Decisions with Multiple Objectives

Preferences and Value Tradeoffs

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CHAPTER 1

The Problem

In an uncertain world the responsible decision maker must balance judgments about uncertainties with his or her preferences for possible consequences or outcomes. It's not easy to do and, even though we all have a lot of practice, we are not very good at it. Here we suggest formal techniques that will be helpful in this decision-making process. We concentrate on formalizing the preference or value side of the problem rather than developing procedures for the assessments of uncertainties. This doesn't mean that we think modeling of the uncertainties is unimportant. However, we feel that many capable scholars have already dealt with the modeling aspects of the kind of problems we have in mind; our efforts on the *value* side of the problem are meant to complement theirs. So, let's assume that the assessments of uncertainties are given, and let's worry about how we, as decision makers, can make sense out of our conflicting values, objectives, or goals and arrive at a wise decision. As one of our associates expressed it, "the aim of the analysis is to get your head straightened out!"

We suggest—or *prescribe*—how a decision maker (perhaps *you*) should think systematically about identifying and structuring objectives, about making vexing value tradeoffs, and about balancing various risks. The following sketches of problems will set the stage.

1.1 SKETCHES OF MOTIVATING EXAMPLES

1.1.1 Electrical Power versus Air Quality*

A mayor must decide whether to approve a major new electric power generating station. There is a need for more electricity, but a new station

* This example is discussed in detail in Section 7.1. That discussion uses the theoretical concepts introduced in the intervening chapters.

would worsen the city's air quality, particularly in terms of air pollutants such as sulfur dioxide, particulates, and nitrogen oxides. The mayor should be concerned with the effects that his actions will have on

The health of residents (morbidity and mortality).
The economic conditions of the residents.
The psychological state of the residents.
The economy of the city and the state.
Businesses.
Local politics.

These broad categories, and others, must be clarified and made more meaningful before measurements and evaluations can be made and before a delicate balancing of the possible impacts can be systematically undertaken. Even if the consequences of each possible action of the mayor could be foreseen with certainty, which is far from the true state of affairs, he would be faced with a complex value problem.

1.1.2 Location of an Airport*

What should Secretary Bracamontes, head of the Ministry of Public Works, recommend to President Echeverria regarding the development of future airport facilities in Mexico City? Should Mexico modernize its present facilities at Texcoco or build a new airport at Zumpango, north of the city? The decision is not a static one (Texcoco or Zumpango now!) but, instead, a dynamic one that considers phased developments over a number of years. There are many uncertainties, including the possibility of technological breakthroughs (e.g., noise suppressants, new construction methods for building runways on shallow lakes or marshlands, and a breakthrough on the increased maneuverability of commercial aircraft); the possibility of changes in demand for international travel; the possibility of future safety requirements being imposed by international carriers; and the like. But even if Secretary Bracamontes had a reliable clairvoyant, his problem of making a choice is still complex. He must balance such objectives as how to:

Minimize the *costs* to the federal government.
Raise the *capacity* of airport facilities.
Improve the *safety* of the system.
Reduce *noise* levels.
Reduce *access time* to users.
Minimize *displacement* of people for expansion.

* Chapter 8 is devoted entirely to this example.

Improve *regional development* (roads, for instance).
Achieve *political* aims.

These objectives are too vague at this stage to be operational. However, in making them more specific, the analyst must be careful not to inadvertently distort the sense of the whole.

1.1.3 Treatment of Heroin Addiction

Heroin addiction has reached alarming proportions in New York City and something must be done about it. But what? The problem has been studied and restudied, yet the experts differ widely in their proposed strategies. The reason is partly because the problem is so complex that experts honestly disagree about the implications of any specific treatment modality. Technically they differ on what a reasonable model of the phenomena should include and on what reasonable rates of flow from one category to another within the model should be. Therefore, their probabilistic predictions of the future vary. However, if these experts had crystal balls and their disagreements about uncertainties disappeared, the controversy would still continue. Now it would be focused on values only instead of on both values and uncertainties. The Mayor of New York City would like to:

Reduce the size of the addict pool (this is more complicated than it sounds since there are different types of addicts and tradeoffs must be made between the sizes of these categories).
Reduce costs to the city and its residents.
Reduce crimes against property and persons.
Improve the "quality of life"—whatever that may mean—of addicts and reduce their morbidity and mortality.
Improve the quality of life of nonaddicts, make New York City a more pleasant place to live, and reverse the disastrous trends of in-and-out migration of families and businesses.
Curb organized crime.
Live up to the high ideals of civil rights and civil liberties.
Decrease the alienation of youth.
Get elected to higher political office (perhaps the presidency?).

Sure, the problem is complicated, but the Mayor must act and, at least informally, combine assessments of uncertainties with value preferences*. As already mentioned, we will deal with the value side of these types of problems.

* See Moore (1973) for a formal attempt to examine various policy options concerning heroin use in New York City.

1.1.4 Medical Diagnostics and Treatment

Doctor William Schwartz,* Chief of Medicine at Tufts Medical School, makes the rounds of the wards with his students and insists on sharing his thought processes with them: "Well, for Z we can do this or this or this, and we must worry about the implications of our actions if she has disease state A or B or C. I think the chances are 0.2 that she has A, 0.4 that .... If we do this and that happens, then we'll learn so and so, which will revise my probabilities of A, B, C by .... But if that happens we must weigh the information we get with the possibility of side effects, discomfort, and costs to Z." And on and on. Very few doctors state their thought processes with such clarity. However, all doctors must constantly combine probabilities with value judgments. Some value judgments are not easy to make. Not only are costs to the patient to be considered, but also cost to the insurance companies, payments to the doctor, and utilization of scarce resources (doctors, nurses, surgical facilities, and hospital beds, for example). Doctor Schwartz must worry about pain, suffering, anxiety, the time of the patient's incapacitation, and the possibility of death. Then, societal externalities are involved in the value problem such as contagious effects, the information gained from one patient that can be useful in the treatment of other patients, and development of resistant bacterial strains. These societal considerations often create a conflict for the doctor: what's right for his patient may not be right for society. But all of these matters must be considered, and decisions must be made. Can the value side of the problem be systematically approached? We think so, but there is no "objectively correct solution." Subjective values must be inserted, and we will *develop a framework for assessing and quantifying these subjective values and systematically including them in the decision-making process.*

1.1.5 Business Problems

Most *routine* business problems do not involve complicated value issues. Profit (or even better, the net present value of a profit stream) may be *the index* to maximize. True, there might be difficulties in clarifying what is fixed cost and what is marginal, but generally these details are simple. However, top management does not become personally involved in most routine problems with a dollar-and-cents solution. The problems that filter up to management often involve ethics, tradition, identity, aesthetics, and personal values in contrast to corporate values. The more we study the problems of top management, the more we realize that these

* See Schwartz, Gorry, Kassirer, and Essig (1973).

so-called uncommon problems are not so uncommon, and the slogan "Maximize profits!" has operational limitations. We will see, however, that in business contexts it is often natural to scale nonmonetary intangibles into dollar values. We will be concerned with when is it legitimate to do this and how can it be done.

Top management is well aware that many of its strategic decisions involve multiple conflicting objectives and, therefore, it is simply *not* true that "qualitatively speaking, business decisions are simple because the objective function is crystal clear."

1.2 PARADIGM OF DECISION ANALYSIS

The simple paradigm of decision analysis* that we will study can be summarized in a five-step process.

PREANALYSIS. We assume that there is a unitary decision maker who is undecided about the course of action he or she should take in a particular problem. The problem has been identified and the viable action alternatives are given.

STRUCTURAL ANALYSIS. The decision maker structures the qualitative anatomy of his problem. What choices can he make now? What choices can he defer? How can he make choices that are based on information learned along the way? What experiments can he perform? What information can he gather purposefully and what can he learn during the normal course of events without intentional intervention? These questions are put into an orderly package by a decision tree (Fig. 1.1). The decision tree has nodes that are under the control of the decision maker

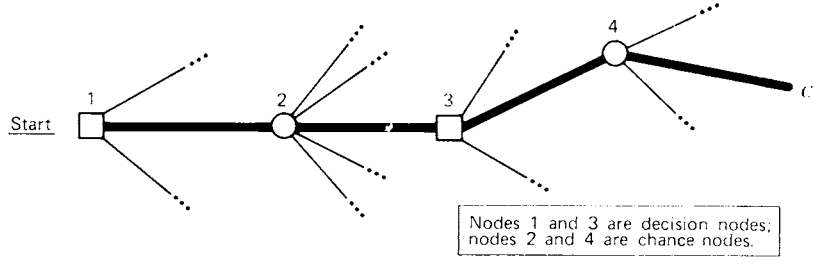

Fig. 1.1. Schematic form of a decision tree.

* See, for example, Brown, Kahr, and Peterson (1974), Howard (1968), Raiffa (1968), Schlaifer (1969), Tribus (1969), or Winkler (1972).

(i.e., the square nodes) and nodes that are not under his full control (i.e., the circled nodes). We refer to these two nodes as *decision* nodes and *chance* nodes.

UNCERTAINTY ANALYSIS. The decision maker assigns probabilities to the branches emanating from chance nodes. These assignments are made by artfully mixing various techniques and procedures based on past empirical data, on assumptions fed into and results taken from various stochastic, dynamic models, on expert testimony (duly calibrated, to take into account personal idiosyncracies and biases resulting from conflict of interest positions), and on the subjective judgments of the decision maker. The assignments should be checked for internal consistencies.

So that there is no confusion resulting from the special schematic decision tree in Fig. 1.1, we include the possibility that certain chance nodes can have a set of outcomes represented by a continuum in a singular or higher-dimensional space.

UTILITY OR VALUE ANALYSIS. The decision maker assigns utility values to consequences associated with paths through the tree. In Fig. 1.1 one possible path (from Start to point C) is shown. In an actual problem, there would be associated with this path various economic and psychological costs and benefits that affect the decision maker and others whom the decision maker considers as part of his decision problem. The cognitive impacts are conceptually captured by associating with each path of the tree a *consequence* that completely describes the implications of that path. The decision maker should then encode his preferences for these consequences in terms of cardinal utility numbers.* This measurement not only reflects the decision maker's ordinal rankings for different consequences (e.g., C' is preferred to C'' which is preferred to C'''), it also indicates his relative preferences for lotteries over these consequences. For example, in Fig. 1.2, we consider a problem of choice between act a' and a'' that is translated into a choice between lottery l' and l''. The decision maker must assign numbers to consequences (such as u_i' to C_i' and u_j'' to C_j'') in such a manner that he feels that

$$(a' \text{ is preferred to } a'') \Leftrightarrow \left(\sum_{i=1}^{m} p_i' u_i' > \sum_{j=1}^{n} p_j'' u_j'' \right).$$

In other words the assignment of utility numbers to consequences must be such that the maximization of *expected utility* becomes the appropriate criterion for the decision maker's optimal action.

OPTIMIZATION ANALYSIS. After the decision maker structures his problem, assigns probabilities, and assigns utilities, he calculates his optimal

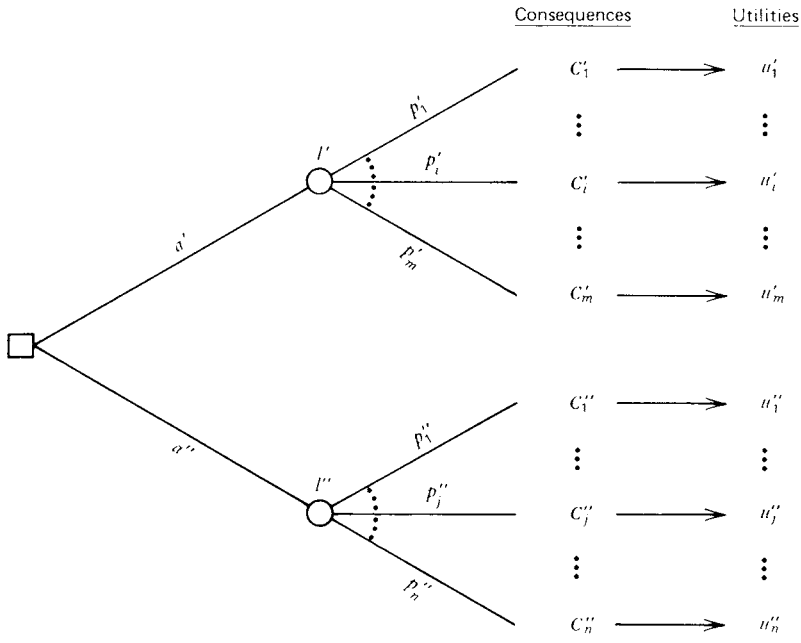

Fig. 1.2. A choice problem between two lotteries.

strategy—the strategy that maximizes expected utility. This strategy indicates what he should do at the start of the decision tree and what choice he should make at every decision node he can possibly reach along the way. There are various techniques an analyst can employ to obtain this strategy, but the simplest is the dynamic programming algorithm of averaging-out-and-folding-back, with which we assume the reader is already familiar.†

1.3 COMMENTS ABOUT THE PARADIGM

Is this a reasonable paradigm for the problems we stated at the outset: air-quality control, airport location, treatment modalities for heroin addiction, medical diagnostics and treatment, and strategic business problems?

* We assume that the reader has some familiarity with cardinal utility theory. However, in Chapter 4, we review aspects of the theory that will be needed.

† See, for example, Raiffa (1968), p. 21–27 and 71–74.

1.3.1 Unitary versus Group Decision Making

Throughout most of this book we assume that there is a unitary decision maker. Shouldn't we be more concerned with group decision making? Aren't most public decisions and many business decisions an intricate composite of different choices made by many individuals? Let's take an example.

New York City is concerned with the poor quality of air being breathed by its residents. Should the city government impose more stringent limits on the sulfur content of fuels burned in the city for space heating and power generation? Many people are involved in this problem: the mayor, the city council, the Environmental Protection Agency, lobbyists for power companies, local politicians, and the citizens, for example. Any *postdescription* purporting to explain what happened in the past certainly must involve many individuals. Descriptively it is a group, interactive decision problem.

But wait!

We are not trying to *describe* what has been done but *prescribe* what should be done.* Let's first clarify for whom we are prescribing. Who is the client for our proposed analysis? Suppose it is an agency head. He alone surely does not dictate what will eventually happen but he might be asked to make a proposal to the mayor, for instance. Suppose he's confused about whether he *should* offer proposal A or B or C. The agency head has a decision problem, doesn't he? *He* might want to analyze systematically what *he* should do. He must consider what others might do and perhaps he might want to view the actions of the mayor and the city council as part of the uncertainties confronting him. One individual's decisions may be another individual's uncertainties.

We emphasize that decisions (as we use the term) do not have to be grandiose end determinations. There are more modest decisions: should an individual vote for passage of a bill, propose an amendment, or apply political pressure? If an individual has choices to make, we consider him to be the decision maker. Thus, there are many decision problems in the public sector where the decision maker can be viewed as a well-specified, identifiable, unitary entity. Now some of these decision makers might want to analyze their particular problem systematically. We want to effectively adapt the previously mentioned decision paradigm to help this decision maker.

* Clearly there is much overlap of interest between the prescriptive and descriptive viewpoints. Over the past 25 years, the contributions of many people concerned with descriptive aspects of decision making has had a significant impact on prescriptive decision analysis. Four excellent reviews of this work are Edwards (1954, 1961), Slovic and Lichtenstein (1971), and Fischer and Edwards (1973).

1.3.2 Personal Conviction, Advocacy, and Reconciliation

We approach problems as if we were an undecided decision maker who has to decide which course of action he should take. He knows that some of his snap judgments may later be wrong; he might change his mind after deeper reflection. He also recognizes that when a problem is decomposed into parts, he might initially give answers to a series of questions that turn out to be internally inconsistent. When this occurs we assume that the decision maker will want to scrutinize his answers carefully and perhaps change some of his earlier responses so that the total pattern of modified responses is consistent and seems reasonable to him. Only if he can structure his preliminary responses in a coherent fashion will we be able to use deductive analysis to carry him to the next step. The spirit is one of Socratic discovery—of *unfolding* what you really believe, of *convincing* yourself, and of *deciding.*

We have found, in many of our consulting contacts, that decision makers undertake formal decision analyses with their minds already made up. They view the formal analysis as a kind of window dressing. We are not against this; instead, we emphasize the class of problem situations where the unitary decision maker has not as yet made up his mind. However, there is often a legitimate purpose for doing careful analyses even if the decision maker has already decided what to do. First, there is the problem of *psychological* comfort: he might want the security of having a formal analysis to corroborate his unaided intuition. Second, he might want to use the formal analysis to help the *communication* process. Third, there is the question of *advocacy*: he might have to justify his conclusions to others or to convince others of the reasonableness of his proposed action. In addition, there is always the possibility that these postdecision analyses will uncover new insights that result in a different alternative—one that is perceived as better than the original.

An analysis done solely to convince yourself might be quite different from an analysis done for advocacy purposes. A personal analysis might very well incorporate very sensitive information, such as assessments of potential future actions of political associates, an economic value placed on the life of a human being, and value tradeoffs between the benefits to various identifiable groups. On the other hand, an advocacy document must often be intentionally vague on such issues. When an analysis is put on public display you can hardly expect your adversaries to give up without a fight. They will carefully scrutinize the reasoning and seek out the soft spots. Unfortunately, this means that it is often impolitic to base a decision on a formal analysis that includes subjective feelings if the analysis will be disclosed to a critical public audience. This is not the place

for us to request moral obligation from government officials or ask that they be open and honest and share their real analyses with other government officials, agencies, and concerned citizens. Again, we are concerned primarily with helping confused decision makers make up their minds.

There is another reason why you might do a formal analysis of a decision problem even though your mind is already made up. Although our proposal might be considered to be a variation of an advocacy role, we think of it as a *reconciliation* process. For example, suppose a mayor must make a decision and two agencies strongly recommend different alternatives. The rhetoric is sharp and divisive, the protagonists are eloquent and able, and the situation is so complex that there is apparent merit on each side. How can the decision maker weigh the arguments and make a responsible decision?

A formal analysis that attempts to break down the overall problem into component parts can often help this reconciliation process. Perhaps the parties can decide what they agree about and what they disagree about. Perhaps they can further break down areas of disagreement in a manner that would highlight fundamental sources of differences of opinion. Would more information help sort out the merits of the two positions? Could they agree on additional objective (or subjective) evidence that could help them decide? Or is it not a matter of assessing uncertainties but rather of differing value judgments? Perhaps here is where the mayor could exert his own overriding value structure.

We don't want to appear excessively naive by implying that formal analysis is the key to the reconciliation process. We are well aware that, in some circumstances, the more confusion that abounds the easier it is to establish a compromise. Still, in principle, we think that familiarization can sometimes facilitate reconciliation. Chapter 8 discusses an example of such an undertaking in which both of us were involved as consultants. We were only partially successful.

1.3.3 Preanalysis and the Iterative Nature of an Analysis

We assume that the decision maker's problem has been identified and viable action alternatives are prespecified. In practice this does not mean that the preliminaries are not crucially important. By creative insight, not only must we recognize that a problem exists, we must be intuitive about what types of problems are worth attempting to analyze.

Complex problems, especially in societal contexts, tend to have spillover effects in all directions. Thus, bounding a problem is critically important. We know the dangers of suboptimization, but if problems are not bounded in some way, they remain hopelessly intractable. The

process of identifying and bounding a problem area is intimately connected with the generation of alternative decision choices to be considered. When we assume that the alternative decision strategies are prespecified, we seriously misrepresent the art of formal analysis. In practice, the process is iterative. The analyst might bound his problem one way only to find that he's in an impossible morass; so he backs up and redefines his problem area by bounding it differently and generating new restricted alternatives. Or, in the course of the analysis, he sees that his conclusions are sensitive to a facet of the problem that has not been delicately enough modeled. If this happens, he may redefine the problem. We believe that a careful analysis of the problem often triggers a line of thought that generates action alternatives that might have been overlooked. Yes, we do recognize the iterative nature of the overall process of analysis but for our purposes, with all due apologies, we assume that the preanalysis stage has been completed.

We think that even experienced analysts often fail to sufficiently exploit the usage of *adaptive* and *process-oriented* action alternatives. Not only is it important for the analyst to know what must be done now and what he can defer to the future, it is also critically important that he recognize the possibility that future actions could depend on information learned along the way. A dynamic strategy for action should be adaptive and exploit the gradual, time-dependent unfolding of uncertainties. The decision-tree framework is especially suitable for thinking about such alternatives. However, it does not help us with process alternatives. Let us explain.

"You analysts want to decide on everything," a nameless voice exhorts. "Why decide at all? Let the contending factors address the issues in an open, democratic process." That advice is often right. Establishing a *process* may be the creative new alternative to which we alluded. Still, someone might have to decide whether decision *strategy* A or B or decision *process* C or D should be adopted. And that is a decision problem. Furthermore, if process C is selected, among the many decision makers who will influence the actual outcome there may be a confused, analytically minded person who wants to straighten out his mind with our framework.

We do not deny that it is often desirable to institute an advocacy process for resolving complex issues in the public domain. However, we do not think that this assertion necessarily diminishes the usefulness of the decision analytic framework. It may, of course, influence the nature of the problems to be analyzed or the identity of the decision maker who employs these tools. Finally, on the subject of process, we think that the decision analytic framework can, in some cases, structure the process of debate and action.

1.3.4 Subjective Values and Formal Analyses*

It is almost a categorical truism that decision problems in the public domain are very complex. They almost universally involve multiple conflicting objectives, nebulous types of nonrepeatable uncertainties, costs and benefits accruing to various individuals, businesses, groups, and other organizations—some of these being nonidentifiable at the time of the decision—and effects that linger over time and reverberate throughout the whole societal superstructure. It would be nice if we could feed this whole mess into a giant computer and program the superintellect to generate an "objectively correct" response. It just can't be done! You can go only so far without introducing subjective attitudes—no matter how hard you squeeze the available objective data, it won't come close to providing courses of action for complex problems. Indeed, a purely "objective" analysis might fall so far short of providing guidelines for decision making that the output of the analysis may not pass the threshold of relevancy. We believe that complex social problems—and, for that matter, complex *business* problems—demand the consideration of subjective values and tradeoffs. It is not whether subjective elements should be considered, but whether they should be articulated and incorporated into a formal, systematic analysis. The choice is between *formal analysis* and *informal synthesis* and this metadilemma does not have an obvious solution.

We have often heard that formal analysis is inappropriate for complex problems, since these problems require subjective evaluations. They do, but formal decision analysis is ready to receive such subjective evaluations as inputs for the decision algorithm. The trouble with formal analysis is *not* that subjective evaluations cannot be accommodated into the framework but that there is a demand for *too many* subjective inputs; and although decision makers argue for inclusion of subjective evaluations, they are most reluctant to write these evaluations down.

Many people feel that we should be wary of analysts that try to quantify the unquantifiable. Let us remember, however, that it is also wrong for us not to learn how to quantify the quantifiable. The question is: *What is quantifiable*? An art expert might be hard pressed to give an objective formula for ranking the quality of paintings; nevertheless, he might be able to rank order these paintings saying, in effect, that given a choice between two paintings he would prefer one over the other. And, where we have rank orders, numbers can't be far behind. Our artist might even be willing to put a price tag on each painting, thereby quantifying one

* Subsections 1.3.4 and 1.3.5 liberally adapt material from Keeney and Raiffa (1972).

aspect of his subjective judgment. This sort of quantification is not done by means of an objective formula but by subjective introspection. Is it legitimate to work with such numbers? We do it all the time. As analysts we must learn how to incorporate such soft, squishy considerations as aesthetics, psychic factors, and just plain fun into our analyses. If we don't, the hard will drive out the soft and efficiency—very narrowly interpreted—will prevail.

However, the quantification of these subjective factors cannot be done frivolously. They should be generated by making the best use of the accumulated experience and expertise available. And on problems of public concern, such as power plant siting, this quantification should undergo the scrutiny of independent "experts" as well as the concerned public.

1.3.5 Strategic versus Repetitive Decisions

Some individuals feel that formal analysis is appropriate for repetitive operational decisions, for example, "Where should we send the sanitation trucks today?" "What procedures should be used for operating airport runways in order to minimize travel delays?" "What should we charge for breakfast cereal WOW?" But these same individuals think analysis is impossible for such one-of-a-kind, strategic decisions as "Should we dispense methadone to heroin addicts?" "Should we spend 200 million dollars for research on nuclear breeder reactors?" "Should the Mexican government build a new airport miles from Mexico City or modernize the old?" "Should Corporation X internationalize its marketing operations?" No one claims it is easy to analyze complicated strategic problems, but we believe that many of these strategic questions are amenable to systematic attack.

1.3.6 Implementation, Postanalysis, and Other Considerations

Other than the very few brief remarks we are about to make in this paragraph, we will say nothing about another critical aspect of an integrated analysis: the *implementation* phase. By this we mean all those indispensable activities required to execute the chosen strategy resulting from a given analysis. This includes the communication of instructions, the delineating of responsibilities, the establishment of incentives and rewards, the punishment of willful deviations, the monitoring of the system, the systematic collection of data, the creation or adaption of a management information system, the dissemination of reports, the further refinement of the model, identification of new key variables, and creation