PLANNING AND RISK

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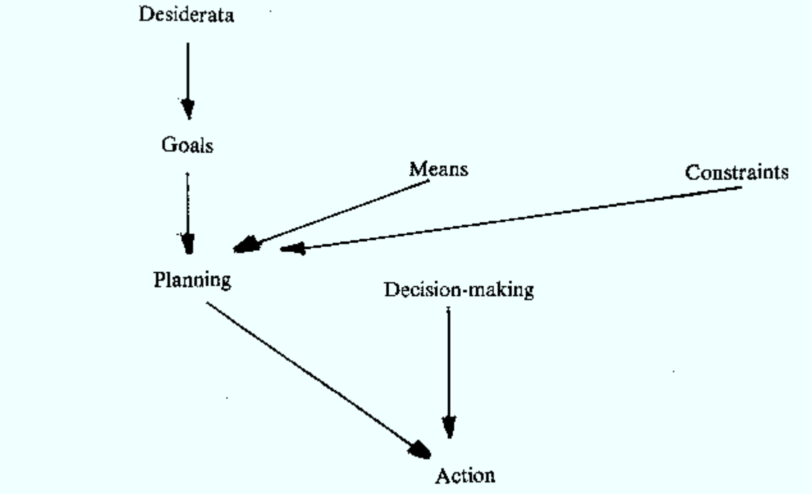
Abstract. The notions of planning, forecasting, efficiency, decision-making, optimality, uncertainty, risk and safety are elucidated. It is claimed that public participation in any technological implementation is essential for improving the quality of life of likely affected people.

1. Planning

A plan is a prescription for a sequence of actions or operations on natural or artificial things (i) performed by rational beings, (ii) with the aim of causing specific changes in these things, (iii) changes that are valuable to someone (the performer or someone else).

In a planned action we can distinguish the following components:

(i) The set of desiderata.
(ii) The set of resources (natural, social, cultural, or whatever).
(iii) The limitations or constraints.
(iv) The set of goals (some desiderata can be unrealistic or non-attainable at a given time).
(v) The design and planning, taking into account the resources, goals, and constraints.
(vi) The decision making.
(vii) The implementation or sequence of actions.
(viii) The study of the effects of the actions and their evaluation.



In particular, the sequence of any technological action is as follows (Alexander 1971, Ostrofsky 1977, Simon 1969, Vidosic 1969, Tobar-Arbulu 1984a Ch. 3):

(i) Primitive needs (general desiderata).
(ii) Needs analysis (choosing the realistic goals from the desiderata).
(iii) Feasibility studies.
(iv) Design proper:
  a) Synthesis of solutions
  b) Criterion modeling
  c) Optimization
  d) Prediction of system behavior
  e) Testing and simplification
(v) Decision (adopt, discard, modify).
(vi) Planning (organization plan of execution of design and production).
(vii) Implementation of design.
(viii) Testing of performance.
(ix) Evaluation of performance.
(x) (New cycle)

Remark

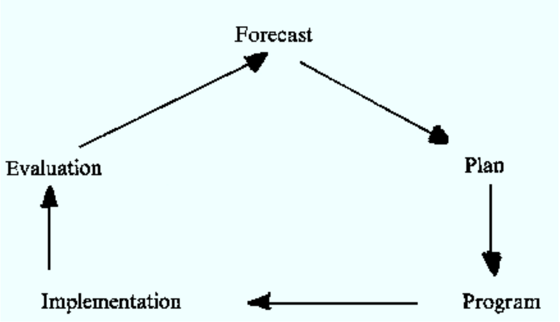
For participative plans, democratic control and public participation, see Ackoff 1970, 1974, 1981, Alexander *et al.* 1975, 1979, Tobar-Arbulu 1984a, 1986a. Here we stress the fact that every plan has to be evaluated before, during, and after implementation.

A good plan should have the following characteristics:

(i) Purposefulness (it should indicate the aims or goals it serves).
(ii) Feasibility.
(iii) Inner consistency and cohesion.
(iv) Reliability.
(v) Flexibility or elasticity.
(vi) Specificity (it should be reasonably detailed).
(vii) Long-term view (the plan should be constructed to cover the longest possible period in the light of existing knowledge of future conditions).
(viii) Maximum simplicity, if possible (the simpler the plan, the more easily we can bridge the gap between conception and realization; in modern design this not usually the case).
(ix) A clear deadline (the date of the completion of work must be specified taking into account point (v)).

2. Forecasting and planning

A forecast provides a statement of future possibilities. On the basis of the forecast, a plan is developed.



The plan describes a sequence of activities which is intended to achieve some goal or other. Once the plan is developed, a program, which is a statement of the resources which will be committed to carrying out the plan, can be devised. The program allocates specific resources to particular activities and assigns specific people to particular tasks. Once the resources are available, the program can be implemented. This involves the expenditure of resources and carrying out of activity by people. After the implementation of the program, it is necessary to evaluate the results: Was the plan successfully carried out? Did the expenditure of the resources achieve the desired results? Was the performance of the activity satisfactory? The evaluation amounts to a determination of the present status, and its comparison with the status which was expected on the basis of the plan. By taking the findings of the evaluation as a new starting point a new forecast can be prepared and the cycle can begin again.

The role of forecasts in planning may be expressed as follows:

a) The forecast identifies limits beyond which it is not possible to go.
b) It establishes feasible rates of progress, so that the plan can be made to take full advantage of such rates.
c) It describes alternatives which are open and can be chosen from.
d) It indicates possibilities which might be achieved, if desired.
e) It provides a point of reference for the plan; the plan can thus be compared with the forecast at any point in time, to determine whether it can still be fulfilled, or whether, because of the changes in the forecast, it has to changed.
f) It furnishes warning signals, which can alert the decision maker that it will not be possible to continue present activities.

(See more in Lenze 1962.)

Since rational actions, in particular long-range actions, are bound to have side-effects, they must be planned and forecast using different techniques (Martino 1972, Jantsch 1967). (For the whole cycle in the context of so-called "technology transfer" —taking into account needs, resources, constraints, impact on society, and kind of development— from technological forecasting to technology transfer to technology assessment, see Tobar-Arbulu 1986b).

3. Efficiency and planning

Given the law statement "If *M* then *G* (with a certain probability *p)",* where *M* stands for means and *G* for goal, a "rule schema" is of the form "to attain *G* use *M",* or "in order not to obtain *G* refrain from using *M".*

Law statement	$M \rightarrow G$ ("If *M* then *G* with probability *p")*
Feasibility	M is technically feasible
Valuation	G is valuable and desirable (Moreover $V(G) \gg V(M)$)
	— — — — —
	M! (Do M, or M *ought* to be done)

Remarks

1. While in science we deal with facts related by "is", in technology we use only nomologically grounded (or justified) rules, norms, or proposals. Further, we introduce the predicate "ought to be done" to apply to an action.

2. Instead of *"x* ought to do *Y",* we may deal with propositions of the form "If *x* does *Y,* then *Z* happens (with a certain probability *p)* and *Z* is valuable" (Churchman 1961). We put it this way because there is no logical deduction of *ought-* statements from *is-* statements —as noted long ago by

Hume (1739-40) and more recently by Simon (1976 Ch. 3). Therefore, the basic pattern of a rule of action has to be justified in practice as well as theoretically.

The degree of efficiency of a means to a given goal is usually taken to be the product of the probability of its outcome by the value of the outcome:

$$e = P(G/M).\ V(G)$$

We can evaluate the goal G, V(G), and for a given means *M,* we know how to evaluate "M → G & S', where *S* stands for side-effects (Tobar-Arbulu 1985b). Therefore, if we know the probability, P(G/M), to attain *G* using means *M,* we will know the degree of efficiency of the whole operation, including the evaluation of the side-effects S. (See Leontief (1977 Ch. 6) for the evaluation of pollution in the economic structure.)

One means is more efficient than another if, and only if, it employs some less valuable means to arrive at a more valuable result.

Not only do our actions, though rational, have unintended and unforeseen consequences, but it is clear enough that no planning, in particular no social planning, can be perfect. This is because planners do not have an exhaustive knowledge of present social systems. Further, (i) social problems are many-sided and their solution requires the participation of experts from different fields as well as public participation (Tobar-Arbulu 1984a Ch. 3); (ii) since social systems are in constant evolution, emergent properties —in particular unpredictable ones— can occur; (iii) since sociosystems (political, cultural, and economic) are related to each other, the events in one of them influence the events in the others; (iv) even in a given sociosystem, individual actions and decisions can alter the system itself. All this, however, does not prevent us from making plans (short-, medium-, and long-term ones). In particular, large scale actions, such as the development of a nation, affect huge numbers of people. Although in these situations flexible plans are preferred to rigid ones, more often than not they produce unpredictable effects. More and deeper social science, more and better sociotechnologies may, and eventually can, improve situations of this kind.

The main problem in modern societies is how to combine public participation (1) with socioeconomic planning. Even when selecting the long-range

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(1) The problem ofparticipation is related to theproblems of power and bureaucracy (Russell 1938, Galbraith 1967-78, 1973-75, 1983). Although these problems deserves further elucidation elsewhere, let us stress here that participation should involve (i) the choice of long-term goals, (ii) the choice of the optimal means to achieve these goals, (iii) the justification of both goals and means. Instead of dealing with endless ideological debates, participation in any political regime whatsoever ought to be measured, for, as Alexander et *al. (1975 p. 38) observe, "only the people can guide the process of organic growth in a community. They know the most about their own needs". Within the Marxian school see Marcovic and Petrovic (1979) for a serious critical elucidation of the concepts of praxis, alienation (in particular alienated labor), self-management in the context of the 1960's and early 1970's in Yugoslavia and for a critique of the bureaucratic establishment. The self-management system, which proceeds from the principle*

goals most likely to be achieved with the available resources, the greater the participation of the people affected by the plan, the more effective its implementation will be (Ackoff 1970, 1974, 1981, Alexander *et al.* 1975, 1979). Further, in social planning both *Small is Beautiful* and *Large is Beautiful* are good slogans, depending on the size and characteristics of the problems at issue. Besides, when dealing with management, each type of sociosystem requires its own study of efficiency. Thus, Greiner (1972) has identified several phases in the development of a business firm, each of them requiring a different kind of management. (See Marcovic and Petrovic (1979) and Milenkovitch (1971) for the Yugoslav experience, where different ethnic groups are combining economic planning within a framework of a mixed economy and political decentralization.)

4. Planning and renewable resources

It is obvious that the fossil fuels are exhaustible. Likewise, it is also obvious that a minority of selfish humans can organize themselves to exploit the majority's dilemmas. A glance at the basic economic, political, cultural, and social problems of present-day society tells us that the solution to these problems is through invention and development. This involves the design of physical, chemical, biological, and social artifacts so that these artifacts —in the hands of competent users— can provide so much performance per erg of energy, kilo of material, and second of time as to make them feasible and economical in order to provide a sustainable standard of living for all individuals of any given society. It is obvious that attaining these goals requires enormous amounts of energy. Besides, our contemporary advanced standard of living, at least in some countries, can be partly sustained by new sources of energy: sun, wind, ocean, and, in the near future, nuclear fusion. It is then clear that this standard can be attained by artifacts that emancipate

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that each development decision ought to be made at that particular management level at which some given goal can be beste and most fully achieved, presupposes multilevel management, i.e., management at more levels than is the case with centralized systems (Stajanovic 1982). Two issues arise when choosing a particular level of management: (i) what the goals of the higher levels mean to the lower levels under the conditions of self-management, (ii) what the optimal decision is, and how it is reached. (See Stajanovic 1982 for planning procedures from a section in a plant —the smallest organizational unit— to the enterprise and various forms of integration of enterprises, to municipalities to republics and the whole federation of republics, as well as for the control of plan implementation and the evaluation of the need for corrective measures.) Stajanovic (1982 p. 41ff) classifies some open problems in the Yugoslav system of self-management planning into three groups: (i) problems related to the selection of development priorities (i.e., selection of priorities in the medium-term development of the country, since Yugoslavia is a multinational state), (ii) problems which stem from the industry-territory relationship (i.e., maximization of gross income per employed person versus maximation of gross income per citizen: finding the optimal relation between industry and territory is essential in the process of planning): (iii) problems from the domain of planning methodology.

humans from piped, wired, and metered exploitation of the many by the few. We might christen these artifacts leading to the fulfillment of human needs *"livingry"* in contradistinction to *"weaponry"*.

We advocate a technological, political, cultural, economic, and biological reform and improvement of the environment so that life may continue to be worthwhile. As technologists we are greatly interested in all that is happening on the political-economic scene and in the impact of unforeseen technological events upon it. We see, for instance, how computers have altered the whole scene, to the point where some people have long since been discussing "artificial intelligence" (Tobar-Arbulu 1984b). We are students of the effectiveness of technology in all its expected and unexpected alterings of the environment and human behavior. With Fuller (1983 p. XX) we know, "that technologically humanity now has the opportunity, for the first time in its history, to operate our planet in such a manner as to support and accomodate all humanity at a substantially more advanced standard of living that any humans have ever experienced", if we are not "atom-bombed into extinction by the pre-emptive folly of the political puppet administrators fronting for the exclusively-for-money-making supranational corporations" weaponry industry of the now hopelessly bankrupt greatest-weapons-manufacturing nation (the USA)" *(op. cit.* p. XXXI).

Social problems, such as poverty or the decay of urban centers, are extremely important. The danger of nuclear war, important as it is, should not make us blind to other problems and dangers. "Many in the Reagan administration", claims Weisskopf (1982 p. 58), "obviously disagree. They seem to argue that the Russian military danger is so great that we must put all our money there [in the arms race] and let the poor go hungry". Human beings, however, are more terrestrial or worldy than ever before. It is evident that the degree of technological development, if realistically appraised and articulated, now shows that all humanity can reach a state of comprehensive technological development adequate to provide a "billionaire's level of living on an indefinitely sustainable base for all of the over four billion human passengers now aboard Spaceship Earth" (Fuller 1983 p. 80). The key point is to shift "from weaponry to livingry production" *(op. cit.* p. 83). While both superpowers have jointly spent six and a half trillion dollars in developing the present capability to destroy all humanity within one hour, humankind at large knows that the same sum spent in the direction of improving the lives of the deprived many might really have brought about better results than the suicide of the entire race. All of us should be involved in converting all industrial production from killingry to livingry products and service systems, which allow more participation and collaboration in the solutions to the problems that beset present-day societies. Further, we know (Galbraith 1967-78, 1973-75, 1983) that economic problems are related to political problems, and in particular to *power* (1).

Given the ecological disasters brought about by the irrational exploitation of resources in the past and the growth of population and consumption, a new discipline, bioeconomics, has been developed to deal with the management of renewable resources from forests to fisheries to prairies. Interdependent and multidisciplinary studies (biological and economic) are being carried out so that harvesting and conservation may be balanced: the rate of harvesting should be, ideally, equal to the renewal rate. The planner should make recommendations based on mathematical models fed with empirical data for the optimal rate of harvesting. It is the task of the decision maker to decide, in view of the information available, and taking into account possible extinction of the species in question or irreversible destruction of resources, as well as the degree of erosion and desertification and the population nutritional needs, the pace and rate of the harvesting of renewable resources.

5. Planning and decision-making

While *choosing* is making a selection among alternatives on their basis of their probable outcomes, *deciding* is making a selection between alternatives on the basis of the results of a comparison, and *planning* is making a succession of decisions prior to the final action in relation to an incentive (Bindra 1976 p. 295).

The behavior of animals frequently consists of chain of causes of action, continuous or interrupted, that have been prepared in advance of their execution. Planned behavior is thus related to a common goal, and may be seen as involving a number of subgoals that are intermediate steps for reaching the specific more remote goal. From a psychological point of view (Miller *et al.* 1960) a *plan* is defined as "any hierarchical process in the organism that controls the order in which a sequence of operations is to be performed", and involves a flexible neural program. However, this flexible neural program still remains to be characterized. According to Bindra (1976 Ch. 10 and 13), the whole matter boils down to the fact that certain situations contain stimuli that can activate the contingency organizations capable of exciting the neural system(s) related to a plan, and this in turn leads to the recall of the decisions reached in connection with certain other stimuli.

On the other hand, *forecasts,* and in particular technological forecasts, are not their own justification (Ayres 1969, Bright 1967, Jantsch 1967, 1972). In fact, every technological forecast is intended to be used as decision information. The sole justification of a technological forecast is its utility in making a decision. This is true regardless of the precision or rigor of the methods of forecasting (see Martino 1972, for different methods used in forecasting), and the accuracy of the data base used. We will discuss below some of the features common to several areas in which technological forecasting can be used. (For details of applying technological forecasts to planning and decision making in specific areas, see Ayres 1969, Jantsch 1967, 1972, Martino 1972.)

A plan is a sequence of decisions, each related to the other. However, a plan may result from a decision to attempt to achieve a certain goal. Thus a decision may lead to planning, just as planning may lead to a decision. In the following, we will consider decision on an individual basis.

Definition 1. Decision-making is the act of selecting one from among a set of feasible courses of action.

Remarks

1. Decision-making is previous to action, which in turn involves some change or other in some present situation.
2. The course of actions must be feasible.
3. There must be a set of courses of action available. The members of the set must be distinguishably different, either in the actions to be taken or the means to be employed.
4. Decision-making implies some limitations on resources. If all the available courses of action can be pursued simultaneously, no decision is needed.
5. As for optimality, in most practical situations a "good decision" can be described as one which "gains the most return for the least cost". However, this point needs further study to provide the decision-maker with some guide for choosing one course of action over another. (See below, Section 7.)

6. The planning process

What is the nature of planning? Is long-range planning any different from medium or short range planning? How are planning and decision-making related? These are questions that we shall try to deal with here.

Remarks

1. According to Drucker (1959) planning (i) is not forecasting; and (ii) is not an attempt to eliminate risks.
2. A plan is not a precise statement of what is going to happen, but rather a statement of what looks like a reasonable course of action in the light of available information.
3. Because the future is uncertain, decisions made in the present commit resources in the present that are inevitably put at risk. The purpose of planning is not to eliminate risk, since that is often impossible, but to secure that the risks taken are the *right* risks.

Definition 2. Planning is the process of preparing a set of decisions for action in the future, directed at achieving some goal by optimal means.

Remarks

1. Planning implies rational activity.
2. In planning one tries to generate a set of possible decisions rather than actually take the decisions. The point is that the planning activity is

usually carried out by people other than the decision maker(s) responsible for the ultimate implementation. Thus the results of planning are often approved and executed by people other than the planner(s). (For the responsibility of technologists, planners and action-performers see Tobar-Arbulu 1986a Ch. 6, 1986c.)

3. While decisions can presumably be considered one at a time, planning must of necessity deal with a set of interdependent and sequentially related decisions.

4. As Dror (1968a p. 36) asserts, "the significant output of planning is not the plan itself but the plan's effect (if any) on social situations".

5. Planning must be responsive to the goals of the individual(s) or organization within which the planning is being done.

6. Planning is not just shaping the future to our desires and wants, but doing this with the most effective and efficient use of the resources available.

A plan provides guidance for all its subordinate elements (recall Section 1). The decision to accept the plan (that is, the result of the planning process) is a decision in the present to carry out certain activities —which can be improved while they are performed— in the future. At the time a plan is made, a certain sequence of steps may appear to be the optimal means to achieve a desired goal. However, as more information becomes available, the sequence may no longer look as good as it did at the outset. Hence it is essential that planning be *flexible,* so that previously made plans can be revised. Any modern technological plan is flexible throughout its implementation. This does not mean that modern technology is based on the trial-and-error method as Popper claims (1974 p. 353). On the contrary, the scientific method —and in particular its application to complex social situations— is applied throughout (Tobar-Arbulu 1985c). (For Operations Research as a technology based on the scientific method and aiming at improving the effectiveness of sociotechnical systems see Tobar-Arbulu 1985d, 1986a Ch. 3.)

A rational plan then is not something which has been approved at corporate or military headquarters once and for all, prescribing in minute detail the activities of every subordinate action from the present to some point in the remote future, and which must be followed without undeviation regardless of the local situation or of changing conditions. (For the evaluation of side-effects before, during, and after any technological implementation, see Tobar-Arbulu 1986b.) A decision maker should be aware that circumstances change, and that proposed actions may have to be revised because of these changes.

7. Long-, mid-, and short-range planning

How long a long-range plan, or how short a short-range one, is depends on the individual(s) or the organization and what it is doing. Short-range planning involves decisions which cannot be postponed for very long. However, although short-range planning involves only current decisions, it must look as far ahead as the degree of futurity involved in its decisions.

Long-range planning involves plans that can be postponed for some length of time. The purpose of a plan is to lay out a general path towards a goal of the individual(s) or organization so that short-range plans can be made in conformity with this long-range plan. Without a long-range plan, there is a real danger that successive short-range plans will be based on experiences of the moment, and that no progress will be made toward the individual(s) or organization's goals even over a period encompassing several short-range plans.

A mid-range plan covers a time intermediate between the short-and long-range plans. It is aimed at goals which are intermediate steps to achieve the long-range goals. It takes its direction from the long-range plan, and in turn provides direction for the short-range plans.

The level of detail, the precision of the timing, and the degree of completeness vary among the three types of plans.

8. Optimality and uncertainty

Let us make here some remarks about the *optimality* of decision making.

More often than not the resources which are available and which may be devoted to the achievement of some goal are fixed, and the objective is to gain as much return as possible from these fixed resources. We can face, in principle, two kinds of problems:

(i) Which investment (of money, energy, materials, or whatever) gives the greatest return; and
(ii) The converse situation, namely where some precisely determined return is to be achieved, a lesser return being acceptable, and a greater one superfluous.

In (i) the objetive is to maximize returns for a fixed cost. In (ii) the objective is to gain the desired return at the lowest possible cost. A common example of situation (ii) is the practice of inviting bids on a set of specifications, say, the construction of a road, dam, or whatever. The desired return, in terms of performance, floor space, or whatever, has been specified. Awarding the contract to the lowest bidder obtains those returns at the lowest cost. (Not only monetary cost for side-effects must also be taken into account.)

The most general case is the situation where neither the costs nor the returns are fixed. There is a range of possible return between the lower limit which is just acceptable, and an upper limit where additional returns become superfluous. Likewise, there is some upper limit on the acceptable cost, and some lower limit (possibly zero) defining the least amount which is to be spent. Optimality involves a balancing of costs and returns, i.e., selecting the particular point where the additional returns above the acceptable minimum are just worth the additional costs, and further returns would not be worth the further costs of obtaining them. (Operations Research, Systems Engineering, and Systems Analysis deal with this problem of optimality when neither return nor costs are fixed, see Tobar-Arbulu 1985d, 1986a Ch. 3.) Better quality of performance can always be obtained at greater cost, but at some point the decision-maker must conclude that the extra return is no longer worth paying for. The key to the decision problem is, in fact, identifying this point.

Since decisions are not made in a vacuum, the decision maker must know the courses of action open to him, the cost of each, the return of each, and their side-effects. However, he often cannot know the full costs, the full returns, and the full side-effects of each course of action. Many are too remote in time or space to be identified. Many occur as the result of complex circumstances where probabilistic or stochastic models are applied. Some of the returns, costs, or side-effects of a course of action do not even become known until the action has been taken, although all of the significant ones of each course of action must have been identified prior to the decision. A decision depends upon the information on which it is based. Information costs time, effort, and money. Hence a decision-maker who obtains far more information than he needs, or who requires more and more confirmation of a given reasonably valid piece of information, is not making an optimal decision. The worth of an additional piece of information in this situation is far less than the cost. Further, the decision-maker who keeps postponing a decision in the hope of gaining yet more information is not behaving optimally. He can never have complete information. Once he has sufficient information, postponing a decision may result in nothing more than a reduction of the alternatives open to him, as some of them are eliminated by circumstances.

Therefore, information, though necessary, is always incomplete. Hence the decision about how much information to gather, and how much time or resources to spend for getting more of it, may be as important as the basic decision for which the information is being gathered. This situation leads us to the problem of *uncertainty,* which is not only that the decision-maker has incomplete information, but also that the information he does have may involve uncertainty, either because he uses stochastic law statements or because the feasibility of some course of action involves some *risk* or other.

We can divide decisions made in conditions of uncertainty into three classes:

(i) decisions under certainty;
(ii) decisions under risk; and
(iii) decisions under uncertainty.

Class (i) deals with decisions whose outcome is known with perfect certainty, i.e., by application of deterministic law statements where the boundary conditions are known. Class (ii) deals with decisions for which the outcome is not known, but all the possible outcomes and the odds on each are known. Class (iii) deals with those for which neither the odds of the outcomes nor even perhaps all the possible outcomes are known. In case (iii), if we are allowed to carry out some experiments we can eventually convert some of the uncertainty to risk. Likewise, if the probability of an outcome is almost one, it is as if the decision is made under certainty. In most technological projects, it is possible to convert some or all of the risk to a practical certainty by uncovering a coefficient of safety underlying the outcomes. Risk and safety go together in modern technology. Let us now take a look at risk.

9. Risk

Human actions may result in either gains or losses. Risk implies something unwanted to be avoided. Risk is then associated with results that involve losses. Risk has been defined in a variety of ways. Most often two concepts, probability of occurrence of an event and the consequences of an adverse occurrence, are part of the definition. For example, Whyte and Burton (1980) define risk as the product of probability and the consequences of an event, where "consequence" is measured by modelling the risk system.

In the case of technological models, the probabilities of different failures, particularly those involving a series of malfunctions, are unknown. A method of estimating the probability of failure in large technological systems is the so-called "event tree analysis". This method works as follows:

(i) An initiating event is postulated —i.e., a pipe break in the primary system of a nuclear reactor. The tree is then developed (White and Burton 1980 p. 50) by determining, from a working knowledge of the reactor, which other systems might affect the subsequent course of events.
(ii) The systems are ordered in the sequence in which they are expected to affect the course of events.
(iii) For the initiating event a probability of its occurrence is estimated. I.e., how often can such pipe breaks be expected to occur? This is obtained from experience with non-nuclear systems.
(iv) For each of the subsequent events the probability of the system's performing its function as well as the probability of its failure is estimated.
(v) Once the event tree is constructed, the sequence of events in each accident chain is defined so that it si possible to calculate the consequences for that series.

The event tree approach can thus provide a definition of possible consequences of an accident.

In our view however, one must distinguish *risks from natural hazards* —such as floods, earthquakes, volcanic eruptions, avalanches, landslides, tornadoes, hurricanes, high winds storms, all of which occur in nature independently of human presence from *risk from man-made hazards*— such as nuclear technology, dams, weather modification, avalanche control technologies and flood control structures. While risk estimation refers to the systematic determination of risk characteristics, evaluation of risk is part of the decision-making process.

Definition 3. Risk is the potentiality that exists in the realization of an event that it will have unwanted, negative consequences.

Remarks

1. In particular, when dealing with man-made hazards, risk takes into account the application of some means to do (or to refrain from doing) something, in some environment or other, and relative to some individual(s) or other.
2. The causative event may be a single event, some combination of events, or a continuous process.
3. The consequences may affect individual(s) or organization(s).

10. Evaluation of risks

Let A be an action using means *M* to achieve goal *G.* If P(G/M) stands for the probability to get goal *G* when using means *M,* "1 — P(G/M)", is the improbability of that event. If we assign means it4 value V(M), the risk can be evaluated as follows:

$$R\ (G/M) =_{\mathrm{def}} [1 - P(G/M)]\ V(M)$$

A conservative technologist will not perform any action unless P(G/M) = 1, or unless the safety coefficient covers the risk (2). Safety is

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(2) *A more complex evaluation of risk can be the following one. Suppose that we face a situation in which a single catastrophic event may or may not occur. Let* P(A/E) *be the probability of* A's *occurrence in environment* E, *and* P(-A/E) = 1 — P(A/E) *be the probability of the complementary event. (Recall that "negative" events are interpreted as the failure of performing them.) Suppose that we can evaluate losses* L(A) *and* L(-A). *According to Raiffa and Schlatfer's (1961) risk can be evaluated as follows:*

$$R(A/E) =_{\mathrm{def}} P(A/E) \cdot L(A) + P(-A/E) \cdot L(-A)$$

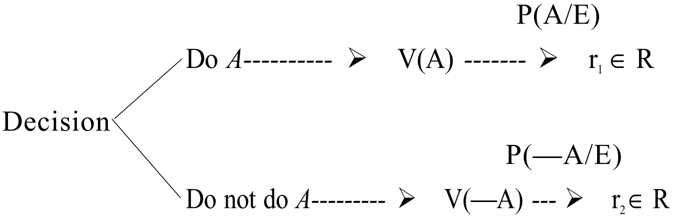
Remarks

1. *The specification of* L(A) *is a dificult problem. Losses may not only be monetary, but they must also include destruction of the environment andpublic goods, and even guilt if the event is avoidable.*
2. *If the event affects individual(s), the difficulty increases. Each of several groups of invididuals can have its own evaluation of losses. Whose perceptions are relevant? How can conflict in perceived risk be achieved?*
3. *The view of probability to which we subscribe is the objective propensity following the probability calculus proposed by Rényi (1970a,b), Tobar-Arbulu (1985e).*

often legislated, so that no harm will result from the proposed use of the technological action when dealing with the "public" or "collective" or "common" good —such as air, water and natural parks—; or normalized when dealing with private ones. (See Tobar-Arbulu 1986d for the notion of basic human needs.) A major thrust of effective legislation is to make sure of the non-exploitation and infeasibility of projects involving public harm. The main requirement for minimal danger is to devise legislation and decision processes that lead to stable cooperation among the parts involved. The experience of self-governing organisms gives examples of loyalty to public concerns (3).

11. Decision and risk

When facing a specific situation for performinng (or refraining from performing) an action A in a given environment *E,* the schematic decision situation is as follows:



Where V(A) and V(—A) stand for the values of actions A and *non-A* respectively (a "negative" action is interpreted as the failure of performing

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(3) *For different methods and models of evaluating risks see Rowe (1977), Lind (1982), and Schwing and Alberts (1980). To estimate precisely the probability of an event, such as a coremelt accident in a nuclear installation, is extremely difficult because of a lack of directly relevant data, and because it is virtually impossible to model adequately all the systems involved. According to Rasmussen (1981), the risk associated with a number* n *of events is:*

$$Risk = \sum_{i=1}^{n} (\text{probability of event } i) \times (\text{consequence of event } i), \text{ where } 1 \le i \le n,$$

namely, the expected value of the consequences. (The consequences may be expressed in many different ways: lives, dollars, worker-days, and so on.) The application of this evaluation requires a common measure of the consequences of all events i, *and the corresponding probabilities. Thus, in the Reactor Safety Study, also known as the Rasmussen Report, WASH-1400 (Rasmussen 1975), a special technique is used —the event-tree and fault tree (Rasmussen 1981)— to predict the probabilities of rare accidents. This study was reviewed and criticized (Lewis 1978, Glasstone and Jordan 1980) as being deficient in several respects: (i) the use of inadequate data bases, (ii) the inability to quantify common-made failures and human adaptability during the course of an accident, (iii, questionable statistical procedures.*

it), and P(A/E) and P(—A/E) for the probabilities of the events *A* and *non-A,* in the given environment *E.*

In general, we shall find this situation for all the different actions A_i that might be performed to arrive at some goal.

In modern technology a program must be developed in which design analysis, studies and testing will identify system performance limitations, failure modes, safety margins, and critical operator tasks. All the known facets of safety optimization must be considered in identifying, eliminating, or controlling hazards. Systems safety management and engineering must be integrated with other management and engineering disciplines in the interests of an optimal system design.

13. *Safety*

Safety and risk go hand in hand in modern technology. In any technological design, procedures for the development and integration of system safety must be developed to assure a program consistent with the overall system requirements.

After a feasibility study, where a set of workable solutions to the design problem are developed, evaluation of the safety of the system concepts under consideration are needed. System safety verification includes, among other things, the following:

(i) Preparing a system safety program plan.
(ii) Evaluating all materials, design features, procedures, operational concepts, and environments under consideration which will affect safety throughout the life cycle of the system.
(iii) Preparing a preliminary hazard analysis to identify hazards associated with each alternative concept.
(iv) Identifying possible safety interface problems.
(v) Highlighting special areas of safety consideration, such as system limitations, risks, and person-rating requirements.
(vi) Reviewing safe and successful designs of similar systems for consideration in alternative concepts.
(vii) Defining the safety requirements based on past experience with similar systems.
(viii) Identifying safety requirements that may change during the system's life cycle.
(ix) Identifying any design analysis, test, demonstration, and validation requirements.
(x) Documenting the system safety analyses, results, and recommendations for each promising system concept.
(xi) Preparing a summary report of the results of the system safety verification conducted during the program initiation phase to support the decision-making process.

(xii) Tailoring the system safety program to the subsequent phases of the system's life cycle, and including detailed requirements in the documents.

(See Appendix for system safety verification tasks during the validation phase and engineering development.)

The system safety program plan is the management document that tells what the system safety objectives are and the methods by which these objectives will be pursued. This plan describes how the system safety program will be established and carried out. It should describe:

a) The safety-management organization and how it relates to other program functions.
b) The types of analyses required to identify and evaluate all hazards associated with the system.
c) The specific hazards to be minimized and controlled to an acceptable level.
d) The types of records to be established and maintained.

(See more on system safety in Brown 1976, Hammer 1976, Marshall 1982, Riddley 1983.)

13. Safety and public participation

Efforts to enhance the public acceptability of decisions involve —in addition to scientists, technologists, and experts— not only the leaders of major associations and state and regional officials but also the general public, in an attempt to get a consensus on controversial projects. Thus in West Germany, in 1975, 927 consultant experts from industry, research, trade unions and other interest groups were employed by the Ministry of Science and Technology. In the Netherlands, the government organized an elaborate public inquiry system on the principle that the public must be consulted on all decisions affecting the environment. Government plans are preceded by the publication of "policy intentions" dealing with political questions: the objectives of growth, the goals of particular projects and their likely impact (Nelkin 1977, Nelkin and Pollak 1977).

More and more participatory models have been developed during the last decade. The traditional "welfare model", in which risks were defined mainly by experts, is nowadays becoming obsolete. A midway point between technocracy and democracy is the approach to solve this kind of problem. The main steps in dealing with controversial policies are the following:

(i) Statement of the problem. (Is opposition to a technological implementation really based on concern about risk or is it the surrogate for more fundamental social concerns? Too often highly political issues are defined as technical and questions about the impact of a technology on community values are translated into arguments about the degree of risk involved.)

(ii) Participation of appropriate interest.
(iii) Management of consensus procedures. (Choice of commissioners, supervising, and consulting agencies.)
(iv) Distribution of expertise. (Inadequate distribution of expertise allows control of information.)
(v) Limits of choice. (Most inquiries are simply structured discussions of predetermined policy with few real options. The financial and administrative investments involved in specific technologies are simply too profound to allow for a real margin of choice.)

(We deal in Tobar-Arbulu 1986b with *technology assessment* as the framework in which technology implementation ought to be discussed.)

Let us emphasize here that when risks are known, legal criteria and procedures for determining societal acceptability of risk are usually established by governmental institutions performing legislative and/or judicial functions (Green 1980).

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Appendix:
SYSTEMS SAFETY VERIFICATION

Systems safety verification during the *validation phase* should include the following:

i) Prepare or update a plan to describe the integrated system safety effort planned for this phase.

ii) Perform preliminary hazards analysis (see below), or update the analysis performed during the program's initiation phase. (Prepare a preliminary hazards analysis report of the proposed system and operational environment).

iii) Identify technology, design, production and the risks affecting safety.

iv) Establish system safety criteria for verifying that requirements have been met.

v) Carry out trade-off studies to assess system safety requirements and risk. Recommend system design changes based on these studies to ensure that optimum safety is achieved as well as performance and system requirements.

vi) Identify, for inclusion in the appropriate specifications, both qualitative and quantitative system safety requirements.

vii) Perform subsystem, system, and operating and support hazards analysis.

viii) Review all test plans to assure that tests are conducted safely.

ix) Ensure that identified hazards are eliminated or controlled.

x) Review training plans and programs for adequacy of safety measures.

xi) Evaluate results of failure and investigations recorded during the validation phase. Recommend redesign or other corrective action.

xii) Ensure that system safety requirements are incorporated into the system specification based on updated safety studies, analyses, and tests.

xiii) Prepare a summary report of the results of the system safety tasks conducted during the validation phase to support the decision-making process.

xiv) Refine the system safety program. Prepare a plan for the full-scale engineering development and initial production phases.

Systems safety verification during *full-scale engineering development* should include the following:

a) Ensure effective and timely implementation of the system's safety program for the full-scale engineering development phase.

b) Review preliminary engineering designs to ensure that safety design requirements are incorporated and that hazards identified during validation are eliminated or controlled.

c) Update system safety requirements in system specifications.

d) Perform or update subsystem, operating and support hazard analyses and safety studies concurrent with the design/test effort to identify operating and support hazards. Recommend and require design changes and control procedures.

e) Identify testing facilities, test requirements, specifications, and criteria to ensure that design safety is verified. Review the test plan and programs to ensure safe execution of the tests.

f) Carry out technical design and program reviews, and present results of subsystem, system, and operating, and support hazards analyses.

g) Identify and evaluate the effects of storage, packaging, transportation, handling, test, operation and maintenance on the safety of the system and its subsystems.

h) Evaluate results of failure analyses recorded during full-scale engineering development. Recommend redesign or other corrective action.

i) Identify, evaluate, and provide safety considerations for trade-off studies.

j) Riew appropriate engineering documentation (drawings, specifications) to verify that safety considerations have been incorporated.

k) Review and provide safety inputs to preliminary system operation and maintenance publications.

l) Verify the adequacy of safety and warning devices, life-support equipment, and protective equipment.

m) Provide input to safety training courses.

n) Review preliminary production including purchase specifications, process quality control, inspection and acceptance, and test procedures to confirm that safety in the process and end product is established and maintained during production.

o) Ensure that requirements are developed for safe disposal of hazardous materials and equipment.

p) Prepare a summary report of the results of the system safety tasks conducted during the full-scale engineering development phase to support the decision-making process.

As for the *preliminary hazards analysis,* which provides and initial risk assessment of a system, it should identify critical areas, evaluate hazards, and identify the safety design criteria to be used. This preliminary analysis established the framework for other hazard analyses and safety engineering evaluation of design. It should consider the following for identification of hazards:

i) Hazardous components (energy sources, fuels, explosives, high-pressure conduits).

ii) Safety-related interface conditions among the various elements of the systems (material compatibilities, static electricity, electromagnetic interference).

iii) Environmental constraints including normal operating environment (temperature extremes, hazardous noise, illumination and humidity).

iv) Operating test, maintenance, and emergency procedures (human error analysis of operation and maintance functions, life-support requirements).

The consequences of risk analysis may be summarized as follows:

A) *Health effects*

1. How many people are (will be) affected?
   - a) In the entire population
   - b) In sensitive groups
2. How much are they affected?
   - a) Morality
   - b) Morbidity
   - c) Severe pain and suffering
   - d) Psychological discomfort
   - e) Anxiety
3. Who are they?
   - a) Age distribution
   - b) Income distribution
   - c) Race/ethnic group
   - d) Sex
   - e) Occupation
   - f) Geographical location
   - g) Quality of life/health status

4. When will they be affected?
    - a) Now
    - b) With some time lag
    - c) Future generations
5. How voluntary/involuntary is the risk?
6. How catastrophic is the risk (clustering of fatalities over time and space).
7. How identifiable are the victims and how accountable will the decision maker be?

B) *Non-health effects*

1. Aesthetics.
2. Effects on nature.
3. Economic costs (and to whom).
4. Effects on economic growth, productivity/innovation.
5. Effects on business competition.
6. Effects on other countries.
7. Effects on distribution of income.
8. Effects on public satisfaction with government.

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