the dose received.

Then a model was developed to show how toxic materials could be dispersed under varying weather conditions, geographical and geological circumstances, in order to understand the likely uptake of the hazardous substances by individuals. These various model results were synthesized by calculations involving the population distribution, and health effects and their probabilities, to produce overall estimates of risks and their uncertainties.

These analyses not only formed the basis of safety precautions at the plant but also provided valuable input to local negotiations. The Rijnmond Council established a commission to supervise the risk study, which was carried out and cross-examined by independent consultants. The Contact Group for the Safety of the Population, as the commission was called, consisted of members of the district council, regulatory administrators and representatives from industry. Aided by the commission's work, agreement was reached between the district council and industry on safety requirements. Several companies have concentrated their refineries and chemical storage facilities in the Rijnmond area.

Constraints and potential of this approach

The main objective of the engineering approach is to find the best way of using available technical resources to achieve a single goal. Its focus on measuring risk as if it were a physical property presupposes an imaginary world in which technology, people and social constraints operate completely independently of each other. Important factors are ignored, such as economic comparisons of scarce resources or the social and political contexts that determine the development and impacts of technological capabilities[6]. As it is almost impossible to find quantifiable patterns in the incidences of human failure over time, the crucial role of human action and judgement in the causes of accidents cannot be integrated into this approach.

Despite these limitations and its inherent biases, the engineering approach to risk analysis can have a valuable role to play. Some analysis, however constrained its 'rationality' may be, is better than no analysis at all, as long as its limitations and uncertainties are well understood by those who use its results. The importance of this approach lies not so much in absolute risk quantification but in its ability to provide a basis for comparing alternative ways of achieving a certain benefit, aid safety design and offer a fair basis for evaluating alternative technologies[7]. In addition, of course, scientific analysis is the only way of discovering relevant data on particular hazards, such as the identification of toxic substances and their health effects. Doubts about certain aspects of expert advice should not completely undermine credibility in science and technology (*see* Chapter 6).

The decision-analytic approach

In the 1970s, a new technique began to be applied to risk analysis to overcome some deficiencies of the engineering approach by including criteria other than technical factors and more openly confronting the significance of subjective judgements. Based on decision theory, the decision-analytic methodology uses *multidimensional* models derived from identifying the pertinent factors (*attributes*) likely to influence a decision and assigning priorities (*weightings*) and probabilities to each attribute selected by those with a stake in the solution of the problem being analysed (known as the *stakeholders* or *problem owners*). Analyses and calculations are made on the basis of their weighted evaluations, resulting in advice to the decision-maker in the form of a range of options ordered according to their likelihood of meeting the problem-owner's decision objectives. Statistical data on past behaviour can be assimilated into the analysis with the decision-maker being allowed to determine the degree of reliance that is to be placed on it. *Cost-benefit* analyses can be viewed as a special case of decision analysis in which all attributes are evaluated in the same units, usually monetary (*see* Chapter 1).

The decision-analytic approach to risk analysis can be characterised as follows.

(1) Risk is not regarded as an objective property of an object or situation but as a subjective mental construction based on personal beliefs about the occurrence of specific outcomes or of an event or action.
(2) The context in which a decision is made is regarded as being of primary importance, so the decision-maker(s) or decision-making institution, working with the analyst, can influence the model that is developed, rather than having scientific and technical experts dominate both the nature of the model and the values and weighting input to it, as frequently occurs in the engineering approach.
(3) Probabilities and preferences are deliberately derived from subjective judgements, intuition, speculation and other sources of knowledge, as well as from statistical evidence.
(4) The options analysed must relate to the same goal or problem.
(5) The benefits and costs (*utility*) to the decision-maker of each option is regarded as important, so attitudes that help or hinder this utility can be incorporated in the analysis, such as aversion or proneness to particular risk-taking.
(6) The decision-maker can include as many dimensions of the risk problem as necessary, for example a wide range of potential health effects, environmental damage or even the gain of social prestige.

(7) The problem of human interaction with the risk source and the subjective probability of human failure can be more readily addressed than in the engineering approach.

(8) The nature of the analysis can vary from task to task. It can be close to the engineering approach if the decision-maker wants it to be, or it can rely only on the elucidation of subjective beliefs because quantified data are unavailable or are not appreciated by the decision-maker.

Decision analysis in action

The basic philosophy and methods of decision analysis can be examined in relation to a project sponsored in 1982 by the FRG Ministry of Research and Technology to study comparative risks between different options for generating energy[8]. 'Risk' was defined in broad terms to encompass environmental, economic, social and international dimensions.

One study group tried to identify the categories and criteria that should be selected for the evaluation of energy options using one of the newly developed *conflictual decision-analysis* techniques, *value-tree analysis*. A 'tree' in this context is similar to the network of connections used in event- and fault-tree analyses discussed earlier, except that it is structured by the analyst on the basis of salient values and beliefs elicited from the affected individuals or groups. The tree is constructed with general values at the top and specific *attributes* at the bottom, and quantified weightings are associated with each attribute. A wide spectrum of participants in the decision process were consulted in the FRG energy project, including regulatory agencies, industry, intervenor groups, and members of the exposed population. Individual trees were constructed for each group and the findings gained from them were used to construct a joint value tree for all groups. This provided a summary of the prevailing energy concerns in the FRG, such as pollution control, the danger of nuclear proliferation and the impact on the national economy.

The concerns identified in the joint value tree were used later as the criteria for evaluating each energy option. In contrast to the engineering approach, which requires statistical data for calculations, experts in various fields were asked to give their best estimates of the likely magnitude and probability of occurrence for each option of risk dimension, such as environmental deterioration, employment effects and equity of risks and benefits. A randomly selected group of citizens was then asked to assign weights to these dimensions and evaluations, taking into account the experts' opinions. Using this information, the impacts on the criteria in the value tree were calculated using a relatively simple linear model to yield an overall judgement on each option. The aim of this process was not just to estimate the magnitude of risks but also to provide the foundations for developing practical risk-management policies. The result of this project has been an assessment of different energy strategies according to technical, economic and social impacts and an evaluation of the strategies by educated members of the public. Politicians and administrators were informed about the revealed preferences of the citizens, for example that most people favoured an energy policy which emphasized energy conservation and the development of solar energy, but included nuclear energy as an additional source which should be kept available in case shortages occurred.

Constraints and potential of this approach

Decision analysis makes a virtue of taking into account decision-makers' views and preferences, rather than claiming to be 'objective', but it makes the doubtful assumption that the analysts do not influence the decision-making process. Analysts, however, often have to interpret decision-makers' views to make them suitable for the procedures and calculations involved, which decision-makers often find difficult to understand. Not only can this interpretation process introduce the analyst's own inferences and preferences, but the whole process may be biased towards prerequisites for decision analysis that might not be relevant to the decision-maker, such as the need to provide quantified scales to allow for the computerization of calculations and a consistent basis for comparing risks. The analyst can also influence the process by the selection of measurement scales to be used, the way data are presented, and the procedures chosen to elicit probabilities and weightings.

Decision analysis can fail to take into account many crucial institutional responses and social and political influences on decision-making, which is usually a complex process characterized by power interplay, negotiation and bargaining between various interests. By trying to decompose political decisions into assessments of outcomes, probabilities and preferences, decision analysis makes the generally incorrect assumption that the decision-maker is interested only in rational reasoning processes and tends to focus on many factors that are of little importance in the real political arena. Further, the decision-maker may not wish to, or be able to, reveal his or her true political objectives.

There is, however, a potentially important role for decision analysis in the legitimation of policies and decisions. Faced with potential criticism from opposing groups, investigations by the media, and the threat of withdrawal of support by the public, decision-makers need to be able to defend their conclusions and predictions. This makes it necessary to show that decisions were based on some form of 'rational' analysis. With its sensitivity to many subjective and statistical criteria, decision analysis offers an attractive tool for showing that decisions are based on a broad analysis of which events are most likely to occur and which courses of action provide the most appropriate responses. The client-orientated nature of decision analysis means that those who understand the realities affecting the problem can influence the analyses. This can be of great assistance in producing results of practical use, but it can also be deliberately misused to produce judgements that satisfy the predetermined prejudices of the client, who can then use the 'scientific' image of risk analysis to legitimate a decision that would have been taken in any case.

Despite its limitations and dangers, decision analysis is an important development in risk analysis because it widens the focus of the engineering approach and provides tools that have the potential for drawing a vast spectrum of values and beliefs into a systematic analysis that previously seemed to be confined to a limited number of scientifically observable measurements.

The risk-perception approach

The engineering approach is able to compare risks in different activities within a narrow measure of likely negative outcomes, often expressed in terms of the statistical concept of 'man days lost': for example, relating the risk of smoking tobacco for one year with the risk of living near a nuclear power plant for a year. Decision analysis extends the range of factors considered but compares options aimed only at the same goal because it considers that there are too many variables to make meaningful comparisons between different technologies or activities. Decision analysis also bases its rationale on having a consistent set of values and unambiguous assessment of probabilities.

The next step in the evolution of risk analysis was to move beyond a perspective based primarily on a formal view of the decision process as seen by the decision-maker to investigate the preferences of particular groups or the general public as a whole. This interest in public perception was provoked because there is often a marked difference between decision-makers and sections of the public in their appreciation of the balance between risks and benefits for certain hazards. In considering risk perception, it became clear that there are many ambiguities about the notion of a 'risk' itself. In some contexts, risk refers to the thrill and excitement of undertaking a difficult challenge, such as mountain climbing or rescuing someone from a burning house, or taking a chance to achieve a possible goal, such as investing money in an entrepreneurial business venture or gambling on horse racing.

Risks associated with continual pending danger, for example those from an explosion at a chemical plant, generate considerable attention and anxiety because there is much uncertainty about when a disaster may occur and the nature and extent of its consequences. These uncertainties are vital to the way people perceive industrial hazards, provoking intense anxiety that helps to explain why public attention is focused on newer technologies with an unknown disaster potential.

Attempts to compare risks in different activities are usually meaningless, although such comparisons are frequently used to try to calm fears about particular hazards. Comparing the risks of, say, asbestos in school buildings with motorcycle accidents cannot be understood by most people because they involve such different concepts of risk. It is possible, however, to make comparisons within the same category, say between different food additives, which have a common basis both in scientific theories and in public understanding.

It is not necessarily 'irrational' to take a different view of the concept of risk than that suggested by the 'rationality' of 'scientific' analyses. Putting extra weight on risks with high uncertainty, being more afraid of risks that one cannot cope with personally, defining some risks as a challenge to one's own abilities, or taking a chance on carrying out an action only if the worst thing that could happen would not cause too much regret (the *minimax* strategy) are all valid and reasonable tools to assist people to cope with various kinds of hazards in modern society. Innovative survey methods have been developed combining attitude measurement, information and participation to investigate how such preferences of ordinary citizens can influence policy-making, for example by analysing the views of *planning cells*, small groups that participate in a network of decision making[9].

Lessons for risk analysis

The risk-perception approach implies that regulatory policies should take into account the expectations of those affected by the consequences of a given risk. Potential hazards should be evaluated against these expectations, not just the requirements of scientists, as in the engineering approach, or decision-makers, as in decision analysis. Risk-perception studies, therefore, are aimed at addressing two main issues: what are the important criteria used by those at risk when evaluating potential hazards, and how are they applied in practice?

A flaw in the risk-perception approach is that it assumes most people have similar underlying patterns of perception and apply them in the same way when evaluating similar classes of risk. These assumptions are highly contentious. Nevertheless, risk perception has provided some valuable insights that have been of assistance to risk-analysis developments:

(1) Those factors which people who have to bear risks consider to be violations of their values and interests must be regarded as important determinants of risk-management processes. For each risk source, therefore, potential outcomes and underlying perception dimensions should be investigated separately.

(2) Beliefs about the nature and effects of risk sources vary from risk to risk, individual to individual, and group to group. It is therefore incorrect to seek a universal level of *acceptable risk* that can be regarded as a threshold below which a risk is regarded as acceptable, either for different risk sources perceived by the same individual or group, or a single risk perceived by different individuals or groups. The subjective strength of belief that a catastrophe can happen is of great importance and can override calculations of the expected loss of life over a period of time, or even the magnitude of a potential catastrophe.

(3) Although there are great variations in how different groups and individuals perceive risks, there are some basic dimensions that can be found in almost every risk estimation, including the degree of unfamiliarity with the risk source; whether or not a person has control over the risk; the extent to which a hazard is regarded as a 'sensible' risk to take; the level of dread in which the risk is held; the potential of the hazard to cause harm; the concreteness with which the causes of an accident can be imagined; and the social impact made by the need to enforce excessively strict and possibly far-reaching security precautions[10].

The policy-analytic approach

The enhancement of the decision-analytic approach by taking account of the preferences and perceptions of those who bear the risks, as well as the decision-maker, helped to overcome some limitations of risk-analysis techniques. This was still insufficient, however, to provide an understanding of how to use the information from risk analyses in different contexts. An enriched view of how decisions are actually taken and implemented has been derived from policy-analysis techniques.

Policy analysis emphasizes the *process* rather than the outcome of decision-making. Policy analysts are more designers of procedures for group decision-making and catalysts in the implementation process than problem solvers or advisers[11]. They avoid specifying any particular set of general rules on what should be done but, instead, focus on the social and political processes of making decisions, taking account of personal and group values, institutional constraints, communication interactions, judgements made by other groups that may be taken as reference points, the power interchange in negotiation and bargaining procedures, and, importantly, the distribution of power among participants.

From this view, the degree of accuracy of particular risk assessments is relatively unimportant. Each group uses its own experts and interpretation of expert advice to rationalize an attitude to risk that supports its interests. Those who are likely to gain most from the taking of a risk, in terms of money, status, power or inflence, are likely to make more favourable assessments than those who are likely to lose out. There is no clear-cut distinction between scientific 'truths' contained in quantified risk assessments and subjective and qualitative preferences and judgements, although the social process involved in the generation and use of knowledge is taken into account.

A narrower view of policy analysis has been taken in some risk-analysis circles, where it has been seen as providing additional dimensions, such as conflict costs and implementation problems, to traditional decision-analysis models. Risk-perception studies are regarded as the basis for conclusions on how these social and political costs and benefits can be calculated and evaluated. Once this has been done, decision analysis is used to advise on decision options. Policy analysis, however, should not be confined to this limited role and should be understood in its broader context.

The social concept of risk-taking

The sources of technological risks are not autonomous external stimuli to which society can adapt or not. They are products of social forces and are embedded within a political environment in which many actors continually interact while trying to protect their own interests. The development of particular technologies and the pattern of demand for their use derive from this social and political process. The outcomes of the process often differ from the intentions of 'decision-makers' because what occurs in practice is dependent on *arena rules*, the ways in which actors engage in bargaining and power battles within arenas defined by particular cultural, institutional and political conditions. Policy analysis examines the external forces affecting these arenas and the internal pressures and underlying motivations of the actors, as well as the constraints on scientific and technological disputes (*see* Chapter 6).

A good example of how such policy arenas operate is provided by reaction to possible environmental damage caused by acid rain (*see* also Chapters 3 and 8). Once the effect was identified, claims and counter-claims were made by different groups about who was responsible for it. Power utilities blamed car manufacturers, who in turn blamed car drivers, who gave responsibility back to industry. Industrial spokesmen replied that they were only responding to consumer demands. Consumer associations complained about lack of adequate participation in creating industrial policies. Environmentalists blamed politicians for failing to reduce what they believe is a major cause of the problem, sulphur dioxide emissions. Some political groups accused environmentalists of obscuring more fundamental inequalities in society.

The net result of these conflicts in many countries was to raise doubts about the credibility of all parties and to paralyse political action because any initiative was bound to cause some strong adverse reaction. In the FRG, for example, a speed limit for cars on highways was rejected in 1983, when a two-year study was launched, involving regional testing of speed limits as a way of gaining time until the issue was less controversial.

Constraints and potential of this approach

Policy analysis cannot be a substitute for other approaches to risk analysis. Its strength lies in its exploration of the social environment in which decision-making takes place, explaining how regulatory decisions are taken, and identifying the factors motivating actors in political arenas. An advocate of this approach, Michael Thompson, has commented that policy analysis suggests that risk acceptance, avoidance and absorption are 'distinctive social styles of action that emerge in response to the different risk environments that individuals, as social beings, construct for themselves' rather than just a method of behaviour that characterizes how individuals adapt to their 'objective external world'[12].

The main limitation of policy analysis is that, like risk perception, it fails to provide *normative advice* which provides a consistent, generic set of rules that can be widely applied to deal with risks and formulate requirements for regulation. The engineering approach can yield data on the magnitude of risks that can be useful in all regulatory contexts despite doubts about inherent biases that affect these data, and decision analysis provides a systematic methodology and set of tools for structuring and analysing the decision-making process. Policy analysis, however, tends to provide 'just' enlightenment, although it is producing some useful techniques to allow policy analysts to play a catalytic role in resolving conflicts and in comparing regulatory styles according to criteria which can be linked to decision-analytic methods.

Policy analysis often underestimates the influence of existing scientific approaches. As Arie Rip explains in Chapter 6, there is generally still considerable faith in science, despite a growing awareness of the limits of expert advice. Strategic reasoning by policy-makers is insufficient to resolve regulatory conflicts because scientific arguments are relied on by all parties to bolster their positions and to try to counteract the arguments of opposing interests. Rip's concept of 'pragmatic rationality' is of significance in developing a kind of expertise that takes account of the political arenas in which it is developed and used. It is likely to gain a broad acceptance by different interests because it is directed at producing outcomes that are sufficiently robust to withstand pressures from opposing forces.

Conclusions

(1) There is much ambiguity about the meaning of the term 'risk'. Two broad attitudes to it are exhibited by risk analysts: either risk is regarded as a property of an object that can, at least in principle, be measured by scientific methods, or risk is defined in terms of subjective judgements about possible outcomes of decisions and events, using knowledge about all relevant aspects, although much of this may not be quantifiable.

(2) Risk analysis should attempt to consider all aspects of risk. It should gather, analyse and manage pertinent information, being aware that this process is itself affected by personal and methodological biases, then use scientific conventions or subjective judgement to decide:
   - (a) which data are selected as being most relevant;
   - (b) how different risk dimensions are to be aggregated;
   - (c) which common measure, if any, is to be used for comparing data;
   - (d) what principles are to be used to reduce data and analyses to compact summaries of advice on likely consequences of different options; and how the inevitable uncertainties of risk regulation are to be dealt with.

(3) Four main approaches to risk analysis have emerged, each of which can contribute to the processes recommended in the previous conclusion, although none provides the complete answer:
   - (a) The engineering approach provides a consistent set of rules and objectives to compare quantifiable aspects of risks, providing some degree of scientific 'objectivity' to certain risk dimensions. It is incapable, however, of dealing with important subjective psychological and social factors and its results must be reviewed critically to understand how they have been affected by the biases inherent in analysis.
   - (b) Decision analysis does not seek an 'objectivization' of results and gives priority to subjective views of decision-makers. This helps to make analyses more relevant to practical problem-solving, although it allows the decision-maker to use it for 'justificatory analysis', conducted to legitimate decisions that have already been made intuitively[13]. The range of factors considered, although broader than in the engineering approach, is still relatively limited. More recently developed methods of

conflictual decision analysis, however, allow all stakeholders in the outcome of a decision to have a wide spectrum of their beliefs and values taken into account within a structured analysis.

(c) Risk perception incorporates into risk analyses the extent to which individuals and groups regard a risk as a violation of their values or interests, and how they consider the balance between costs and benefits resulting from a potential risk source will affect their own circumstances. This opens the possibility of allowing the views of many more people to influence decision-making. There are many problems, however, in finding a consistent and systematic way of categorizing and measuring attitudes, and in deciding how to interpret the reasons for, and consequences of, particular perceptions and in actually using these data in policy-making in a democratic way.

(d) Policy analysis provides useful insights into how different groups in society use notions of risk as part of their interaction in social and political arenas, thereby helping to understand what the results of policies are likely to be in their real-world settings and to foresee future demands from different social groups. It provides few generalized practical guidelines and analytical tools that can be applied to solving particular problems.

(4) Regulatory policies can best be assisted by taking into account the factors addressed by each of these approaches and seek to reconcile their various and distinctive goals.

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