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PROBLEM FORMULATION AND STRUCTURING: THE DECISION AIDING PROCESS

Consider the following situations:

1. A family discovers that their daughter systematically refuses to eat any type of food claiming that eating for her is "disgusting" (a typical symptom of "anorexia mentalis"). It is reasonable to expect that the family will contact a psychotherapist in order to conceive appropriate therapies to face this (possibly extremely dangerous) situation.

2. A lady becomes pregnant. Soon after she gradually becomes physically upset. Again we can expect that she will consult a physician in order to establish an appropriate treatment.

3. A large company providing mobile communication services is facing the possibility that the European Union will introduce a new directive concerning ownership of networks across Europe, thus seriously affecting its business. We can expect that this company will contact a primary legal adviser in order to appropriately redesign the company's structure.

4. A manager has to reconsider the company's supply chain management in order to improve productivity and delivery time to the customer performance. It is reasonable to believe that he will contact a supply chain management specialist in order to study different policies and establish one.

These situations all share a common characteristic: there is "a problem", for which "a client" (the family, the lady, the company, the manager) asks the advice of "an analyst" (the psychologist, the physician, the lawyer, the supply chain management specialist) in order to "find a solution".

There is, however, an important difference when we compare the advice of the psychologist, the physician, the lawyer to that of the supply chain management specialist: the language (for more details on this issue the reader is referred to Ackoff, 1962; Bevan, 1976; Capurso and Tsoukiàs, 2003). Although all of these advisers might use a "scientific approach" to help their clients, the psychologist, the physician and the lawyer will use a human natural language (naturally ambiguous) and a terminology depending on their specific domain, while the supply chain specialist will be likely to use a formal language (like mathematics) which reduces (if does not exclude) ambiguity and is independent of the field of supply chain management. He will use what we call a "decision support language", thus introducing a "model of rationality" in his decision aiding activity.

Does it make sense to use such a language in any context and at all times? Obviously not. The use of a "decision support language" presents several disadvantages:

- it is much less effective with respect to human communication;
- it has a cost (not necessarily monetary);
- reducing ambiguity might not be desirable;
- it imposes a limiting framework on people's intuition and creativity.

Nevertheless, such a language also presents several advantages, which in some circumstances can be interesting (see also Bouyssou et al., 2000):

- it allows the participants in a decision process to speak the same language, a fact that improves the transparency of the process and possibly increases participation (for an example see Bana e Costa, Nunes da Silva, and Vansnick, 2001);
- it allows the identification of the underlying structure of a decision problem (if there is any) and therefore allows the re-use of procedures and models (for interesting examples see any textbook of Operational Research, e.g., Williams, 1990);
- it is not affected by the biases of human reasoning that are due to education or tradition (for examples see Rivett, 1994);
- it may help to avoid the common errors that are due to an informal use of formal methods; a typical case being the use of averages as a universal grading procedure (see Bouyssou et al., 2000, chapter 3, for a critical discussion of this issue).

In this chapter we will focus on a number of this language's concepts and terms. In our first volume (Bouyssou et al., 2000) we have shown that within such a language we make choices about models, procedures, numerical representations and logics, which are not neutral with respect to the final result of the interaction between the client and the analyst. Furthermore we have shown that a problem situation is not perceived and modelled in a unique and objective way, but there exist several different problem formulations. The use of a formal, domain-independent language forces us to be more precise when terms such as problem, objective, solution etc. are adopted (see, e.g., Belton and Stewart, 2001; Checkland, 1981; Rosenhead, 1989; Roy, 1996; Roy and Bouyssou, 1993).

The aim of this chapter is to introduce the reader to the concept of "decision aiding process", the activities occurring between a client (somebody looking for decision support) and an analyst (somebody providing decision support). Although each such process has a unique history (once accomplished), we claim that there are a number of invariants within it and that these can be used in order to provide useful recommendations on how such a process can be conducted. In other words: conducting a decision aiding process is a combination of personal skills (in human communication, group conduction, listening etc.) and of formal skills characterised by the establishment of precise cognitive artefacts which are used by the client and the analyst in order to represent the problem and its solution(s). This chapter as well as the whole book is dedicated to analysing such steps, providing concepts, tools and methods to appropriately follow them.

In order to better understand our point of view, in the first section of this chapter we discuss four different decision aiding approaches: normative, descriptive, prescriptive and constructive (Bell, Raiffa, and Tversky, 1988; Dias and Tsoukiàs, 2004). Under our perspective, the decision support language makes sense within a particular context: the interactions between the client and the analyst. Such a stream of interactions is denoted as "decision aiding process" and is viewed as a particular type of decision process. For this purpose, we briefly discuss the concept of decision process in section 2.2 as well as the differences between "deciding" and "aiding to decide". In section 2.3, we then introduce a formal model of the decision aiding process. Such a model is based on the cognitive artefacts, the "products" of the process: a problem situation, one or more problem formulations, one or more evaluation models, a final recommendation. In section 2.4, we focus on the construction of such cognitive artefacts. Large part of the book will be dedicated to a deeper analysis of the problems identified in section 2.4. A final section concludes showing the research directions opened by such an approach.

2.1 Decision Aiding Approaches

In order to help someone to "make" a decision we normally elaborate preferences. *"Preferences are rational desires"* (Aristotle, 1990). Practically what we usually know is what a decision maker or a client [1] desires. Where does rationality come from?

Suppose a client faces a health problem. He has a set of more or less sure diagnoses and a number of possible treatments of more or less uncertain results. A manual of decision theory will suggest to consider each possible treatment as an alternative action and each possible diagnosis as a possible state of the world to which a probability might be associated. For each treatment we thus obtain the consequences of its application for each diagnosis. Such consequences allow to establish a utility function. Maximising such an utility (function), will provide the client with the best solution to his problem. The existence of such a utility function is guaranteed through a number of axioms (Savage, 1954) which are supposed to express the idea of rationality in a formal way. Such axioms are independent of the client. Preferences among the potential consequences should be transitive and this is imposed because it is considered essential in order to be rational, otherwise

[1] Hereafter we will substitute the term "decision maker" with that of "client". The reason will become clear later in the text. A "client" is someone who seeks advice for a decision issue. From such a perspective, he is a potential decision maker, but not necessarily.

the client should be ready to pay an infinitely increasing amount of money for the same solution (see the "money pump" discussion in Raiffa, 1970, p. 78). Similarly, preferences about consequences ought to be "independent" (the fact that we prefer a certain consequence to another should not depend on the likelihood that any of the two will occur) (see Fishburn, 1970, p. 107). Rationality here is established independently from the client. We should also note that, although we allow for uncertainties in the diagnosis, there is no uncertainty in the model itself. Diagnoses are all the possible diagnoses, the treatments are all the possible ones and it is clear that the problem is to choose the best one for this specific client (who only has to express his preferences) who is supposed to be "rational". If he is not, then he should modify his preferences in order to become so. Which is what we call a normative approach.

Since von Neumann and Morgenstern (1947) and Savage (1954) this is the dominant paradigm in decision analysis and decision support with or without uncertainty, in the presence or not of multiple evaluation dimensions. Traditional Operational Research techniques fit the same idea: maximise an economic function in the presence of feasibility constraints (usually all expressed in terms of linear functions). Rationality is imposed through a number of hypotheses and axioms which exist independently from the client and his problem.

Returning to our client, we can argue whether his behaviour is effectively "rational" (in the sense of the axioms of economic rationality). Indeed, since Allais (1953) (see also Kahneman and Tversky, 1979), it has been shown that real decision makers in real decision situations behave in a way that violates the axioms of economic rationality. For instance "negative" outcomes may be considered in a totally different way with respect to "positive" outcomes such that the axioms are violated. Moreover, to explain observed patterns of behaviour of decision makers it is often necessary to adopt "distorted probabilities" (Kahneman and Tversky, 1979) in order to take into account the perception of uncertainty that the decision makers have. What should we do? One way could be to use any of the so called "decision heuristics" derived through direct observation of real decision makers. Consider the following frequent decision situation for instance. A decision maker has to choose among candidates using a number of criteria. He may first rank the criteria from the most important to the less important one. He then uses the most important one in order to extract a subset of candidates who are the best on that criterion. He then uses the second most important criterion in order to extract a further reduced subset of candidates from the previously established one. He then uses the third criterion in the same way until he (possibly) ends with a single candidate. This is a lexicographic procedure (extensively studied in Fishburn, 1974). Another example is "dominance structuring" where the decision maker, having once identified a "promising alternative" (intuitively or through another decision procedure) will try to consolidate his opinion by looking whether it is possible to construct a dominance relation between this alternative and the rest. This might be possible by the de-emphasising of certain criteria (up to eliminating them), bolstering the positive features of the "promising alternative" or modifying the criteria set (Montgomery, 1983; Montgomery and Svenson, 1976). Clearly this procedure aims at establishing a justification rather than making a choice.

It should be noted that in the above approach, although we do not impose a normative model of rationality we do impose one, but on empirical grounds. Its validity derives from the fact that several "other" decision makers do behave following a precise model. It should also be noted that we again consider the model as sure. Diagnoses, treatments and probabilities are given and the client has to choose one. The difference is that the model of rationality adopted is derived from analysing the cognitive effort of other decision makers (Svenson, 1996). We call such an approach descriptive since it is based on *descriptive models* of human behaviour when decision situations are faced.

Both approaches presented impose a model of rationality to the client. The question one could introduce is what happens if such a model of rationality cannot be imposed. What happens if the client expresses preferences which do not fit any model of rationality be it normative or descriptive. It might be the case that the client has preferences which are neither transitive nor complete. He might not be able to tell whether one alternative is preferable to another or he might not be willing to do so. He might have a perception of the uncertainty associated with the potential states of the world, but he might not be able to consider them within a model of probability. It is also probable that, although he understands the necessity to better shape his preferences, he has neither sufficient resources nor the time to do it. At the same time, something has to be done and the analyst has to be able to produce a recommendation.

In such cases we may adopt an approach which tries to construct a model as coherent as possible with the information provided by the client, while trying to satisfy minimum requirements of meaningfulness in manipulating such information. In other words we are not going to ask the client to adapt himself to a model of rationality, but try to adaptively model the available information and derive a reasonable recommendation. Considering the health example, we will try to identify a prescription which fits best with the client's preferences (even if these do not obey a model of rationality) and his personal perception of the uncertainty. Nevertheless, we are not going to accept any type of information manipulation, but only those which respect the "nature" of the data (Bouyssou et al., 2000; Roberts, 1979).

It should be noted that, while in the normative and the descriptive approach we consider models of rationality defined "from outside" the client's decision situation, in this case we try to model the precise rationality the client exhibits at the moment. Therefore, rationality is defined "within" the decision situation and not "from outside". We call such an approach prescriptive since it is aimed to "prescribe" to the client the action which appears hic et nunc as the most preferred.

However, again the problem is not discussed. We always consider that the diagnoses, the treatments, the uncertainties are given and that we are looking for the best therapy to follow. In other words, the problem is well established and our main concern is the potentially "irrational" information the client may provide or the fact that such information is difficult to represent under usual quantitative measures. Is it always the case? Are we really sure that all possible diagnoses have been obtained? What if there were other experimental treatments we are not aware of at this moment? Are we sure that the problem is to find a treatment? In several real decision situations neither the client nor the analyst are really aware of what the problem exactly is. What often happens is that, while these two actors try to model a problem, they also shape what the decision situation is about, thus ending up formulating a completely new problem and so on. In our example, although the client claims that he is looking for the best treatment, he might well end up understanding that his problem is to take a long holiday (possibly together with the analyst).

In other words, looking for the solution of a well established problem is always possible, but could be the wrong thing to do, since it might not be the right problem to solve. The problem is that neither the client nor the analyst know what the problem is a priori. Therefore, a decision support activity should also contain the structuring of the problem situation in which the client claims to be and the construction of several different problem formulations. Moreover, representing the client's preferences is not merely an elicitation process in which the analyst helps the client to state his values or to discuss them. It is a dialogue aimed at strengthening the conviction of the client that he actually does prefer "x" to "y", establishing the reasons for supporting such a conviction or the opposite one. Within such an approach we do not limit ourselves to using the most appropriate method for well established problem formulation, but we try to support the whole decision process in which the client is engaged. From such a perspective, nothing can be considered as "given" (if not the client's demand for help), while everything has to be constructed. Furthermore, within such an approach there is a fundamental learning dimension, since both the analyst and the client have to learn about the client's problem. We call such an approach *constructive* in the sense that the problem and its solution are constructed, while in all other approaches the problem is given and the solution is more or less discovered.

We can summarise the above presentation as follows.

Normative approaches

Normative approaches derive rationality models from a priori established norms . Such norms are postulated as necessary for rational behaviour. Deviations from these norms reflect mistakes or shortcomings of the client who should be aided in learning to decide in a rational way. These models are intended to be universal, in that they should apply to all decision makers who want to behave rationally. We may consider ethical norms, laws and religious norms as analogies (for more detail, the reader is referred to the following classics: Fishburn, 1970, 1982; Luce and Raiffa, 1957; Raiffa, 1970; Savage, 1954; von Neumann and Morgenstern, 1947; Wakker, 1989).

Descriptive approaches

Descriptive approaches derive rationality models from observing how decision makers make decisions. Such models are general, in that they should apply to a wide range of decision makers facing similar decision problems. We may consider scientists trying to derive laws from observed phenomena as an analogy (for more details, the reader can refer to: Allais, 1979; Barthélemy and Mullet, 1992; Gigerenzer and Todd, 1999; Humphreys, Svenson, and Vári, 1983; Kahneman et al., 1981; Kahneman and Tversky, 1979; Montgomery, 1983; Montgomery and Svenson, 1976; Poulton, 1994; Svenson, 1996; Tversky, 1969, 1972; von Winterfeldt and Edwards, 1986).

Prescriptive approaches

Prescriptive approaches *discover* rationality models for a given client from his/her answers to preference-related questions. Modelling consists in discovering the model of the person being aided to decide, i.e. unveiling his/her system of values. Therefore, they do not intend to be general, but only to be suitable for the given client in a particular context. Indeed the client can run into some difficulties trying to reply to the analyst's questions and/or be unable to provide a complete description of the problem situation and his/her values. Nevertheless, a prescriptive approach aims being in a position to provide an answer best fitting the decision maker's information *here and now*.Here, we may consider a physician asking questions to a patient, in order to discover his illness and prescribe a treatment as an analogy (for more details, the reader is referred to: Belton and Stewart, 2001; Brown, 1989; Keeney, 1992; Larichev and Moskovich, 1995; Roy, 1996; Tversky, 1977; Vanderpooten, 2002; Vincke, 1992b; Weber and Çoskunoğlu, 1990).

Constructive approaches

Constructive approaches *build* rationality models for a given client from his/her answers to preference-related questions. However, the "discussion" between the client and the analyst is not "neutral" in such an approach. Actually such a discussion is part of the decision aiding process since it constructs the representation of the client's problem and anticipates, to some extent, its solution. If, while talking about what to do tonight, we ask the question *"where should we go tonight?"* we implicitly do not consider all options implying staying at home. If we ask *"Who should we meet?"* we implicitly do not consider all options involving staying alone. In such an approach, structuring and formulating a problem becomes as important as trying to "solve" it. Recent real world applications (see, e.g., Bana e Costa, Ensslin, Corrêa, and Vansnick, 1999; Belton, Ackermann, and Shepherd, 1997; Paschetta and Tsoukiàs, 2000; Stamelos and Tsoukiàs, 2003) do emphasise the importance of supporting the whole decision aiding process and not just the construction of the evaluation model. Modelling using this approach consists in aiding a client to construct his own model, suitable for that contingency and particular context. Indeed, we can adopt the term of "co-modelling" (co-construction of the model). Here, we may consider a designer or an engineer tentatively developing a new car as an analogy (for details, the reader is referred to: Checkland, 1981; Genard and Pirlot, 2002; Habermas, 1990; Landry, Banville, and Oral, 1996; Landry, Malouin, and Oral, 1983a; Landry, Pascot, and Briolat, 1983b; Rosenhead, 1989; Roy, 1996; Schaffer, 1988; Watzlawick, Beavin, and Jackson, 1967).

Approach	Characteristics	Process to obtain the model
Normative	Exogenous rationality, ideal economic behaviour	To postulate
Descriptive	Exogenous rationality, empirical behaviour models	To observe
Prescriptive	Endogenous rationality, coherence with the decision situation	To unveil
Constructive	Learning process, coherence with the decision process	To reach a consensus

Table 2.1: Differences between approaches.

Theoretical differences...

Table 2.1 summarises the differences between the approaches. We may start by dividing these in two groups. On the one hand, normative and descriptive approaches use general models of rationality, established independently from the client and the decision process, intended to model the rationality of decision makers in general. On the other hand, prescriptive and constructive approaches derive a model for the rationality of the contingent client, and only that particular client.

The difference between normative and descriptive models mostly lies in the process of obtaining the model. Normative models are grounded on abstract economic considerations (rationality corresponds to the behaviour of an abstract "homo economicus"), whereas descriptive models are grounded on empirical observation. The former focus on how decision makers ought to decide, whereas the latter focus on how decision makers actually make decisions.

The difference between prescriptive and constructive models also lies to a great extent in how the model is obtained. Prescriptive models intend to unveil a system of values that exists before the decision aiding process starts, hidden somewhere inside the client's mind. Constructive models do not assume that preferences pre-exist, but let the client construct his/her system of values while the model is being constructed, recognising that one construction cannot be isolated from the other. Indeed, the final model is expected to be validated through a consensus reached between the client and the analyst. Such a "consensual" model is expected to satisfy both the client's perception of his/her problem and the analyst's methodological requirements of meaningfulness and formal coherence (on this point see Genard and Pirlot, 2002; Landry et al., 1996, 1983a,b).

...and practical issues

It should be noted that it often (usually in practice) does not happen that an analyst follows any of the above approaches as if he was following a decision theory manual. Normative approaches might be used with weaker versions of their axiomatics (see, e.g., Dubois and Prade, 1995; Dubois, Prade, and Sabbadin, 2001c; Wakker, 1989) knowing that this is empirically grounded. At the same time, someone adopting a prescriptive or a constructive approach might decide to introduce and fix a dimension of rationality in order to ease the dialogue with the client and "force him" to accept a certain point of view. Such interactions between the approaches can be better understood when decision support tools come into practice (see also Belton and Stewart, 2001).

The number of decision support tools and methods available today in literature and more or less applied is incredibly high (see Bouyssou et al., 2000). They range from optimisation techniques to cognitive approaches, from artificial intelligence tools to multiple criteria decision analysis methods, from extremely sophisticated tools (such as logic argumentation and ordered sets) to "soft", natural language-oriented and user-friendly ones. We are not going to present these tools here. Each of such tools however, has been created with a more or less precise "philosophical" background (see Genard and Pirlot, 2002) and with a more or less precise decision aiding approach in mind.

It is clear for instance that traditional Operational Research techniques such as linear programming, combinatorial optimisation and queuing theory reflect a normative idea of rationality as well as expected utility theory and game theory (see the discussion in Moscarola, 1984). On the other hand, several decision heuristics as well as some early artificial intelligence knowledge representation techniques reflect a descriptive approach: capture the way in which decision makers and/or experts do it and generalise it. Much cognitive analysis can be associated to such an approach.

At the same time, several multiple criteria decision support methods were developed under a prescriptive approach and several artificial intelligence tools make explicitly or implicitly reference to such an approach. Note for instance the common argumentation concerning intransitive preferences in decision analysis and non monotonic reasoning in logic (see, e.g., Doyle and Wellman, 1991; Tsoukiàs, 1991). It should also be noted that the seminal work of Simon (1954, 1979) on the concept of bounded rationality can be viewed as the background of both of several decision support methods (developed under a descriptive or a prescriptive approach) and of several artificial intelligence achievements.

Finally, several "soft" OR methods implicitly and several MCDA methods explicitly refer to a constructive approach. Indeed Roy (1996) explicitly claims that the philosophical justification for the methods developed by himself and his group is "constructivism", while the description of the Soft Systems Methodology (Checkland, 1981) clearly focuses on the decision aiding process and the structuring issue although it does not explicitly mention a constructive approach.

However, despite the fact that more or less each decision support method can be associated to a decision aiding approach, we claim that such an association is misleading since it reduces such approaches to a mere collection of methods (on this, note the examples used in chapter 1 of this book).

Our thesis is that decision aiding approaches do not imply the use of an exclusive set of methods and that at the same time, the use of a precise method does not imply the adoption of a decision aiding approach. In the extreme: we consider it possible to use a constructive approach and adopt at a certain point a combinatorial optimisation technique as well as using an outranking based preference aggregation procedure within a normative approach. The difference really is observable in the conducting of the decision aiding process. This is the reason why we dedicate a chapter to discussing how such a process can be structured and conducted.

In the following we are going to explore the constructive approach in more detail. This book however, and the one we have already published (Bouyssou et al., 2000) can be used in order to build models within any approach.

2.2 Decision Processes and Decision Aiding Processes

The concept of decision process is due to Simon (1947). As early as in 1947, Simon observed decision processes occurring within real organisations and concluded that the behaviour of real decision makers is far from the postulates of decision theory, at least as this theory was formulated at that time. During the '50s, Simon (1954, 1956, 1957) developed his "bounded rationality" theory, which states that a decision maker facing a choice behaves on the basis of a local satisfaction criterion, in the sense that he will choose the first solution that he subjectively considers as satisfactory without trying to attain an unrealistic (and useless) optimal solution. Actually Simon considers decision theory to be based on three implicit hypotheses (see the discussion in Moscarola, 1984):

- decision makers always know their problems well;
- such problems can always be formulated as an effectiveness (or efficiency) problem;
- the information and the resources necessary to find a solution are always available.

According to Simon, any of these hypotheses is not true in reality:

- decision makers never have a very precise idea of their problem;
- often their problems can be formulated as the search for a compromise;
- solving a problem is always constrained by the available resources and time.

The innovation introduced by Simon is radical. Decision theory as had been developed up to that moment always considered the rationality model as existing independently from the decision maker and his decision process. Simon put the decision process (the mental activities of a decision maker) and postulated that a rationality model has to be found within such a process at the centre of his reflection and not outside it. Most of the literature around this concept is based on the hypothesis that such cognitive activities are scientifically observable (either empirically or in experimental settings) and that "patterns" of "decision behaviour" can be established (see Humphreys et al., 1983; Kahneman and Tversky, 1979; Montgomery, 1983; Montgomery and Svenson, 1976; Slovic and Lichtentstein, 1983; Slovic and Tversky, 1974; Svenson, 1996; Vári and Vescenyi, 1983). The use of this concept in decision theory introduced two major innovations:

- rationality is expected to be linked to the process and not to the final decision; coherence is expected along the process, but such coherence is not necessarily reducible to the classic economic rationality;
- rationality is bounded in time, space and the cognitive capacity of the decision maker, therefore is subjectively defined and only locally valid.

The concept of decision process was later associated to organisational studies and more precisely to the study of how organisations and other collective bodies face decision situations (see Cyert and March, 1963; Emerson, 1962; March and Simon, 1958). These works showed that the behaviour of an organisation (assumed to be composed of rational decision makers) does not correspond to the rational behaviour as described by decision theory (the reader can see an extreme model in Cohen, March, and Olson, 1972, which describes the famous garbage can model, in which organisations are seen precisely as garbage cans). The problem, already observed by Weber (1922) in his studies during the 20's on bureaucracies, is that within an organisation different forms of rationality may co-exist (see Simon, 1976). Later on, related research was condensed in Mintzberg's work (see Mintzberg, 1979, 1983; Mintzberg, Raisinghani, and Théoret, 1976) as well as by other authors (see Benson, 1975; Dean and Sharfman, 1996; Huber, 1991; Ilgen, Major, and Tower, 1994; Mackenzie, 1986; Masser, 1983; Mélèse, 1978; Norese and Ostanello, 1984, 1989; Nutt, 1984, 1993, 1999; Ostanello, 1990; Ostanello and Tsoukiàs, 1993).

The observation of organisational decision processes leads to at least the following remarks:

- multiple rationalities that can be associated to different individuals and/or organisations coexist within organisational decision processes;
- such different rationalities rarely aggregate into a unique rationality characterising a process; an organised collection (a system) of rational individuals does not constitute a rational entity.

We are not going to further discuss the issue of the decision process and its models. Indeed, our aim is not just to propose another model of how decisions are made, but to show how analysts can help their clients when they act as "decision makers" either in individual or in organisational decision processes. Of course accepting an hypothesis on how decision processes are structured might influence the adopted decision aiding approach, but this is only one dimension among others in conducting a decision aiding process. The following section considers a model of decision process, but our choice is essentially operational.

2.2.1 A descriptive model of the decision process

In this section we will use a descriptive model of the decision process, introduced by Ostanello and Tsoukiàs (1993). This precise model originated to describe inter-organisational decision processes, but is sufficiently general to be used in more abstract contexts.

A decision process is characterised by the appearance of an "interaction space", an informal abstract space in which actors introduce and share a set of concerns (named "objects"). The awareness of the existence of such an interaction space is due to the existence of a "meta-object" (a concern which only exists in order to allow the actors to justify their presence in the interaction space projecting their concerns on such meta-object).

A temporal instance of a decision process (a state of the process) is characterised by: the participating actors, their concerns (the objects) and the resources committed by each actor to each object. Different levels of commitment and the number of actors interested in the same object characterise the structure of such a temporal instance, anticipating the dynamics under which such a state can be reached. In Ostanello and Tsoukiàs (1993), the following characteristic states were suggested:

- controlled expansion;
- uncontrolled expansion;
- controlled reduction;
- stalemate;
- dissolution;
- institutionalisation

in order to show the different directions towards which the state of the process can evolve (for more details, the reader can refer to Ostanello and Tsoukiàs, 1993).Recognising the present state and fixing a state one wishes to reach can help in understanding the strategy to follow within the decision process.

Example 2.1
Consider the construction of a new highway expected to improve the accessibility of two towns and going through a certain region.

There are a number of participating actors: the potential constructors of the highway, the local, regional and national institutions (including the "National Road Agency"), which have to authorise the construction besides as well as be concerned by the use of the highway and the consequences of its construction, the population affected by the highway and its construction, the social, political and economic groups etc.

Each of these actors has specific concerns about:

- the highway construction;
- the environmental impact;
- the socio-economic impact;
- the transformation of the land use;
- the transportation policy;
- the environmental policy;

which are all evoked by the "meta-object": the idea of a highway between A and B. Each participant commits and demands resources: for instance the potential constructors commit money and demand knowledge and authorisation, the regional authority commits authorisation and political legitimation and demands infrastructures and political legitimation, etc. Different decision problems can be identified such as:

- build the highway or not?
- freeway or toll-highway?
- which route?
- what the procedure to approve the route should be?

and each of them will be treated differently by the different actors depending on the concerns they have.

An external observer could identify the interaction space in which the concerned actors "meet" and can also recognise how the process reached its present "state". However, there are several different ways to conduct such a process (in a more or less authoritarian or participatory way) and for each of these, different types of decision, support can be demanded by different participants. It is not possible to identify a unique decision support. Decision aiding always refers to a participant and his concerns. ◇

As already discussed in the previous section, we are interested in decision aiding. From such a perspective the introduction of the above model of the decision process is functional to our purpose to describe the decision aiding process. Intuitively, in decision aiding we also make decisions (what, why and how to model and support). *Decision aiding is also a decision process but of a particular nature.*

Our claim is that in decision aiding contexts an interaction space (for at least two actors: the client and the analyst) appears, characterised by a meta-object which is the "consensual construction of a client's concern representation" through the use of the technical and methodological skills of the analyst and the domain knowledge of the client. Such a hypothesis implies that the two actors engage themselves in a decision process, that is, the decision aiding process is a special type of decision process.

2.2.2 Decision Making and Decision Aiding

The difference between these two concepts has already been discussed in Roy (1993) (see also Brown, 1989; Brown and Vári, 1992). However, Roy considers these as two different approaches and not, as we do, as different situations. In a decision making context we consider a decision maker who, having a concern, might use a decision theory tool in order to establish potential actions to undertake (although in more general terms decision making can be decision theory free). From such a perspective, the reader will often find the term "decision making" in this text. With this term, we will indicate the activities of an individual who develops some information in order to establish a "decision" to carry on within a decision process.[2] In such a setting, decision theory is directly used by the decision maker. There is no distinction between an analyst and a client. The decision maker is at the same time someone looking for support in his decision process and someone endowed with the appropriate knowledge to give himself this support. If there is an analyst, his presence is justified either because he acts as a tutor or because he is a "clone" of the decision maker (somebody who represents the decision maker, but who shares the same information, knowledge and values). It should also be clear that in such a setting we consider the decision maker as endowed with decision power and therefore also responsible for the decision to make.

On the other hand, a decision aiding context implies the existence of at least two distinctive actors: the client and the analyst, both playing different "roles" with respect to the concern of the client. More actors may exist in such a setting, the client not necessarily being a decision maker (he might not have decision power and be for instance in turn the analyst for another client). For simplicity, we only consider the simpler setting with only these two actors present and use with no further distinctions the concepts of decision maker and client.

A decision aiding context only makes sense with respect to one or more decision processes, the ones in which the client's concerns originate. In this chapter we focus our attention on the set of activities occurring within such a setting. We will call such a set of activities a "decision aiding process". The ultimate objective of this process is to attain a consensus between the client and the analyst. On the one hand, the client has a domain knowledge concerning the decision process. On the other hand, the analyst has a methodological knowledge, which is more or less domain independent. The task can be summarised as: given the client's domain knowledge and the analyst's methodological knowledge (and the associated formal and abstract language), interpret the client's concerns and knowledge so that he can improve his perceived position with respect to the reference decision process. Such an interpretation ought be "consensual": the client should consider it as his own interpretation, while the analyst should consider it correct and meaningful. However, the coherence sought by the actors does not refer to a given situation, information or knowledge, but to the cognitive artefacts they produce working together. From this point of view, the decision aiding process is an autopoietic

[2] This is not in contradiction with our emphasis on decision aiding. Indeed the activity of supporting a decision maker can be considered as the support to a decision making process.

system (a self reference system which maintains its organisation constant, but not a closed system since the environment is part of the system's organisation, see Maturana and Varela, 1984). Using a stakeholder approach (see Banville, Landry, Martel, and Boulaire, 1998)decision aiding sees the emergence of a new stakeholder in the decision process, which is the couple "client-analyst". The decision aiding process represents the cognitive efforts undertaken by this couple in order to "positively" influence the decision process in which they are involved.

Example 2.2
Consider again the previous section's highway example. If decision aiding is requested by any of the participating actors, this will concern "an object" among those evoked by the decision process (and its meta-object: the new highway).

Providing some decision aiding in this context raises questions of the type:

- what is the precise issue concerning the client and why (money, authority, natural resources, power, etc.)?
- how can we formulate such an issue in a decision support language, in terms of a decision problem (do we have to convince, to justify, to choose, to analyse, etc.)?
- how exactly will the decision support be designed (which alternatives do we consider, is there any uncertainty, are there several scenarios etc.)?
- what will effectively be done (negotiate with the other actors, impose a precise policy, expand the interaction space, etc

In a constructive decision aiding approach the answers to the above questions are not unique and have to be provided by both the client and the analyst who are now perceived as a unique stakeholder within the process. ◇

Within a decision process, several specific decision processes are structured. A particular type of decision process occurs when an individual (or more), acting as a client, asks another individual (or more), acting as an analyst, some advice concerning an object of the client's concern within another decision process.

We denote such a process as a "decision aiding process", where we can recognise:

- at least two actors, the client and the analyst;
- at least two objects, the client's concern and the analyst's (economic, scientific or other) interest (economic, scientific or other) to contribute;
- a set of resources including the client's domain knowledge, the analyst's methodological knowledge, money (or whatever the analyst asks), time;
- the meta-object being the construction of a shared representation of the client's object and concern.

Example 2.3
Consider an airline company. The sales department (the client) considers that, in order to face tough competition (the decision process), it needs to diversify the offer of seats on each route with respect to the season and the prices to apply, possibly adapting the offer dynamically as the demand evolves (the client's concern). They contact the company's Operational Research department (the analyst) asking for support. The Operational Research department replies positively since this is its job, but also because this is a good opportunity to show to the CEO that they are useful (the analyst's concern). The two actors (which in this case are units of an organisation and not individuals) will share the knowledge of the sales department (structure of the demand, structure of the supply, constraints of the commercial policy, competitors policy etc.), the analyst's knowledge (models and methods for yield management), the company's investment (time, money, resources) as well as the "award" in the case of success. The Operational Research department will possibly convince the sales department that their problem fits the well know "yield management problem" (thus creating the meta-object of the decision aiding process). However, we can expect that the result of the decision aiding process will not just be the construction of a yield management model (and possibly its successful implementation), but more generally an improvement of the company's commercial policy through the adoption of further actions conceived while discussing the yield management problem. ◇

2.3 A model of the Decision Aiding Process

A decision aiding process is a process of distributed cognition (Massey and Wallace, 1996; Vygotsky, 1978). With this term we indicate any process in which different agents endowed with cognitive capabilities have to share some information and knowledge in order to establish some shared representation of the process object. We call such shared representations *shared cognitive artefacts.* For example, consider two persons observing a painting at an exposition, discussing the interpretation to give to the artist's effort.

Within a decision aiding process we have at least two such "cognitive agents" (the client and the analyst) who share information and knowledge with the perspective of producing a set of shared cognitive artefacts, replying to questions such as:

- who has which problem?
- what could a solution to that problem be?
- why such a solution could be successful? etc.

However, our analysis of the decision aiding process will not be cognitive (describe and analyse the mental activities of the actors involved), but operational (how to conduct the process?). Actually, we are not going to analyse how such a distributed cognition occurs and how it works (although analysing how the two agents interact can be extremely interesting). Our basic hypothesis is that since we are looking for formal models of decision support, there is a basic agreement between the client and the analyst that they are looking for such a model and that they are going to use a formal representation language (this may possibly reduce the cognitive effort). There is no loss of generality with such a hypothesis. If such an agreement does not exist in reality, it is always possible to consider that the analyst will spend some of his time to convincing his client of the opportunity to follow a formal approach. The operational question we therefore have to ask is the following: what are precisely the cognitive artefacts that we expect from a decision aiding process?

In other words, we model the decision aiding process through its main products, the ones we consider mandatory in order to obtain "a consensual representation of the client's concern". At the same time, we can see such products as the deliverables honouring the contract with the client.

We introduce four cognitive artefacts as products of the decision aiding process:

- a representation of the problem situation;
- a problem formulation;
- an evaluation model;
- a final recommendation.

In the following section we intend to discuss such artefacts in the form of "checklists" to follow during the interaction with the client. We are aware that a real decision aiding process rarely follows such a checklist, but we have adopted such a rationalisation for the following two reasons.

1. It may help a novice decision analyst in structuring his interaction with his client in order to better conduct their discussion.

2. It may allow any experienced analyst going through a validation of his work to verify if the key issues and deliverables have been appropriately considered and how.

We understand that there is a risk of reducing decision aiding to "applying a manual", but we are confident that the reader also understands that a real decision aiding process is far more complex and that these are suggestions for support.

2.3.1 The Problem Situation

The first deliverable consists in offering a representation of the problem situation for which the client has asked the analyst to intervene. The main idea is to enable the analyst to answer questions of the type:

- who has a problem?
- why is this a problem?

- who decides on this problem (who is responsible)?
- who pays for the job?
- what is really important for the client?
- how is the client committed in this situation?

Such an analysis might also be useful for the client since it could help him to better situate himself with respect to the decision process for which he asked the analyst's advice.

A representation of the problem situation can be conceived as a triplet

$$\mathcal{P} = \langle \mathcal{A}, \mathcal{O}, \mathcal{S} \rangle$$

where:

- $\mathcal{A}$ are the actors involved in the process (as described by the client and perceived by the analyst);
- $\mathcal{O}$ are the objects (stakes) of the different actors;
- $\mathcal{S}$ are the resources committed by each actor on each object of his concern.

The reader should remember that a decision aiding process always refers to a decision process in which the client is involved. Decision support is always requested with respect to a decision process. Representing a problem situation corresponds to taking a picture of the decision process at the moment the decision support is requested. In this picture, the analyst and the client should recognise who participates (the actors), why they participate and what their concerns (the objects) are and what their level of commitment (the resources) is. Several different representations of the problem situation can be constructed during a decision aiding process. This is due both to the natural evolution of the decision process in which the client is involved (the pictures will be different) and to the decision aiding process itself which might modify the perception of the decision process for the client and the analyst (they might observe the same picture differently).

Example 2.4 (Selection of a Billing System)
A new mobile telecommunications operator has been established in a small, but highly competitive European market. One of the basic operational tools of such companies is their billing system (*BS*). This system allows both a structured accountancy of the traffic and a flexible policy towards the existing and potential clients (enabling for instance a variety of services beyond the basic ones, the creation of packages of services oriented to specific market targets, the monitoring of each subscriber's traffic).

Some years after the establishment of the company, the necessity to upgrade or to substitute the existing billing system became evident to the management. A decision process was therefore triggered, and we were asked to provide decision support (for details, see Stamelos and Tsoukiàs, 2003). An analysis of the problem situation showed that:

- The actors $\mathcal{A}$ involved were:
  - the acquisition manager;
  - the information systems manager (IS);
  - the marketing and sales manager;
  - the software suppliers;
  - the IS consultants.
- The objects $\mathcal{O}$ involved in the process were:
  - the market share of the company;
  - the policy towards the suppliers;
  - the company's internal organisation;
  - the billing system itself.
- The resources $\mathcal{S}$ implied in the process included the necessary funds for the billing system, the knowledge about billing systems and the relations with the software suppliers. The available time was very short, since all decisions had to be made in the least possible time due to the extremely competitive environment.
- The problem situation $\mathcal{P}$ results from the explicit representation of the sets described above.

The client in this study was the IS manager. The identification of the actors, their concerns and the resources were exploited in order to establish a set of problem formulations (see next section) that were meaningful for the client and his concerns within this situation. ◇

2.3.2 Problem Formulation

Given a representation of the problem situation, the analyst may provide the client with one or more problem formulations. This is a crucial point of the decision aiding process. While the first deliverable has mainly a descriptive (possibly explicative) nature, the construction of a problem formulation goes further towards formalising the interaction between the client and the analyst and introduces the use of the decision support language. The result is by definition reductive with respect to the reality of the decision process.

The idea is that a problem formulation translates the client's concern, using the decision support language, into a formal "problem" (a problem to which decision support techniques and methods apply). For instance, the client may claim that he has a problem to "buy a new bus in order to improve service to the clients". This may result in different problem formulations such as:

- choose one among the potential suppliers of buses;
- choose one among the set of offers submitted by the suppliers;

- choose one among the set of all combinations of two offers.

The above problem formulations are not similar and are not neutral with respect to the possible final recommendation. Indeed we, want to emphasise that adopting a problem formulation implies adopting a precise "strategy" towards the problem situation. Each such strategy will lead the decision aiding process to different recommendations. It is necessary to establish which strategy is going to be pursued with the client. Returning to the bus acquisition example, the first problem formulation focuses the attention on the suppliers and not on the offers they may make. The second problem formulation implicitly assumes that only one type of bus will be bought, while the third one allows to buy combinations of two different offers. It is clear that the choice of one of the above problem formulations will greatly influence the evaluation of the alternatives and the final solution.

A problem formulation can be conceived as a triplet:

$$\Gamma = \langle \mathbb{A}, V, \Pi \rangle$$

where:

- $\mathbb{A}$: is a set of potential actions that can be undertaken by the client with respect to the problem situation $\mathcal{P}$;
- V: is a set of points of view from which the potential actions are observed, analysed, evaluated, compared, etc.;
- Π: is a problem statement which anticipates what is expected to be done with the elements of $\mathbb{A}$. The reader will find more details on this point in Bana e Costa (1996), Ostanello (1990) and Roy and Bouyssou (1993) (see also section 2.4.3).

The use of problem formulations aims to anticipate the possible conclusions of the decision aiding process. The awareness of such possible conclusions allows the client to check whether these are compatible with his expectations. Moreover, if the effective conclusions are unsatisfactory to the client, he has the possibility of revising the problem formulation opening new modelling possibilities. The analyst's second deliverable consists in submitting a number of problem formulations to the client . The client validates them and chooses the ones with which the analysis might continue. Hereunder, we continue with the real case study (Stamelos and Tsoukiàs, 2003) concerning the selection of a billing system.

Example 2.5 (Selection of a Billing System BS)
The strategic decision with which the management was faced consisted in choosing one among the following options: upgrade the existing BS, buy and customise an existing BS, buy a BS created ad-hoc for the company by an external supplier (*bespoke system*), develop an ad-hoc BS in collaboration with an external supplier. However, the management was not able to choose an option without analysing what the billing system would eventually be in all such options. We therefore provided three problem formulations (the fourth option being the upgrade of the existing BS, was considered familiar) which we will call:

- B: buy (and customise an existing BS);
- M: make (externally a new ad-hoc BS);
- D: develop (a new ad-hoc BS in collaboration with a supplier).

In all three cases, a call for tenders was provided. The three problem formulations become:

1. $\Gamma_B = \langle \mathbb{A}_B, V_B, \Pi_B \rangle$ where:

   $\mathbb{A}_B$: offers proposed by specific suppliers of existing BS accompanied by a proposal for the customisation phase.

   V_B: points of view of the evaluation:

   - costs (including training, insurance fees and payment conditions);
   - quality (based on ISO9126 and benchmarks on the proposed product);
   - timing (of delivery, test and installation);
   - installed base of the proposed BS (including performance reports on already installed BS of the same type).

   Π_B: ranking of the offers in order to enable further negotiations on the price.

2. $\Gamma_M = \langle \mathbb{A}_M, V_M, \Pi_M \rangle$ where:

   $\mathbb{A}_M$: offers proposed by specific software developers with different degrees of experience in BS development.

   V_M: points of view of the evaluation:

   - costs (including training, insurance fees and payment conditions);
   - requirements satisfaction (client driven requirements);
   - timing (of delivery, test and installation);
   - type of supplier-developer (taking into account the company's supplying policy);
   - consequences for the company's internal organisation (including project management).

   Π_M: selection of a supplier - developer with whom to establish a supplying process (consisting of benchmarks, tests, training and delivery).

3. $\Gamma_D = \langle \mathbb{A}_D, V_D, \Pi_D \rangle$ where:

   $\mathbb{A}_D$: set of suppliers with whom it could be possible to co-develop a new BS.

   V_D: points of view of the evaluation:

   - costs (distinguishing internal and external costs);
   - requirements analysis and satisfaction;
   - timing (including the time in which the product could be ready for the market);

- type of supplier-developer (including company's supplying policy);
- consequences for the company's internal organisation (including project management);
- benefits to the company by entering the market of billing systems as a supplier itself.

Π_D: selection of a co-developer to establish a co-makership policy and therefore a long-term collaboration.

The client finally chose the first problem formulation, implicitly accepting a pure buying policy with respect to the basic strategic choice. We are not going to explain this choice. We would however, like to emphasise two observations:

1. From a general point of view, each problem formulation may generate quite a different evaluation model. The set of potential actions is different (existing BS in Γ_B, offers of non existing software in Γ_M, co-developing suppliers in Γ_D). The set of criteria may also be quite different (it is sufficient to note that the "make" and the "development" option requires to consider as a criterion the implication of the information systems department in the development process, a fact that may alter the distribution of resources and responsibilities in the company's organisation or that the development option requires to evaluate the eventual benefits of "selling" the new billing system). The relative importance of the criteria may also be different, while the aggregation procedures in each model have to be adapted to the different problem statements and the different nature of the criteria.

2. Focusing on the problem, the different problem formulations also lead to different models. In the Γ_B case, existing software products must be compared (even if the one chosen will be customised), a fact that allows the use of existing models (as the ISO9126 standard). Benchmark tests must also be performed. On the other hand, in the Γ_M case, the software artefact does not yet exist. The attention of the evaluation will shift to the satisfaction of the requirements during software development, and therefore some of the supplier's quality requirements have to be considered a priori. Finally, in the Γ_D case, the evaluation consists in the comparison of possible partners for software development, implying the comparison of the compliance of the partner's software development process with the company's standards (assuming that they exist).

   Furthermore, the priorities among the different criteria and attributes will change from one problem formulation to another, independently of the uncertainty associated with the available or required information. Finally, in order to aggregate the different software measurements, different necessities arise from one problem formulation to another (e.g., in the Γ_B case, measurements may correspond to observations and therefore a functional aggregation can be allowed, while in the Γ_M and in the Γ_D cases, the measurements are predictions or estimations based on expert opinions, a fact that requires a different treatment). ◇

Obtaining the client's consensus on a problem formulation leads to a gain of insight, since instead of having an "ambiguous" description of the problem we have an abstract and formal problem. Several decision aiding approaches will stop here, considering that formulating (and understanding) a problem is equivalent to solving it, thus limiting decision aiding to helping to formulate problems, the solution being the client's personal issue. Other approaches might consider the problem formulation as given. Within a constructive approach the problem formulation is one among the artefacts of the decision aiding process, the one used in order to construct the evaluation model.

2.3.3 Evaluation Model

For a given problem formulation, the analyst may construct an evaluation model, that is to organise the available information in such a way that it will be possible to obtain a formal answer to a problem statement (defined within Γ).

An evaluation model can be viewed as an 5-tuple:

$$\mathcal{M} = \langle A, \{D, \mathcal{E}\}, H, \mathcal{U}, \mathcal{R} \rangle$$

where:

- A is the set of alternatives to which the model applies. Formally it establishes the universe of discourse (including the domain) of all relations and functions that are going to be used in order to describe the client's problem.

- D is the set of dimensions (attributes) under which the elements of A are observed, described, measured etc. (the set D might be endowed with different structuring properties such as an hierarchy). Formally D is a set of functions such that each element of A is mapped to a co-domain that we denote as X_i.

- $\mathcal{E}$ is the set of X_i associated to each element of D. Each X_i can be considered as a set of "levels" or "degrees" to which a structure such as an "order" is possibly associated. Intuitively we can consider the functions in D as measurements using the X_i as "scales". Issues concerning measurement are discussed in more detail in chapter 3 of this book.

- H is the set of criteria under which each element of A is evaluated in order to take in account the client's preferences. Formally a criterion is a preference relation, that is a binary relation on A (a subset of $A \times A$) or a function representing the relation. The reader will find more details about preference models in chapter 3 of this book.

- $\mathcal{U}$ is a set of uncertainty structures to apply to D and/or H. Formally $\mathcal{U}$ collects all uncertainty distributions that can be associated to the relations and functions applied to A, besides possible scenarios to which uncertainty measures can be associated.

- $\mathcal{R}$ is a set of operators such that the information available on A, through D and H can be synthesised to a more concise evaluation. Formally $\mathcal{R}$ is a set of operators such that it is possible to obtain a comprehensive relation and/or function on A, possibly allowing to infer a final recommendation.

The reader can observe that a large part of the existing decision aiding models and methods can be represented through the above description. It also allows to draw the reader's attention to a number of important points:

1. It is easy to understand why the differences between the approaches do not depend on the adopted method. The fact that we work with only one evaluation dimension, a single criterion, a combinatorial optimisation algorithm can be the result of applying a constructive approach. It is important not to choose the method before the problem has been formulated and the evaluation model constructed, but to show that this is the natural consequence of the decision aiding process as conducted up to that moment.

2. The reader should note the difference between D and H. The former represents the "empirical" knowledge available or collected about A, but says nothing about the preferences of the client. The fact that such knowledge may use a structure such as an order (possibly coded in X_i) does not establish any knowledge about the client's "desires". These are modelled in H where preferences are explicitly represented. In the literature the elements of D are often called "attributes". Chapter 6 will extensively discuss the direct use of such "dimensions" in decision aiding.

3. The technical choices (typology of the measurement scales, different preferences or difference models, different aggregation operators) are not neutral. Even in the case in which the client has was to formulate his problem clearly and he is convinced about it (possibly using one of the techniques aiding in formulating problems presented in section 2.4), the choice of a particular technique, procedure, operator can have important consequences that are not discussed when the problem is formulated (for a critical discussion see Bouyssou et al., 2000). Characterising such techniques, procedures and operators is therefore crucial since it allows to control their applicability to the problem as formulated during the decision aiding process.

4. The evaluation models are subject to validation processes. This includes namely (see Landry et al., 1983a):

    - conceptual validation: verify whether the concepts used within the model in order to describe the client's concerns and problem situation are meaningful for the client, i.e., that he understands them and finds them useful; in other words the client and the analyst have to agree on what each precise concept represents and how this is useful for the client's problem;
    - logical validation: verify whether the concepts and the tools used within the model are logically consistent and meaningful (from a measurement

theory perspective); the reader should pay attention to the fact that logical consistency does not necessary imply that the client is consistent in his claims, but that the model handles the information consistently (including possible inconsistencies and ambiguities);

- experimental validation: test the model using experimental data (and examples) in order to show that the model provides the expected results and possibly check formal requirements such as convergence of an algorithm, accuracy of a classification, sensitivity to small variations of the parameters, etc.;
- operational validation: show that the model when confronted with the decision process for which it was conceived acts as expected and that the client can indeed use it within such a process; further unforeseen consequences of using the model can be observed at this point.

It should be noted that validating the model is a crucial activity to establish the necessary consensus between the client and the analyst, consensus which (at least partially) legitimates the model to be used within the decision process for which it was conceived.

Example 2.6
Let us again consider the example of buying a bus. Suppose that the problem formulation adopted was the second one (choose one among the offers from suppliers). Suppose also that in reply to a call for tenders a number of offers are available. An evaluation model for this problem formulation could be (we use subscript 2 in order to denote that is the second problem formulation considered):

- A_2: set of offers received, legally acceptable;
- D_2: economic dimension (costs, maintenance, payment conditions), technical dimension (technical characteristics), quality characteristics (comfort, luggage capacity etc.); it should be mentioned that the set of dimensions in this case has an hierarchical nature (each of the above dimensions being further decomposable);
- $\mathcal{E}_2$: we are not going to show the whole set of scales, but we can mention that for instance maintenance is measured in "estimated numbers of man-hours per month", that one of the technical characteristics is the brakes capacity measured in "metres to stop the bus at max speed and full charge", that the comfort is a qualitative measure provided by an external expert on a scale of the type "good", "acceptable", "unacceptable";
- H_2: again we are not going to give the whole set of criteria; a generalised cost criterion putting together all different costs and the number of buses to buy is considered, while several technical and quality criteria have to be constructed such that the client's preferences can be represented; for instance a safety criterion is established (offer x is preferred to offer y iff the "brake's capacity of x" is at least 20 metres less than the "brake's capacity of y"); again an hierarchy of criteria has to be defined;

- $\mathcal{U}_2$ will be considered empty, all measures and preferences being considered by the client as "sure" and "precise";

- $\mathcal{R}_2$ is a set of aggregation procedures including the necessary parameters; it should be noted that the presence of an hierarchical structure on the criteria could be seen as the creation of a number of evaluation models one for each node of the hierarchy excluding the leaves. A precise aggregation procedure can be associated to each such evaluation model for instance, the quality criterion is obtained using a sorting (ordered classification) procedure by which each offer is classified in one among a set of merit classes (very good, good, acceptable, unacceptable) based on the values of the offers on the different quality criteria (comfort, luggage capacity, number of seats) (on such ordered classification procedures, the reader can be referred to: Belacel, 2000; Bouyssou and Marchant, 2005a,b; Bouyssou et al., 2000; Henriet, 2000; Massaglia and Ostanello, 1991; Mousseau, Słowiński, and Zielniewicz, 2000; Paschetta and Tsoukiàs, 2000; Perny, 1998; Yu, 1992b). Of course each aggregation procedure requires a number of parameters (importance of the criteria, thresholds, etc.). In our example the final aggregation was expected to compute a value for each offer and a multi-attribute value function was constructed. Therefore, tradeoffs between the three criteria (cost, technical, quality) had to be established (on such procedures, the reader may refer to Bouyssou et al., 2000, and chapter 6 of this book).

It is worth noting that had the third problem formulation been adopted, the evaluation model would have been quite different. The set of alternatives would be the set of all combinations of two offers. Furthermore, the reason for which such a problem formulation was considered derives from the observation that two different buses might better fit the variety of client the company serves (one for child transportation and the other for medium range tourism services). At least a criterion such as "fitting the market variety" should be added, while an uncertainty could now be considered (unknown behaviour of the market). ◇

2.3.4 Final Recommendation

The evaluation model will provide an output (denoted by Φ) which is still expressed in terms of the decision support language. The final recommendation is the final deliverable which translates Φ into the client's language.

It should be possible to check whether this final recommendation:

1. is technically sound (no incorrect or meaningless manipulations should be undertaken). Since the output Φ is the result of a number of manipulations on the available information (representing consequences, modelling preferences and uncertainties, aggregating measures, preferences and uncertainties etc.), it is important that such operations fulfil basic requirements of meaningfulness (for definitions, see Roberts, 1979). The number of situations in which intuitive reasoning leads us to undertake meaningless operations is incredibly high (for examples and further discussion see Bouyssou et al., 2000).

Care should be taken to verify whether the evaluation model is free of such biases;

2. is operationally complete (the client understands the recommendation and is able to apply it). The fact that the output is technically sound does not necessarily mean that this is useful for the client's problem. An arithmetic average of three measures of length is technically correct, but useless in case the client is looking for an aggregate measure of a volume (where a geometric average will fit perfectly). The final recommendation should be able to give an operational reply to the client's concerns (as these were established in the problem formulation) and enable him to undertake some deliberation and/or action (including doing nothing, provided this is deliberated);

3. is legitimated with respect to the decision process for which it was conceived. We should always remember that the advice requested by the client refers to some decision process in which he is involved. A technically sound and operationally complete recommendation is not sufficient in order to be incisive within the decision process. The reality of such processes includes organisational, cultural, ethical and interpersonal dimensions which are not necessarily (and rarely are) considered within the construction of the evaluation model and the establishment of the output Φ. When we return to the reality of the decision process we should take care to present the final recommendation in such a way that this can be inserted in the process.

In other words, the final recommendation should be able to translate the conclusions of the decision aiding process into a format that can be used within the client's decision process and/or organisation process in which the client is involved. In order to do that, the model, should not only be convincing for the client (which should be the case if a consensus was reached between the client and the analyst), but also should be able to convince the other actors participating in the process in which it is going to be used. Theoretical soundness, operational completeness and legitimation are the essential features the final recommendation should satisfy.

In the following sections we are going to focus our attention on how the previously introduced cognitive artefacts can be established, with particular emphasis on the definition of a problem formulation and the construction of an evaluation model. We try to outline a number of recommendations on how the decision aiding process should be conducted as well as a number of technical issues to which the analyst should pay attention. In this chapter, we do not provide the precise theory concerning the items of the evaluation model. These are discussed in a structured way and with much more detail in the following chapters. More precisely, the use of D, $\mathcal{E}$ and the construction of elements of H are mainly discussed in chapter 3. $\mathcal{R}$ is thoroughly discussed in chapters 4, 5 and 6 since it represents a crucial component in multiple criteria decision and evaluation models. Chapter 7 is dedicated to several technical aspects of the final recommendation construction and the treatment of robustness.

2.4 Problem structuring

There is a lot of literature on problem structuring (Abualsamh, Carlin, and McDaniel, 1990; Belton and Stewart, 2001; Binbasioğlu, 2000; Buchanan, Henig, and Henig, 1998; Corner, Buchanan, and Henig, 2001; Courtney and Paradice, 1993; Eden, 1988, 1994; Eden, Jones, and Sims, 1983; Keller and Ho, 1988; Landry, 1995; Lehaney, Martin, and Clarke, 1997; Massey and Wallace, 1996; McGregor, Lichtenstein, Baron, and Bossuyt, 1991; Mingers and Rosenhead, 2004; Norese, 1996; Pidd, 1988; Smith, 1988, 1989; Sycara, 1991; Woolley and Pidd, 1981). A common characteristic of this literature is the emphasis on the claim that supporting decisions should not be limited to solving well established decision models, but should help in facing more "soft", "ill-structured" decision situations that need to be "structured". The idea is that trying to fit a decision situation to a given decision model may result in solving the wrong problem correctly. It is therefore necessary to have methods and tools enabling to establish a problem formulation *before* any choice concerning the decision and/or evaluation model. The issue is (simplifying): *first set what the problem is and only then consider how to solve it.* This may appear to be common sense, but several authors cited above have shown that decision theory traditionally focuses its attention on how to solve the problem and not on how to formulate it.

Our claim is that our model of the decision aiding process can be used as a problem structuring method. Before showing how this can occur in detail, we discuss some of the best known methods found in the literature.

2.4.1 Problem Structuring Methods

Problem structuring methodologies aim to help decision makers to better understand their concerns (Checkland, 1981; Landry, 1995; Landry et al., 1983b; Rosenhead, 1989), better justify and legitimate their conclusions (Landry et al., 1996) and ease the validation process (Landry et al., 1983a; Ostanello, 1997).

Several among the problem structuring methodologies consider that decision aiding *is* problem structuring (see, e.g., Checkland, 1981; Friend and Hickling, 1987; Rosenhead, 1989). In other words, the quantitative aspects on which evaluation models usually rely are considered irrelevant, neglected or not at all considered under the not unrealistic claim that once the decision maker has a definitely clear idea of what the problem is, he also knows how to solve it.

2.4.1.1 Cognitive Mapping

Particularly "cognitive mapping" (see Eden, 1988, 1994; Eden et al., 1983) aims to give a representation of how a person (the client) "thinks" about a set of issues. The basic tool is simple: a network in which nodes represent the issues concerning the client(s) for whom the map is constructed and arrows represent the way in which one issue may lead to or have an implication on another. Issues are represented as sentences calling for "action" or "problem solving" and arrows show how one such action (or possible solution) will influence the outcome of another.

What is important in this method however, is not the tool itself, but the conducting of the interview which will lead to the establishment of the cognitive map. Indeed, the existing software implementing the method (Decision Explorer™) [3] is just a support for the discussion rather than a decision support tool. In the construction of a cognitive map a key role is played by the "facilitator" (the analyst in our terminology). He is expected to conduct the discussion and practically to design the cognitive map using the client's replies as well as the discussion developed during a cognitive mapping session. Actually, such sessions are carefully prepared and precise rules on how the discussion has to be conducted by the facilitator are established (see Rosenhead, 1989, ch. 3).

Cognitive mapping seems extremely useful when the client(s) consist in a group of people involved in organisational decision processes in which the emergence of consensus on different issues is extremely difficult and remains subject to power manipulations. In such a situation, it can also be very useful in giving a "sense" to discussions occurring within an (formal or informal) organisation.

The scope of a cognitive mapping session (possibly more than one session might be necessary) is to provide the client(s) with a representation of how they perceive their "problems" and how they expect to act on them. This a clearer representation and the structuring of the problem situation should enable the emergence of a consensus among the participants on how to act further and which actions it might be necessary to undertake.

2.4.1.2 Strategic Choice

Another well known problem structuring method is "strategic choice" (see Friend and Hickling, 1987; Friend and Jessop, 1969). Such a method is expected to handle the complexity of interconnected decision problems. The basic idea is that these complex problem situations are characterised by large uncertainties requiring strategic management. The authors claim that the basic philosophy of their method is "managing uncertainty in a strategic way". Within such a method three principal sources of uncertainty are identified:

- uncertainties about guiding values;
- uncertainties about the working environment;
- uncertainties about choices and related agendas.

The dynamics of a "strategic choice process" distinguish four "modes" of decision making:

- the "shaping mode" where the decision maker(s) are add concerns about the structure of the set of decision problems they are facing;
- the "designing mode" where the decision maker(s) are concerned about which actions are feasible with respect to their view of the problem;

[3] Decision Explorer is a product of Banxia Software, see http://www.banxia.com.

- the "comparing mode" where the decision maker(s) look for the different dimensions under which different actions could be compared;
- the "choosing mode" where the decision maker(s) look for arguments and commitment to pursue actions over time.

Strategic Choice can be seen as a toolbox of procedures aimed to support the four different "modes" previously introduced. However, such a toolbox (see also the software STRAD2^{TM})[4] is expected to be used within a precise approach in which the decision makers are seen as "stakeholders" of the final decision. It is mainly based on conducting workshops facilitating communication among the participants through the use of graphical tools manipulated by a facilitator who also conducts the workshop. The different modes of decision making are seen as interchangeable loops. This implies that within a workshop it is also important to register the dynamics of the interactions and of the outcomes. Indeed, the result of the method should not only be the deliverables (argued actions and policies), but also new ways of pursuing the organisational decision process.

2.4.1.3 Soft Systems Methodology

Soft Systems Methodology was developed by Checkland (1981) as an alternative to classic systems engineering (see Hall, 1962) seen mainly as a problem solving process (in which traditional OR techniques could apply).

"SSM is a learning system. The learning is about a complex problematical human situation, and leads to finding accommodations and taking purposeful action in the situation aimed at improvement, action which seems sensible to those concerned. SSM articulates a process of enquiry which leads to the action, but that is not an end point unless you choose to make it one (in Rosenhead, 1989, p. 67, ch. 4).

Although its presentation has evolved in recent years, we are going to present SSM in its original form, as a series of stages taking place in two worlds: the real world and an "abstract world" created through "systems thinking" on the real world:

1. enter situation considered problematic (real world);
2. express the problem situation (real world);
3. formulate root definitions of related systems of purposeful activity (abstract world);
4. build conceptual models of the systems used in the root definitions (abstract world);
5. compare models with the real world actions (real world);
6. define possible changes which are both feasible and desirable (real world);

[4] STRAD2 is a product of Stradspan, see `http://www.btinternet.com/~stradspan/products.htm`.

7. take action to improve the problem situation.

From a modelling point of view what is important is how "root definitions" are formulated. Under such a perspective SSM suggests a checklist of the following demands:

Context: who would be victim or beneficiary of the purposeful activity?

Actor: who would carry out the activities?

Transformation process: what is the purposeful activity expressed as "input-transformation-output"?

Weltanschauung: what view of the world makes this definition meaningful?

Owner: who could stop this activity?

Environment constraints: what constraints in its environment does this system take as given?

The second important modelling step is to build conceptual models of the system used in the root definitions. In order to do this, on the one hand it should be possible to consider actions on the systems and on the other hand, it should be possible to monitor and control them. This generates the following three basic modelling criteria:

Effectiveness: is this the right thing to be doing?

Efficacy: do the means work?

Efficiency: is a minimum of resources used?

The reader should pay attention to the fact that the above recommendations have to be seen within the whole process of understanding the problem situation and the different purposeful activities that can be undertaken. SSM is not just a simple checklist of modelling acts to follow in order to establish a deliverable for the client.

Practically SSM is applied through extensive interviews with the problem owners and large workshops including the stakeholders of the problem situation. The aim is that the modelling process suggested by SSM will allow such stakeholders to converge to a shared representation of both the problem situation (what is the problem?) and the actions to undertake (what to do?). Again the reader should consider that SSM has to be viewed as a "methodology" and not just a method, thus remaining situation driven and not method driven (the reader is referred to Checkland and Scholes, 1990, for more details concerning the use of SSM).

2.4.1.4 Valued Focussed Thinking

In his challenging book, Keeney (1992), suggests that usually decision making methods focus their attention on evaluating alternatives *after* such alternatives have been established or given. Instead, focus should be given to how such alternatives are or can be established and the author's suggestion is: *thinking about values and objectives.*

The idea is that as soon as the client has been able to structure his objectives (with respect to a given problem situation) he is also able not only to compare ready-made alternatives, but also to consider alternatives that were not there at the beginning of the process, but appear desirable and feasible within the objectives and values structure. For instance, it might be that only after understanding the importance of CO reduction in car engines for future sales, that CO absorption devices could be considered as components of such car engines.

Structuring objectives implies establishing an hierarchy of values starting from what Keeney calls "fundamental objectives". These should be (see table 3.2, in Keeney, 1992, page 82):

essential: indicate consequences in terms of the fundamental reasons for interest in the decision situation;

controllable: address consequences that are influenced only by the choice of alternatives in the decision context;

complete: include all fundamental aspects of the consequences of the decision alternatives;

measurable: define objectives precisely and specify the degrees to which objectives may be achieved;

operational: make the collection of the information required for an analysis reasonable, considering the time and effort available;

decomposable: allow the separate treatment of different objectives in the analysis;

non redundant: avoid double counting of possible consequences;

concise: reduce the number of objectives needed for the analysis of a decision;

understandable: facilitate generation and communication of insights for guiding the decision making process.

Fundamental objectives are then structured in attributes for which value functions (or utility functions in the case uncertainty has to be considered) can be constructed in order to "measure" the desirability of the outcomes and achievements for each objective. Such attributes result in "decomposing" the fundamental objectives into "sub-objectives", dimensions that contribute to defining the client's values. For instance, while looking to buy a car, a fundamental objective could be "safety". Such an objective can be decomposed into two attributes: "brakes efficiency" and "steering efficiency" which can be appropriately measured and for which the client could express preferences. The resulting structure of objectives (and attributes) allows the decision maker to have insight into the problem situation and, more importantly, to have an organised insight. Indeed he might be able to concentrate his attention on high-valued alternatives or make use of generic alternatives, to expand the decision context or even to consider any of his concerns as decision opportunities rather than as decision problems, thus allowing new unforeseeable paths of action to be taken into account. Keeney considers his approach as a path to creative decision making, claiming that structuring the client's values enables to expand the set of feasible actions through structured desirability. From this perspective his suggestion can be considered as a problem structuring approach, although, in this case, the use of quantitative methods is essential (in order to build the value and/or utility functions to be associated to attributes).

2.4.1.5 Integrating Approaches

In their book, Belton and Stewart (2001), advocate the necessity of integrating different approaches of multiple criteria decision analysis. In doing this they base their argumentation on their model of the process of decision analysis in which the following stages are distinguished:

- identification of the problem issue;
- problem structuring;
- model building;
- using the model to inform and challenge thinking;
- development of an action plan.

In discussing the problem structuring part of the MCDA process, the authors suggest a checklist of issues to analyse in order to be able to establish a model:

- criteria;
- alternatives;
- uncertainties;
- stakeholders;
- environmental facts and constraints.

However, since the author's proposal is essentially a way through which to integrate different approaches, the idea is to consider within a MCDA process the use of different techniques, driven by the problem situation and not by a particular method, an idea shared by several scholars in this field (see Bana e Costa et al., 1999; Belton et al., 1997; Norese, 1988, 1996). Multi-methodological approaches have been considered in a wider perspective in the literature (for a presentation see Rosenhead, 1989, ch. 13).

2.4.1.6 Discussion

All the approaches introduced above are basically prescriptive in nature. They suggest how an analyst should conduct the interaction with his client in order to lead him (the client) in a reasonably structured representation of his problem. However, they are either based on empirical grounds (we tried this several times and it works) or they represent a consistent theoretical conjecture. In all cases they have never been based on a descriptive model of the decision aiding activities, fixing the cognitive artefacts of the process, thus allowing the client and the analyst to control the process in a formal way. The result is that either they have to neglect the evaluation model aspect (ignoring situations when the problem formulated still does not allow to find intuitively dominant solutions or underestimates the cognitive biases that affect the decision maker's behaviour) or they have to fix a priori some of the artefacts by adopting a precise shape for the evaluation model (using value functions) thus limiting the applicability of the approach or they underestimate the influence that the analyst can have on his client, influencing his behaviour. Moreover, all such approaches do not explicitly take the process dimension of the decision aiding activities into account. Such a dimension is essential in order to be able to revise and update the outcomes of the decision aiding as the decision process evolves and the client learns.

The model of the decision aiding process previously suggested aims to fill such a gap. It is a descriptive model (showing how the decision aiding process gets structured) and at the same time is constructive since it suggests a path for the process concerning both the client and the analyst. Moreover, it allows to control the conducting of the process since it fixes the cognitive artefacts that are expected to be constructed during the process. This allows to control the process itself since each such artefact is precisely defined. In the next section, we are going to present how such artefacts can be constructed in more detail, suggesting empirical procedures for conducting the interaction with the client.

2.4.2 Representing the problem situation

We consider as given the interest of the client to work with the analyst. This interest is expected to be due to one or more concerns for which the client seeks advice due to his (possibly justifiable) conviction that he is unable to do this alone.

The construction of such a representation begins by establishing a list of actors potentially affected by the interaction between the client and the analyst (see also the so-called stakeholders approaches in decision aiding Banville et al., 1998; De Marchi, Funtowicz, Lo Cascio, and Munda, 2000; Shakun, 1991). We try to answer the question "Who else could be concerned by the client's concern?". A particular issue to explore here is whether the client is the (only) "owner" of this particular concern. It is often the case that the client himself is involved in a decision aiding process as an analyst or that this concern originates within a particular organisational structure. Actually he might not necessarily be a decision maker. For instance, the advice could be asked:

- for a (a priori or a posteriori) justification purpose;

- in order to understand a problem, but where no immediate action is expected to be undertaken;
- because the client has to report to somebody within the organisational structure.

This leads to the following questions: why could the other actors be concerned and what other concerns could they associate to the client's concerns? Intuitively we trace a map associating actors to concerns. Two questions arise at this point:

- are there any links among the concerns?
- how important are such concerns to the different actors?

In order to reply to the first question we can make use of a "projection" relation (see Ostanello and Tsoukiàs, 1993) showing how a concern projects to another one (usually from simple very specific concerns to more general and abstract ones). Usually such a relation results in a tree in which the leaves represent the simple (not further "decomposable") concerns and the root represents the meta-object characterising the decision process for which the decision aiding was requested.

Example 2.7
Imagine an artificial lake, created by the construction of a dam required to operate a hydroelectric power station, but also used for recreational activities (fishing, sailing etc.). The concern of "fish availability" (associated to the local fishermen) as well as the concern of "hydrogeological stability" (associated to the local electricity company) both project to the concern "lake management" (associated to the local authority: the local province). ◇

In order to reply to the second question we can associate the resources committed or requested by each actor for each of his concerns to each object. The client's commitment is in particular a key issue for two reasons:

- it will influence the content of the problem formulation and the evaluation model;
- it will play a specific role as far as the timing of the decision aiding process is concerned.

Establishing a representation of the problem situation enables the two actors (the client and the analyst) to "situate" themselves with respect to the decision process for which the aid was requested. This is important for at least two reasons:

- it offers the basic information to formulate the decision aiding problem and the associated evaluation models;
- it allows the two actors, in case of unsatisfactory conclusions, to come back and re-interpret the problem situation or to update it in order to take the evolution of the decision process into account.

2.4.3 Formulating a problem

As already introduced, formulating a problem is the first effort to translate the client's concern into a formal problem. The first question to ask here is: "what are we going to decide about"? We might call this set decision variables or alternatives or potential decisions. At this stage, it is important to establish with sufficient clarity what the set $\mathbb{A}$ does represent (e.g., suppliers or bids or combinations of bids etc.) and how (are they quantities, alternatives, combination of actions etc.).

Where does such information come from? One source is of course the client who might be able to provide at least part of the set $\mathbb{A}$ directly (for the cognitive problems associated to this activity see Newstead, Thompson, and Handley, 2002). The actors and their concerns as identified in the problem situation representation can also be sources. However, quite often the elements of set $\mathbb{A}$ have to be "designed" (see Hatchuel, 2001), in the sense that such a set does not already exist somewhere (and we just have to find it), but has to be constructed from existing or yet to be expressed information (the reader can see examples of such process in Keeney, 1992, a couple starting comparing one week holiday packages in national tourist resorts and ending up considering a one month holiday in the Pacific islands). A way to do this can be to work on the client's structure of values and expectations (as Keeney, 1992, suggested by) or using an "expandable rationality" (see Hatchuel, 2001) allowing to make the set of alternatives evolve. Another way is through an analysis of the structure of concerns in the problem situation. The client typically presents himself with a concern that remains somewhere at an intermediate level of the tree of concerns. Going up and down such a tree enables to identify different sets of potential actions (considering the resources the client may commit for each such concern).

Example 2.8
Using the holiday example, the concern of an ordinary holiday may project on a more general one which is the well being of the couple, for which further resources could be committed and thus allow to consider a concern of a special holiday. ◇

The final shape of set $\mathbb{A}$ will only be fixed when the evaluation model is established, but the effort of constructing set $\mathbb{A}$ during the problem formulation will pay during the whole decision aiding process: *half of a problem is deciding what to decide.*

The analysis of the different concerns (and how and why these associate to the different actors) leads to the establishment of the points of view to be considered in the decision aiding process. These represent the different dimensions under which we observe, analyse, describe, evaluate, compare the objects in $\mathbb{A}$. At this stage, the elements of V do not have any formal properties and do not necessarily define a structure (such as a hierarchy). They simply represent what the client knows or wishes to know about set $\mathbb{A}$. The key question here is: "among all this knowledge, what is relevant for the decision situation under analysis?" Again the representation of the problem situation can be useful here, since certain concerns can be of a descriptive nature (thus resulting in points of view), while the identification of the different resources to be committed to the concern may reveal other points of view. A more structured approach for this particular problem can be the use of cognitive maps (Eden, 1988, 1994) or Checkland's soft systems methodology (see Checkland and Scholes, 1990).

Last, but not least, we have to establish a problem statement Π. Do we optimise or do we look for a compromise? Do we just try to provide a formal description of the problem? Do we evaluate or do we design alternatives? Establishing a problem formulation implies announcing what we expect to do with set $\mathbb{A}$. We can first distinguish three basic attitudes:

- the first is constructing a set of feasible and realistic alternative actions without any necessary further evaluation purpose (as, for instance, in the "constraint satisfaction" case, see Brailsford, Potts, and Smith, 1999);
- the second is describing a set of actions under a set of precise instances of the points of view established in V;
- the third one, which we will call "purposeful" (also named operational, see Roy, 1996), consists in partitioning set $\mathbb{A}$.

Let us focus on this third attitude. Partitioning the set $\mathbb{A}$ implies establishing a set of categories to which each element of $\mathbb{A}$ is univocally associated (the "good" elements and the "rest", the "better", the "second best", etc., the "type X", the "type Y", the "type Z", etc.). In all cases and under all approaches, a purposeful problem statement results from the replies to the following questions:

- are the categories predefined or do they result from the comparison of the elements of $\mathbb{A}$ among themselves?
- are the categories ordered (at least partially) or not?
- how many such categories can exist (if they are not predefined)? Just two complementary ones or more than two?

A purposeful problem statement is a combination of answers to the above questions and establishes a precise form of partition of set $\mathbb{A}$:

1. in predefined, not ordered categories (a typical example being a diagnosis problem: patient x has appendicitis, patient y has a simple abdominal pain, etc.);
2. in predefined, ordered categories (as in the "sorting" procedures: tender x is "acceptable", tender y is "good", etc.);
3. in not predefined, not ordered categories (as in the clustering and more generally classification case: cluster the students of a class on the basis of their height);
4. in two, not predefined, ordered categories (for instance, the chosen or rejected objects and the rest or the optimal solutions and the rest: the outcome of all mathematical programming algorithms result in such a partition);

5. in more than two, not predefined, ordered categories (as in ranking procedures: rank the students on the basis of their performances in the different classes they followed in a year).

Up to now we have presented seven possible problem statements, the five purposeful ones previously described, and the two "non purposeful" ones which we call "design" and "description". All such statements can be further characterised by the possibility of looking to "robust" decision aiding. We will not further discuss this issue which already attracted the interest of several researchers (see Chu, Moskowitz, and Wong, 1988; Kouvelis and Yu, 1997; Ríos-Insua and Martin, 1994; Roy, 1998; Vincke, 1999a,b; Wong and Rosenhead, 2000). Further discussion can be found in chapter 7.

Operational Research and Decision Theory usually focus their attention on optimisation and more generally on "choice" problem statements in which one alternative or vector of decision variables is expected to be established as a solution (thus introducing the use of only two categories of solutions: the chosen ones and the rest). However, decision aiding is also provided when we rank-order the alternatives, when we classify them in categories (ordered or not, pre-existing or not) through internal (relative) or external (absolute) comparison. Establishing the problem statement with the client enables to focus on the appropriate methods and procedures to be used and avoids wasting time trying to force the information in irrelevant ones. Nevertheless, the establishment of Π is an anticipation of the final solution and as such it is rare that the client is able to provide it through simple questioning. The work of the analyst here is to show (through examples) the different possible problem statements and the different outcomes to which they lead.

As already mentioned, the establishment of a problem formulation is a key issue in the decision aiding process. It represents a tentative start to foreseeing and anticipating the conclusions of the process and as such has a "strategic" character (de facto establishing a strategy with respect to the decision process). From this perspective, revising the problem formulation represents a revision of "strategy".

2.4.4 Constructing the Evaluation Model

This is the typical task in which the analyst applies his methodological knowledge to the information provided by the client in order to produce a model which can be elaborated through a Decision Analysis method.

Again the first step is to fix the set of potential decisions or alternatives A. At this stage set A should have precise formal properties such as:

- being a compact (in a topological sense) or a discrete subset of an n-dimensional space;
- being a list of objects or an enumeration of options;
- having a combinatorial structure.

The existence of feasibility (or acceptability) constraints should apply here either directly (limiting the enumeration of A) or indirectly (limiting the space where A can be defined). Set $\mathbb{A}$, established in the problem formulation, is the starting point of this process, but new elements may be added (such as dump alternatives or ideal solutions) or eliminated. Within an evaluation model we consider the set A as stable across time and if it has a combinatorial structure, we have to fix whether we are going to focus on the elementary components or on a list of combinations. For instance, in evaluating investment portfolios, we could either consider each single investment (and then possibly try to find an optimal combination) or lists of ready-made combinations proposed by an investment company (and then possibly try to choose one of these).

Set A is described through a set of dimensions D. These represent the relevant knowledge we have about A. Some of these dimensions might have already been introduced in the form of constraints (used in order to fix set A), but other dimensions might be necessary for evaluation purposes, that is they should allow to evaluate the performance of each element of A under certain characteristics. Again the establishment of D requires fixing some formal properties. Each element of D is considered as a form of measurement, therefore the precise structure (X_i) of such a measure should be established ("a measurement scale"). Several types of measurement scales are possible and might co-exist within an evaluation model such as nominal, ordinal, etc (for more details see chapter 3 in this book). Furthermore, set D may have a structure such as a hierarchy. Set D cannot be empty. At least one dimension (the nominal description of A) exists. Usually set D is constructed using set V as a starting point. Typically the construction of D involves structuring V (if necessary) and associating a measurement structure to each element thus defined.

In the case in where a purposeful problem statement has been adopted (such as an optimisation or a ranking one), we then have to construct the set of criteria H to be used for such a purpose. The key issues here are the client's preferences. We define as a criterion any *dimension to which it is possible to associate a preference model, even a partial one, such that the client should be able to make a choice along this single dimension.* The construction of the set of criteria is a central activity in the decision aiding process. Dimensions expressed under "nominal measurement" (dimensions where we only know "labels" of the alternatives, but we are unable to provide any ordering among them) definitely require the establishment of a preference model. Dimensions using X_i endowed with some ordering structure can be transformed directly into criteria using an ordering as a preference structure, but this is rather exceptional. Usually the preference model is an interpretation of the available ordering (consider for example the use of a semi-order as a preference structure for a dimension endowed with a ratio scale) and therefore requires careful elaboration. The reader will find more details in chapter 3. Furthermore, it should be clear that if we are looking for a "rich" (in information) final result (such as an optimal solution), then the preference information ought to be "rich" itself. It should also be noted that the construction of H can be either the result of a direct process (creating criteria from dimensions through direct questioning of the client) or of an indirect process (establishing criteria "explaining" global preferences expressed by the client on examples or already known cases). When several criteria are considered, the first approach is described in more detail in chapter 5, while the second approach is described in chapter 6.

Last but not least, set H has to fulfil a number of conditions depending on the type of procedure that is foreseen to be used in order to elaborate the solution. A basic requirement is separability of the criteria: each criterion alone should be able to discriminate the alternatives, regardless of how these behave under the other criteria. A more complex requirement is the establishment of a consistent family of criteria: a set which contains the strictly necessary criteria and only these (see also chapter 4 in this book). Further conditions can apply, such as independence in the sense of the preferences (when an additive composition of the criteria is foreseen), etc. (for more details, the reader is referred to Keeney and Raiffa, 1976; Roy and Bouyssou, 1993; Vincke, 1992b).

At this point an element which has to be added to the model is the presence of any uncertainty structure $\mathcal{U}$. Uncertainty can be exogenous or endogenous with respect to the model. Typical cases of exogenous uncertainty include the presence of different scenarios or states of the nature under which the evaluation has to be pursued, poor or missing information as far as certain dimensions or criteria are concerned, hesitation or inconsistency of the client in establishing his preference on one or more criteria. Typical cases of endogenous uncertainty include the difficulty to discriminate alternatives in a dimension or criterion due to its ambiguous definition or linguistic nature, the appearance of inconsistencies due to conflicting information in different parts of the model, the impoverishment of the information due to the aggregation of dimensions or criteria. In all such cases the model must contain the appropriate structure for each particular type of uncertainty (if any). It should be noted that choosing a particular representation for a given uncertainty is not neutral with respect to the final result and that the client should be aware of the different results to which such a choice may lead.

The last element to be established within the evaluation model is the precise method $\mathcal{R}$ to be used in order to elaborate a solution to the model. Such a choice is not neutral, since different methods can result in completely different conclusions. Classic decision theory usually neglects this issue since it always considers as given the method (an optimisation procedure).This is however, not generally the case. The choice of $\mathcal{R}$ depends on the problem statement Π adopted in the problem formulation and should depend on two criteria:

- theoretical meaningfulness (in the sense of measurement theory): the method should be sound with respect to the information used. Typical errors in this case include the use of averaging operators on ordinal information, the use of a conventional optimisation algorithm when the cost coefficients are only ordinal, the underestimation of the importance of the independence of criteria when an additive value function is used.

- operational meaningfulness (in the sense that the client should be able to understand and use the result within the decision process). It should be noted that theoretical meaningfulness does not prevent the problem of establishing a useless result (an arithmetic mean of lengths is theoretically sound, but useless if the client is looking for a volume). Typical errors here include the underestimation of the quantity of information required by the client (a simple ranking of the alternatives can be insufficient for the client's concerns) or the aggregation of criteria without verifying their coherence.

A critical aspect in establishing $\mathcal{R}$ is the set of properties each such method fulfils. Each method may satisfy some useful properties, but may also not satisfy some other useful ones. It may present undesired side effects (see Bouyssou et al., 2000)such as non monotonicity, dependence on circuits, different forms of manipulability etc. The analyst should establish a set of properties that the method should fulfil (not necessarily of normative nature, but simply prescriptive ones) and make the client aware of the possible side-effects of the use of a potential method. From this perspective, the axiomatic study of the methods is a key knowledge for the analyst since it allows to have a precise map of the properties each method satisfies (see the discussion in chapter 4).

Furthermore, each method $\mathcal{R}$ requires the use of a number of parameters: some of these directly representing preferential information to be obtained from the client and his/her knowledge, others more or less arbitrary interpretations of such knowledge and depending on $\mathcal{R}$ itself.

The best known example concerns the use of coefficients of importance when several criteria have to be considered simultaneously. Here the client can have an "intuition" on "how important" certain criteria are with respect to others, but the precise formalisation of this concept strictly depends on how $\mathcal{R}$ works (see Borcherding, Eppel, and von Winterfeldt, 1991; Mousseau, 1997). If, for instance, $\mathcal{R}$ is based on the construction of a value function, then such parameters are tradeoffs among the criteria and have to be established together with the value function associated to each criterion. If on the other hand, $\mathcal{R}$ is a majority procedure then these parameters are "power indices" to be associated to potential coalitions of criteria. It is clear that, depending on what $\mathcal{R}$ is and on the available information, the establishment of these parameters requires precise procedures and interaction protocols with the client (see Mousseau, 1995; Mousseau, Dias, Figueira, Gomes, and Clímaco, 2003; von Winterfeldt and Edwards, 1986; Weber and Borcherding, 1993).

The same reasoning applies to other parameters that could be necessary for a given $\mathcal{R}$, such as discrimination thresholds, cutting levels for valued preference relations, cost coefficients and right hand side terms in mathematical programmes, boundaries of categories in classification procedures etc. Most of these parameters are an interpretation of what the client considers relevant for the problem and such an interpretation depends on how $\mathcal{R}$ is defined. Not all interpretations might be consistent with the client's information and knowledge and different consistent interpretations might lead to completely different results. The reader will find further details in section 4.4 of chapter 4.

Although constructing the evaluation model can be seen as a traditional decision aiding activity, on which the analyst's decision aiding knowledge usually focuses, it remains a crucial activity to which major attention has to be dedicated. Several technical choices have to be made here and not all of them are either straightforward or neutral with respect to the final recommendation. The accurate selection and justification of such choices enables on the one hand to guarantee meaningfulness of this artefact and on the other hand to identify the precise reasons why this specific final recommendation has been obtained. from this perspective, a sound construction of the evaluation model is crucial for easy revision and update, as well as enabling a clear justification of its adoption.

2.4.5 Constructing the final recommendation

The output of the evaluation model is essentially a result which is consistent with the model itself. This does not guarantee that this result is consistent with the client's concern and even less with the decision process for which the aid has been requested. As the client and the analyst return to reality they should take at least three precautions before they formulate the final recommendation (to be noted that due to the expected consensus between client and analyst, we consider that the outcome is also considered as "owned" by the client).

Sensitivity analysis. How will the suggested solution vary when the parameters of the model are perturbed? What is the range of values of such parameters for which the solution will remain, at least structurally, the same? A solution that appears to be sensitive to very small perturbations of some technical parameters implies that the solution strongly depends on this particular instance of the parameters and less on the preferential information. Since such an instance can be quite an arbitrary interpretation, a thorough investigation of the model should be conducted.

Robustness. We have already seen that robustness can be conceived as a dimension of the problem statement within a problem formulation. How good will the solution (or the method) be under different scenarios and combinations of the parameters? Being able to show that a particular solution will remain "good" (although perhaps not the best one) under the worst conditions that may occur should be considered as an advantage. Depending on the particular type of robustness considered, it is reasonable to verify whether such a feature holds or not. On the other hand a typical error in robustness analysis consists in testing different methods in order to find out if a certain solution will remain "the best". This is meaningless, since each method provides qualitatively different results that cannot be compared.

Legitimation. How legitimated is the foreseeable recommendation with respect to the organisational context of the decision process (David, 2001; Hatchuel and Molet, 1986; Landry et al., 1996)? As already mentioned, each decision aiding process refers to a decision process that usually occurs within a certain organisation (possibly of informal nature). Coming up with a recommendation that could be in conflict with such an organisation implies assuming risks. Either the client and the analyst explicitly pursue this conflict or they risk wasting time and resources. It should be noted that in considering legitimation, besides its precise contents, we have to take into account how a recommendation is presented, implemented and perceived by the other actors. From this perspective, a valid representation of the problem situation helps in verifying the legitimation.

Establishing the final recommendation implies the return to the reality of the decision process for the client and the analyst. A successful return is not only guaranteed by the scientific legitimation of the final recommendation (theoretical and operational meaningfulness), but also by the capacity of the two actors to take the dynamics of the decision process as well as its organisational complexity into account.

2.5 Update and Revision: an open problem

Conducting a decision aiding process is not a linear process in which the four cognitive artefacts are established one after the other. Since a decision aiding process always refers to a decision process which has a time and space extension, it is natural that the outcomes of the decision aiding process remain *defeasible cognitive artefacts*. Usually the process will encounter situations in which any of the above artefacts:

- may be in conflict with the evolution of the client's expectations, preferences and knowledge;
- may be in conflict with the updated state of the decision process and the new information available.

It is therefore necessary to adapt the contents of such artefacts as the decision aiding process evolves in time and space. see example 2.9 below.

Example 2.9
Consider again the case of the bus acquisition. A client looking for decision support within a problem situation described as: "the client's bus company is looking for a bus". He presents a set of offers received from several suppliers, each offer concerning a precise type of bus (thus a supplier may introduce several offers). The analyst will establish a problem formulation in which:

- $\mathbb{A}$ is the list of offers received;
- V is the list of points of view that are customary in such cases, (e.g., retrieved from past decisions) let's say cost, quality and transportation capacity;
- Π is a choice problem statement (an offer has to be chosen).

It is possible to construct an evaluation model with such information in which:

- A are the feasible offers;
- D are the dimensions under which the offers are analysed: price and management costs (for the cost point of view), technical features (for the quality point of view), loading capacity (for the transportation capacity point of view), etc.;
- H are the criteria that the client agrees to use in order to represent his preferences (the cheapest the better, the more loading capacity the better, better quality resulting from better performances on technical features, etc.);
- there is no uncertainty;
- $\mathcal{R}$ could be a multi-attribute value function provided the client is able to establish the marginal value function on each criterion.

When this model is presented to the client his reaction could be: *"in reality we can buy more than one bus and there is no reason that we should buy two identical buses, since these could be used for different purposes such as long range leisure travels or urban school transport"*. With such information, it is now possible to establish a new evaluation model in which:

- A are all pairs of feasible offers;
- D are the dimensions under which the offers are analysed (price, management costs, technical features, loading capacity etc.), but now concerning pairs of offers plus a classification of the buses in categories (luxury liner, mass transit etc.);
- H are the same criteria as previously plus a criterion about "fitting the demand" since two different types of buses may fit the demand better;
- uncertainty is now associated to the different scenarios of bus use;
- $\mathcal{R}$ could be a multi-attribute utility function provided the client is able to establish the marginal value function on each criterion.

A possible reaction to this suggestion could be the following: *"meanwhile we had a strategic discussion and the company considers that in reality the issue is to find a supplier with whom to establish a strategic partnership considering the expansion of our activities"*. Clearly, not only does the evaluation model makes no sense, but the problem formulation also has to be revised. We now have:

- $\mathbb{A}$ are potential suppliers;
- V concern the suppliers reliability, market share, availability to strategic partnerships, quality record, etc.;
- Π will now become a classification problem statement, the issue being to find out whether each supplier fits the company's strategy.

A new evaluation model has to be built now in such a way that:

- A are potential suppliers;
- D are the dimensions under which the suppliers are analysed (market share, quality certification, history of past supplies, management structure etc.);
- H are the criteria the client agrees to use in order to represent his preferences;
- there is no uncertainty;
- $\mathcal{R}$ could be a multiple criteria classification procedure.

The process may continue revising models and problem formulations until the client is satisfied. ◇

The above example shows that during a decision aiding process several different versions of the cognitive artefacts may be established. However, such different versions are strongly related to each other since they carry essentially the same information and only a small part of the model has to be revised. The problem is: is it possible to give a formal representation of how such an evolution occurs? In other words: is it possible to show how a set of alternatives or some preferential information may change while shifting from one model to another? It is out of the scope of this volume to find an answer to this question which requires further theory on the dynamics of the decision aiding process. We will just mention that the descriptive model of the decision aiding process turns out to be useful since it allows to establish a set of possible problem formulations and evaluation models to be used in different contexts, thus preventing the necessity of re-starting the modelling process from the beginning each time.

2.6 Conclusion

This is a book aiming at helping decision makers, analysts, practitioners and researchers to appropriately use tools and methods of decision support. However, such tools and methods are not independent algorithms and models which we just have to apply to some information to obtain the conclusion. They are used within a stream of interactions structured around a decision process in which an actor involved (the client) asks for advice and support from another actor who becomes involved (the analyst). In other words they are used within a *decision aiding process*. It is therefore necessary to analyse them from the perspective of such a process. Talking about the correct use of such tools, about their meaningfulness, about their legitimation and the usefulness of their results only makes sense with respect to such a decision aiding process.

In this chapter we tried to introduce a general description of what such a decision aiding process is and how it can be conducted in order to pursue meaningful, useful and legitimated recommendations. In order to do so, we first had to show that aiding someone involved in a decision process cannot just be limited to solving a well established formal problem. It concerns a wide set of issues including the understanding of the problem situation in which the client is involved as well as formulating a number of formal problems to choose from. Such concerns are independent of the formal model that is going to be used to elaborate the client's problem. In practice, such concerns are always considered. However, different decision aiding approaches can be characterised by the fact that such concerns are explicitly or implicitly considered as outcomes of the decision aiding approach.

In the chapter we basically introduce two contributions.

1. A model of the decision aiding process based on the description of the cognitive artefacts such a process produces. Indeed, our point of view is that decision aiding is a process in which the actors engaged have to establish a set of shared representations of issues such as:

    - a representation of the problem situation within which the client (and consequently the analyst) are engaged;
    - one or more problem formulations, a formal anticipation of the model to construct, in which the client's concerns are expressed in a "decision support language";
    - one or more evaluation models enabling to elaborate the problem formulation(s) and to establish a conclusion;
    - a final recommendation in which the conclusions of the decision aiding process are summarised, expressed in natural language and prepared to be confronted with the real world (the client's decision process).

2. A number of recommendations on how the above cognitive artefacts can be constructed through interaction with the client. Such recommendations are expected to be helpful in order to:

    - guarantee the theoretical soundness of the result (meaningfulness);
    - guarantee the operational completeness of the result (usefulness);
    - guarantee the legitimation of the results within the client's decision process.

In the following chapters the reader will see how the construction of the evaluation model can be pursued following the above requirements in further detail. More precisely, chapter 3 will discuss how it is possible to establish models of preferences (on a single criterion) and how to use numerical representations of measures and preferences correctly. Chapter 4 gives a general introduction to the problem of aggregating preferences expressed on several criteria or performances established on several dimensions (attributes). Chapter 5 will focus on the use of "procedures" allowing to undertake such an aggregation (and will therefore study the properties of such procedures), while chapter 6 will focus on the use of "models" representing a global preference and how these influence the preferences on single criteria and their aggregation (and will therefore study the properties of such models). Finally, chapter 7 will discuss the problem of constructing the final recommendation, mainly when the result of the aggregation is not directly usable and issues concerning the robustness of such a recommendation.

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