SCENARIO-ROBUSTNESS METHODOLOGY: AN APPROACH TO FLEXIBLE PLANNING UNDER UNCERTAINTY WITH AN APPLICATION TO AIDS-RELATED RESOURCE ALLOCATION

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ABSTRACT

In this thesis the problem of planning under uncertainty is examined. A classification of uncertainty is given with the purpose of identifying those areas where traditional methods for planning under uncertainty fail to prescribe suitable courses of action. Traditional planning methods have increasingly proved inadequate in their handling of the uncertainty inherent in complex and turbulent environments. Methodologies suitable to planning under uncertainty should attempt to preserve future flexibility, by keeping options open for later resolution.

This thesis describes the development of Scenario-Robustness Methodology (SRM), a flexible methodology for planning under uncertainty. SRM uses scenario analysis to develop alternative futures, and robustness analysis to determine the most flexible options under those futures, for both the short and long term. A new criterion is proposed for evaluating the consequences of initial decisions in terms both of the positive options which are maintained and of the undesirable options still left open. This criterion is a composite measure which enables decision-makers to give relative weights to positive outcomes (robustness) or negative outcomes (debility), by varying a key parameter.

A number of alternative measures of uncertainty which may be employed in a planning situation characterized by a set of initial decisions and a set of alternative future scenarios, are also examined. The coefficient of concordance W is found to be the most useful of such measures.

An example is given of the application of SRM to an HIV/AIDS-related resource allocation problem. Planning for HIV/AIDS is selected as a suitable area of application because of the uncertainties surrounding the nature of the disease, the availability of treatments and their timing, and the size of the planned for population. SRM is used to assist in structuring the problem and to identify those initial commitments which are preferable in terms of flexibility. The problem structuring capability of SRM is of particular value since it initiates a process of reflection and negotiation which helps to incorporate in the analysis, in addition to flexibility, other relevant factors which will shape the final selection of an appropriate course of action.

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To my parents

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INTRODUCTION AND THESIS OUTLINE

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INTRODUCTION AND THESIS OUTLINE

The current stage and form of social organization generates problems which make planning essential in the environment of institutional decision-making. Uncertainty, complexity, and conflict are inherent in planning problems and past experiences show that there is a strong need for flexible decision-making.

Businesses and public agencies operate in an increasingly turbulent environment, in which future trajectories of events cannot be predicted with certainty. Striking examples of this volatility include the oil crises of the 1970's, the transformation of the political map of Eastern Europe, successive revolutions in computer technology, the recent NHS reforms, and the emergence of AIDS, to name but a few. Such conditions of uncertainty cannot be accommodated by traditional planning methodologies which were largely developed for the conditions of the 1960's, a period of relatively steady economic expansion. In today's turbulent environment, new methodologies designed to recognize the presence of uncertainty and the possibility of rapid and radical changes need to be developed, so as to enable appropriate and effective responses to be made to the changing circumstances.

The current work presents a new methodology for planning under complexity and uncertainty, and applies it to the problem of planning the provision of health services to persons infected with the Human Immunodeficiency Virus (HIV) and to those who have developed the Acquired Immunodeficiency Syndrome (AIDS). To this end, a microcomputer based model, AIDSPLAN, has been developed as a tool to assist the decision-making process in conjunction with the new planning methodology.

The following chapter deals with uncertainty as a factor which renders traditional methodologies inappropriate for present-day organizational planning, and also with the inflexibility which arises as a result of the implementation of such methodologies, rather than as a result of the structural organization of the activities which give rise to the need for planning. A review and critique of existing traditional planning methodologies is followed by a discussion of the required properties of methodologies for planning under conditions of uncertainty. A review of alternative methodologies which recognize the presence of uncertainty is given with special emphasis on metagame theory and robustness analysis. Finally a set of criteria to evaluate and interpret the results of robustness analysis is proposed.

The need for flexibility when planning under uncertainty is discussed in Chapter 3. Alternative definitions of flexibility are given together with a discussion of flexibility and other properties related to it.

Chapter 4 presents the foundations of a new framework for planning under conditions of uncertainty. This methodology is called Scenario-Robustness Methodology (SRM) and is based on robustness analysis with elements of scenario analysis. Scenario analysis itself is described first, followed by the new methodology.

Chapter 5 proposes a set of measures of uncertainty when a number of initial decisions are considered and where a number of alternative scenarios about the future have been constructed. The most promising of these measures is the coefficient of concordance between system performance under the various scenarios.

The ideas presented in Chapters 4 and 5 are applied in Chapter 7 to an example of HIV/AIDS planning situation, using AIDSPLAN, a decision support system, as an option-scanning tool. Chapter 6 provides the necessary background on HIV/AIDS-related planning, and is divided into four sections: The first of these describes the disease itself, the second discusses available treatments, and the third identifies the uncertainties associated with planning for AIDS. The fourth section discusses HIV/AIDS-related modelling and explains the purposes for which the HIV/AIDS planning model, AIDSPLAN, was developed. This model is described more fully in Appendix I.

Finally, Chapter 8 gives a summary of the thesis and the conclusions reached and identifies areas where further research might be indicated.

CHAPTER 2

PLANNING UNDER UNCERTAINTY

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2.1 Introduction

Definitions of planning commonly refer to it as a process activated by the need to achieve some objective in a formulated or organised method. Both the form and content of planning have been the subject of extensive study over the last thirty years. The form of planning has been examined by planning theory, whereas theory in planning deals with its content. Within planning theory three main positions have been articulated: rational comprehensive planning, disjointed incrementalism, and mixed scanning which, as its name suggests, takes features of both the other two positions.

An examination of the three approaches will point out the weaknesses of both rational comprehensive planning and disjointed incrementalism in handling uncertainty, and will argue that mixed scanning is the most promising alternative. Indeed, this thesis will propose a method for planning under uncertainty which can best be seen as an example of the mixed scanning approach.

We cannot, however, proceed with the development of a method for planning under uncertainty, without making some preliminary remarks about the nature of this uncertainty, and how it influences different planning approaches and methodologies. The first part of this chapter, therefore, will concentrate on uncertainty, examining alternative definitions and classifications. The second section will present and criticize the principal planning theories with respect to their handling of uncertainty, and pinpoint the required elements of a methodology appropriate for planning under uncertainty. Finally, the third part of this chapter will present and discuss two of the less traditional planning methods that have been proposed as appropriate to uncertainty situations, with particular emphasis on robustness analysis, which forms the basis of the methodology which will be proposed in this thesis. Also, in the third part, some possible measures of decision flexibility will be introduced.

2.2 Uncertainty: Definition and Classification

Real-world problem situations are suffused with uncertainty. Authors in a variety of disciplines such as operational research, systems analysis, social policy, social psychology, decision analysis and politics have recognized that uncertainty is the main factor restricting choice. According to Ackoff [1962] a state of doubt in the decision maker as to choice is a necessary condition for a problem to exist. By this definition, some degree of uncertainty is therefore inherent in any problem.

Uncertainty is the situation of not certainly knowing. It is the absence of perfect information about something. However, the degree, kind, and object of uncertainty encountered in problem situations may vary widely. Luce and Raiffa [1957] partition the decision field into conditions of:

(a) Certainty, where each action is known to lead invariably to a specific outcome

(b) Risk, where each action leads to one of a set of possible outcomes with known probabilities, and

(c) Uncertainty, where the probabilities of occurrence of each outcome are unknown or not even meaningful.

In the following section, we present an overview of the dominant paradigm in decision making, and argue that it is inadequate as a normative theory of decision making under conditions of uncertainty.

2.2.1 The traditional model of decision making

The traditional Justificationist (or Bayesian) model of decision making is the dominant paradigm in decision making theory. It is called Justificationist because it attempts to show how at least some choices may be justified. At the centre of this model is the claim that a decision is rational to the extent that it can be justified by the person who makes it. Decisions that cannot be justified may sometimes have to be taken, but the rational person will make decisions s/he can justify wherever s/he can. A decision is justified by being shown to be the best of all options available to the decision maker. It should be noted, however, that an option has no intrinsic value except that which accrues from its consequences.

Three axioms form the basis of the model:

(i) for every set of options A, B, either A is preferred to B, or B to A, or the decision maker is indifferent between the two options.

(ii) only one of these three cases is true for any pair of options.

(iii) if option A is preferred to option B, and option B is preferred to option C, then option A is preferred to option C (Transitivity).

When there is a single decision maker who knows all options open to her/him and who knows all the consequences which each option would have if chosen, then decisions fall within the <u>certainty</u> classification. The decision maker should:

(i) list all the consequences of each of the options which are available

(ii) place the consequences in order of preference

(iii) choose the option with the most preferred consequence.

Decisions under <u>risk</u> are the ones where the consequences of at least one of the options are not known with certainty, but a list of possible consequences may be drawn up and assigned a probability distribution. Then the decision maker chooses the decision which maximizes her/his expected utility.

To assign a probability distribution, certain statistical information has to be available. In some cases, information of this sort may not exist, or worse, may not even be possible. Such cases may be the introduction of new technology, launching of a novel product, developing cures for new diseases etc. A decision of this sort is said to be under uncertainty. Bayesian decision theory suggests the use of subjective probabilities to replace the missing information. Then the decision maker can choose as if s/he were deciding under risk conditions.

In the case of a single decision maker with multiple conflicting objectives, the traditional paradigm offers the application of multi-attribute utility theories (MAUT). Almost any important decision engages multiple values. Sometimes these may go together, but the tough problems arise when, within the set of options available, doing well on one value requires doing poorly on another. Rarely does luck offer an option that is simultaneously best on them all; trade-offs must be made. Trade-offs are judgements which depend on the decision maker's assessment of the relative desirability of the available options on each dimension and on his/her feelings about the relative importance of these dimensions. Trade-offs are subjective; there can be no objective or universal rules for making them.

All MAUT procedures include the following 5 steps :

1. Define options and value-relevant attributes
2. Evaluate each option separately on each attribute
3. Assign relative weights to the attributes
4. Aggregate the weights of attributes and the single-attribute evaluations of options by means of a formal model (either additive or multiplicative) to obtain an overall evaluation of options
5. Perform sensitivity analyses and make recommendations.

All approaches are essentially identical in steps 1 and 5. They differ in the procedures for single attribute evaluations (step 2), in the techniques for weighting (step 3) and in models for aggregation (step 4). Von Winderfeldt and Edwards [1986] give a comprehensive discussion of the available alternatives in each step.

Collingridge [1982] argues that the Justificationist model, even when it is expanded to accommodate cases of conflicting objectives and multiple decision makers, is still operational only under very restricted conditions. The reasons he puts forward are the following:

1) All states of the world must be identified. They must be mutually exclusive and exhaustive. In real world decisions the problem is not how to ascribe probabilities to the states of the world, but rather to identify what states of the world are relevant to the decision.

2) All options must be identified. A decision maker who has not considered all the options open to her/him should place a premium on options that are easily revised so that s/he may improve her/his decision if a superior option is discovered in time. This is an additional factor to the conventional one of expected utility and some trading between ease of revision and expected utility may be required. It is very difficult to see how this could be accommodated within Bayesian methodology.

3) All pay-offs must be known. But pay-offs (consequences of decisions) can be known only if a set of options that is known to be complete is considered. Not only must the set of options be complete, and all states of the world identified, but a utility must be assigned to every option/state of the world pair, except where sensitivity testing can marginally reduce the severity of this condition.

4) All relevant information must be collected. Since information has a decreasing marginal expected value under risk, there comes a point where the decision maker stops collecting information and chooses on the basis of the information already collected. Under uncertainty, however, qualitative information may be needed, and it may prove impossible to make sure that all information that is relevant has been collected. Bayesian methods are nevertheless often applied to such decisions, using what relevant

information has been identified. This is inappropriate. A decision maker who cannot be sure that all significant information has been gathered should rather favour options that are easily revised, so that s/he may improve her/his decision if more information is discovered between her/him taking it and its full implementation.

5) All interpretations of data must be examined. Data are the raw unanalyzed observations, which become information when analyzed and interpreted. For any set of data there are always many, mutually incompatible interpretations. For decisions under uncertainty, rival interpretations of data may not just be theoretically possible but may be a central feature of the decision problem. Even if there is a rule to select the best interpretation available, there is no way to ensure that this is the best of all interpretations. As before, ease of revision becomes a factor in the decision together with maximization of utility or expected utility.

Collingridge therefore makes a proposal to change the spectrum of certainty/risk /uncertainty to certainty/risk/restricted uncertainty/*ignorance*. Ignorance covers all decisions where Bayesian techniques cannot be applied because the above conditions do not hold. Restricted uncertainty covers decisions where subjective probabilities may be employed and where all the conditions are met, so that Bayesian methods can be used.

2.2.2 Sources of uncertainty

In this section three factors contributing towards the uncertainty which surrounds a planning situation will be discussed. The first is the availability of information, the second is time, and the third is the presence of conflict.

When dealing with uncertainty, a distinction should be made between things we cannot know and things we could know or learn more about if a reasonable effort was made, both now and in the future. For example, the size of the AIDS epidemic is uncertain because, among other things, we cannot know what is or will be the future behaviour of people belonging to high risk groups. We cannot know if or when our competitors are going to launch a new product. Of course, there are different reasons why knowledge about something cannot be obtained. There could be observational problems by nature, or even conflict of interests: in the case of competitive companies, secrecy about future plans is often essential. It could be argued that the collection of information could help to reduce uncertainty. However, whenever a decision whether to collect information or not arises, there are numerous factors that have to be considered, such as the size, cost and complexity of such an exercise, the organization's priorities, the necessary selection of the separate data items, etc. When all these factors have been considered, the effort might seem unreasonable.

Time is also a differentiating factor. Already existing situations can be shrouded in uncertainty since it can be very difficult or expensive to get more information about a question, or the available tools and methods may be inadequate, or the resources may be scarce. As mentioned before, this type of uncertainty can be partly resolved by assigning more resources or developing new tools. Uncertainty about the future is more difficult to tackle since the events we try to predict have not yet taken place. Again, the development of new tools may partly abolish some of the uncertainties. However, the more important "hard" uncertainties and surprises will still remain.

To illustrate this, we may use the example of AIDS. There are various estimates of the number of people who are currently infected with HIV, but there is uncertainty concerning the actual number. Sophisticated projection methods can eliminate part of the uncertainty, that is they can put upper and lower bounds to this number with varying degrees of confidence. Future numbers depend not only on current numbers but on unknown factors such as behavioural trends. Behavioural studies combined with current estimates can produce ranges of future forecasts. However, fifteen years ago, the emergence of the disease itself was not anticipated and there was no way one could have predicted it, although there is proof today that some earlier deaths from unknown causes were due to AIDS. Shackle's principle of expected surprise applies in this example. If the doctors who tried to find the cause of death of a patient from AIDS before the disease was discovered, had added to their list of alternatives a "residual cause" they would not be surprised to find later that the actual cause of death was an unknown syndrome. They would be however very surprised to learn the nature of AIDS itself.

In some situations the prevailing uncertainty is due to conflict between interested parties. The resulting uncertainty can have two facets. It can either be uncertainty about whose views will prevail or uncertainty which is internal to one or more players; even in the case of one decision maker conflict can exist. This happens when goals are not simultaneously achievable. To correctly identify the source of the uncertainty in a conflict situation and devise appropriate remedies we should distinguish between three types of conflict:

1) Internal conflict. Internal conflict applies to the case of a single decision maker, either a group or a person. In the event of a group, it is assumed that the persons that comprise it have common interests, agree on their objectives unanimously, and take up concerted action. In such situations conflict is confined to mutual incompatibility of the objectives. Even in this almost ideal situation, where the members of the group agree on a set of objectives, it does not follow that these can be achieved simultaneously. Decision analysts have used extensively methods known as multiattribute utility techniques or theory (MAUT), which have already been described in section 2.2.1, to deal with this kind of conflict. These techniques, however, are appropriate for resolving the simplest form of internal conflict, which can hardly constitute a problem once priorities are set and agreed upon.

A more complicated form of internal conflict is moral conflict, or conflict of values. Dewey and Tufts [1932] distinguish between two kinds of moral struggle: one is when the individual is tempted to do something which s/he is convinced is wrong. The other is when there is a struggle between values each of which is an undoubted good in its place but which may get in each other's way. The moral struggle in the first case, is a struggle against temptation. There is no doubt as to what should be done. In the second case, the agent is undecided as to what s/he ought to do. Levi [1986] claims that in this case inquiry, and not therapy is required to address the issue at hand.

Davidson's discussion of weakness of will [1980] states that all occasions where strength of will is demanded arise when there is moral conflict in a "minimal sense", which exists "whenever the agent is aware of considerations that, taken alone, would lead to mutually incompatible actions". Davidson's cites as illustrations of moral conflict in this sense situations that coincide with Dewey and Tufts' moral struggle of the second kind. The most common example of this situation is the case of the pacifist who is called to join the army and eventually fight in a war. In this case, pacifism and patriotism, the two principles that the agent endorses, recommend incompatible actions.

Davidson asserts that very little attention has been paid to this problem and two unsatisfactory solutions have been presented: the first insists that there is only one ultimate principle, and the second denies that the allegedly conflicting principles prescribe actions which are not jointly feasible. Davidson thinks that the agent should determine which option is prima facie best, relative to all the known relevant factors.

The difference between the views of Dewey and Davidson concerns the analysis of conflict. Dewey and Tufts maintain that the agent, instead of choosing the best prima facie option, should recognise that he does not know what should be done and acknowledge that this predicament is an appropriate occasion for moral reflection and inquiry. Although Davidson's account of weakness of will is consistent with recognising the possibility that when all the relevant considerations are taken into account there is no uniquely permissible value ranking of the feasible options, he nowhere acknowledges this possibility. To the contrary, he seems to think that contexts of moral dilemma are precisely the occasion where challenges to willpower arise. This is considered by Levi as false. When moral conflicts arise, because the relevant moral considerations yield conflicting prima facie recommendations, it will usually be the case that there is no clear prima facie recommendation if these moral considerations are taken together. Further inquiry will be needed.

2) Conflict between multiple decision makers. Let us now consider the more organizationally relevant example of a situation with multiple decision makers. Obviously, conflict of interests can arise between departments and individuals in the organisation. As Rosenhead [1989a] put it: " An organisation is not an individual ... Decisions and actions emerge out of interactions between a variety of actors internal to the organisation. Each may, indeed will, have an individual perspective or world-view (*Weltanschauung*) through which the actions and statements of others are interpreted." Each actor may define the problem, the objectives and the required actions quite differently. In this case, the application of techniques which facilitate communication is relevant. Cognitive mapping, a technique incorporated in the Strategic Options Development Analysis (SODA) method [Eden 1989], described briefly at a later section of this chapter, is such a technique.

3) Conflict in a multi-organisational context. This type of conflict arises when there is direct conflict of interest between organisations, such as occurs between companies producing competing products. It can arise, even if the objectives of both organisations or collective bodies are common. Take the example of political parties: at least one of their objectives is common. It is, or should be, the welfare of the country. Yet, they have completely opposing views on how this is to be achieved and by whom.

This last type of conflict includes the previous two since the participants are organisations which are aggregates of individuals. The boundaries between conflicts of types 2 and 3 are somewhat blurred. Indeed, if the groups of individuals or the departments within the organisation are to be viewed as micro-organisations, the two types of conflict reduce to one. There is, however, a difference: although nobody expects the departments of the organisation or the individuals to have exactly the same views, it does not automatically follow that these views will be directly conflicting as in type 3.

Although conflict of the first type has been discussed extensively , it is a subject that falls in the territory of philosophers and psychologists. The present analysis will concentrate on the other two types of conflict and discuss methods that have been proposed to deal with such situations while avoiding to use conventional tools and techniques, whose inappropriateness will be discussed elsewhere in this chapter.

2.2.3 Classification of uncertainty

There are a number of alternative bases for classifying uncertainty. In this section we will present those attempts at such classification which could be relevant in structuring a planning problem.

Dror [1988] makes a distinction within uncertainty, differentiating between quantitative uncertainty, that is when the outcomes are known but their probability distribution is unknown, and qualitative uncertainty where the outcomes themselves are not known. Dror says that qualitative uncertainty characterises what he calls explosive situations. He also makes a distinction between "hard" and "soft" uncertainties based on the criterion of predictability. It should be noted though, that the criterion is used in terms of its presence or absence rather than in terms of its measure. "Hard" uncertainties are inbuilt in the dynamics of the phenomena which behave in an indeterminate random mode, and where prediction methods are not applicable. On the other hand, "soft" uncertainty characterises phenomena the dynamics of which follow some orderly pattern, but there is incomplete knowledge about this pattern. "Soft" uncertainty can be compared with quantitative uncertainty, whereas "hard"-uncertainty is of the qualitative form. Soft uncertainties may also be called unreduced uncertainties in contrast to hard uncertainties which may be called irreducible uncertainties. Dror also uses the concept of ignorance based again on the criterion of predictability, but in this case the presence or absence of predictability itself is unknown.

Ravetz and Funtowicz [1990] argue that to approach the problems of uncertainty, a distinction should be made between the sources and the types of uncertainty.

Classification by sources is normally done by experts in a field when they try to comprehend the uncertainties within their particular practice. But for a general understanding, we have to distinguish among the technical, methodological and epistemological levels of uncertainty; these correspond to inexactness, unreliability and the "border with ignorance". Ignorance can be compared with the mathematical infinite. In such a context we can speak of "usable ignorance", that is when we are aware of the extent of ignorance, and recognize its dynamic interaction with knowledge.

Friend and Jessop [1969] have identified three types of uncertainty which can beset long-term planning: uncertainty as to the Environment (UE), uncertainty as to values (UV) and uncertainty as to the actions of decision makers in related fields of choice (UR). This classification in Ravetz's terms could be seen as a differentiation according to the sources of uncertainty and not according to its type. This fact though, does not reduce the practical effectiveness of this classification.

Pye [1978] matches these three types of uncertainty to an extension of the fundamental model which Ackoff [1962] proposed as underlying all models for problem solving. This formulation is

$$\upsilon = f\ (\mathbf{x},\mathbf{r},\mathbf{e})$$

where υ is the measure of the value of the decision made, **x** is the vector of variables subject to control in the decision considered, **r** is the vector of variables subject to control by the decision maker but not in the decision considered, and **e** is the vector of variables not subject to the decision maker's control. UE, UV, and UR concern uncertainty about **e**, f, and **r**, respectively. We could argue here that UR does not exactly correspond to uncertainty about the **r** variables, since UR refers to actions of decision makers in related decision fields which could be outside the decision maker's control in all cases. A relevant example could be the introduction of government legislation. In this case UR could refer to variables in **e** rather than **r**.

Another classification of uncertainty similar to Friend and Jessop's has been proposed by Hopwood [1980], who claims that uncertainty may be of two types: uncertainty as to objectives, and uncertainty about the consequences of actions resulting from decisions. Figure 2.1 shows what form of decision processes are relevant according to the level and type of uncertainty. When both types of uncertainty are low, computational methods can be used. When only uncertainty about consequences is high, an approach which involves judgment is necessary. Conversely, when only uncertainty over objectives is high, negotiations are needed to produce consensus; this is a case for bargaining. However, in problems where both types of uncertainty are high, decisions are taken on an inspirational basis; this is an area for entrepreneurial thinking.

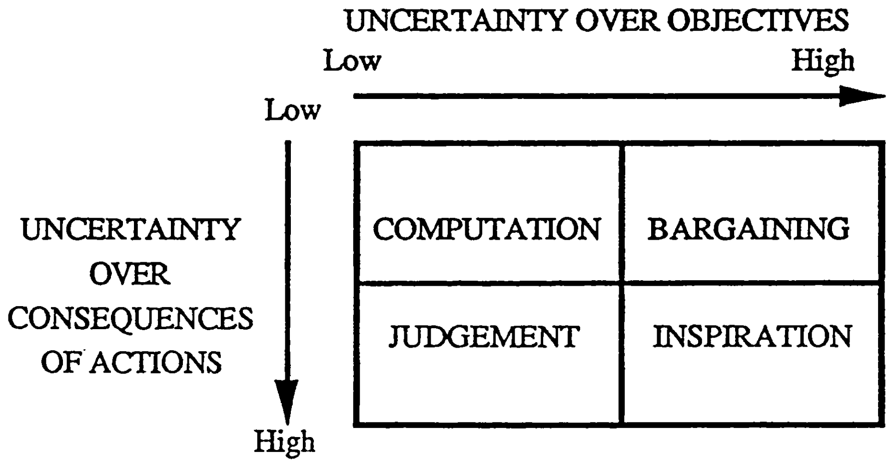

Figure 2.1: Uncertainty and decision making processes according to Hopwood

Hopwood's uncertainty over objectives can be compared with Friend and Jessop's uncertainty as to values. They both include the element of the present and the future: our objectives reflect the future we desire, but this is often determined by our current perception of the world. Consider the example of a district hospital which treats patients with AIDS; an objective might be to discourage non-residents from requesting treatment, so that the workload does not increase to an uncontrollable level. The relative weight of this objective over another depends on subjective judgment about the severity of the problem now, and on the estimate of the current and future in-flows of patients. But then, according to Friend and Jessop, the correct figure for the current inflows can be considered as an uncertainty about the environment. We can therefore see that uncertainties can fall into more than one of the Friend and Jessop classifications. In this aspect Hopwood's categorization seems to have an advantage, as it distinguishes clearly between uncertainties over what we want and uncertainties over how to achieve it, i.e. the subjective and the objective. The methodology proposed in this thesis will concentrate mostly on uncertainty over consequences of actions, or according to Friend and Jessop's classification, uncertainties pertaining to the environment and to actions of related decision makers, without completely ignoring uncertainty over objectives or values.

Figure 2.2 displays the relationships between Friend and Jessop's and Hopwood's classifications according to the source of uncertainty.

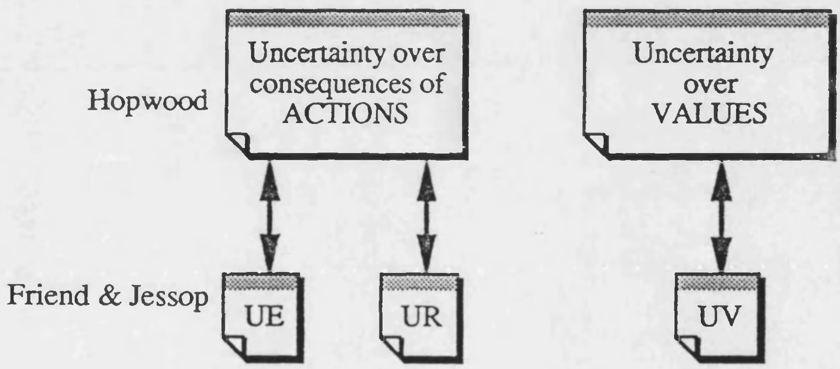

Figure 2.2: Relationships of uncertainties according to their source

The spectrum of uncertainty proposed by Collingridge consisting of certainty / risk / restricted uncertainty / ignorance can be further modified by considering surprises. Dror [1988] defines surprise events as events with a very low chance of occurring. It can be argued that since surprise presumes the element of the unexpected, a very low probability event cannot produce surprise, because the outcome was originally considered as possible, and a probability, however low had been assigned to it. Shackle [1953] explains the paradox of expecting a future surprise although surprise is what one feels when the unexpected has occurred. He supposes that an individual can only be surprised by an unexpected event, that is one that was never formulated in the individual's imagination, and not by a counter-expected event which is an outcome that has been considered at some point and then rejected. When considering a set of rival hypotheses, an individual will have to include a residual hypothesis to make it exhaustive. This residual hypothesis will be a recognition of the non-exhaustiveness of the list of the precisely stated hypotheses. If the residual hypothesis has been assigned zero potential surprise, the individual can both expect the outcome to fall under the residual heading and the outcome's character in detail to surprise him. The recognition therefore of imperfect knowledge can lead individuals to expect surprises in the sense that the nature of the outcome was never conceived. In those terms surprises are of the same nature as "hard" uncertainties.

The various degrees of uncertainty are mapped in Figure 2.3 using predictability as a criterion:

CERTAINTY	RISK	UNCERTAINTY		IGNORANCE
		RESTRICTED, "SOFT" UNCERTAINTY, KNOWN OUTCOMES	"HARD" UNCERTAINTY, UNKNOWN OUTCOMES, SURPRISES	

PREDICTABILITY

Figure 2.3: Degrees of Uncertainty

In the case of "hard" uncertainty and ignorance the arrow of predictability is dashed, which denotes that in these cases predictability is either absent ("hard") or there is no knowledge about its presence or absence (ignorance). Restricted uncertainty as termed by Collingridge falls into the "soft" uncertainty category. It is with the latter two elements on the uncertainty spectrum, "hard" uncertainty and ignorance, that the methodology to be developed in this thesis is concerned.

2.3 Review of planning theories

Before discussing any planning theory, we must clarify the concept of planning itself. At this point, therefore, we will examine different definitions of planning and attempt to give a definition.

Hall [1974] writes that "Planning is concerned with deliberately achieving some objective, and it proceeds by assembling actions into some orderly sequence". Other definitions refer to planning as: "the laying out of a course of action that we can follow and that will take us to our desired goals" [Churchman 1968]; "a process of strategic choice, requiring a capacity to anticipate the future and yet also to adapt to the unforeseen" [Friend and Jessop 1969]; "a process of human forethought and action based upon that thought" [Chadwick 1971]; "the process of preparing a set of decisions for action in the future, directed at achieving goals by preferable means" [Dror 1973]. Planning, therefore, must be seen as a process activated by the need to achieve some objective. The outcome of this process is the plan which is a description of a formulated or organised method by which the objective is to be achieved.

All definitions given above use the words "objectives", "goals", "thought" and so on without referring to any particular "objective", "goal", etc. At the same time, these words acquire a substance of their own , and in this way they become objects about which theories can be built. They become therefore the objects of planning theory.

Theory of planning or planning theory is concerned with theories of the planning process, that is procedural theories. The distinction between theory of planning and theory in planning must be borne in mind when examining these theories; the first deals with questions concerning the form of the planning process, whereas the other examines the content of planning policies.

There are two major positions in planning theory, rational comprehensive planning, and disjointed incrementalism. The incrementalist approach, in contrast with rational comprehensive planning, views planning as a dynamic process where decisions have to be taken sequentially. Both approaches however, have been extensively criticised, and alternative planning concepts and methodologies have been proposed. The most well known alternative approach is mixed scanning. The three approaches will be discussed next.

2.3.1 Rational comprehensive planning

Under rational comprehensive planning, a set of values or objectives is identified and agreed upon. Then, the opportunities of action are listed, the consequences of each course of action are identified, and the "best" course of action is selected on the basis of maximising the objectives. The term rational owes its presence to the fact, or better to the assumption, that decision-makers make rational choices, whereas the concept of comprehensiveness implies complete evaluation of all the available alternatives. However, this is not the only implication: the requirement of comprehensiveness may also refer to the attempt to satisfy all goals of the various interest groups, or to the idea that equal importance must be given to all elements of the area of concern, and the examination of these elements in the same degree of detail. Since rational comprehensive planning implies a highly structured and formalised planning process and stresses the issue of professionalism which distinguishes planners from routine administrators, it was widely adopted and for an extensive period held the dominant position in planning theory.

The major criticisms of rational comprehensive planning question the feasibility of achieving both rationality and comprehensiveness, and doubt the claims made for its scientific status. For the successful application of the method, consensus on the set of values to be maximised is a prerequisite. However, planners' perceptions of the relative merits of each objective are very likely to differ. These disagreements can range from different opinions on the rankings of the objectives up to inclusion or exclusion from the set. Moreover, the "professionalism" and the resulting "objectivity" which is supposed to characterise the resulting plans are heavily questioned. Planners, even if they are hired professionals and not members of the organization's manpower, are seldom detached from the political activity of policy-making. Personal views and pressure from sponsors, trigger processes of bargaining and compromise to reach agreements on key issues.

Comprehensiveness implies that the planners have complete knowledge of their field, but the identification of the consequences of each action requires the acknowledgement of the presence of uncertainty about key factors. However, under rational comprehensive planning there is no such provision. The collection of large amounts of data can only deal with some types of uncertainty, and such an investment could be either very cumbersome or even infeasible. Moreover, the assumption that the decision-makers have full control of the factors affecting their decisions and the power to implement them is often quite wrongly made. Most of the time there is no guarantee that once a decision has been made it will be implemented as well. Again, uncertainty about external influences is not to be ignored. The concept of risk may be included in the method, but then again, the problem of uncertainty is by-passed by attaching subjective probabilities to the possible outcomes. As will be discussed in a later section, attempts to abolish uncertainty by applying probabilities may have disastrous consequences since the idea of a total surprise is being ignored. Methods such as scenario or robustness analysis have been considered as more appropriate in high uncertainty situations.

Comprehensiveness also refers to the effort to maximise the selected objectives. Unfortunately, sets of objectives which are simultaneously maximised are seldom found. The more common case is that of conflicting objectives. As will be seen later, various strategies have been proposed as appropriate to this situation.

Those in favour of rational comprehensive planning argue that its technique-orientation produces "scientific" and hence "objective" results and recommendations. A counter-argument, however, is that techniques are simple tools that can be open to manipulation and can be used in a variety of ways to produce contradictory results. It should also be added that since each planning case is unique in the circumstances that define it, it is impossible to test and evaluate the plans using objective measures as can be done when scientific methods are applied to other types of problems.

It has been argued [Camhis 1979] that rational comprehensive planning is closely related to verificationism- a philosophical position that stresses induction. In both systems (philosophy of science and theory of planning) the evaluation principle is the same, namely the amount of agreement, either with accepted facts (philosophy of science) or with accepted values that acquire the status of facts (planning). In philosophy of science, verificationism has been attacked and successfully overthrown by Popper's falsificationism. In a parallel way, rational comprehensive planning has been attacked by incrementalism which draws upon falsificationism.

2.3.2 Disjointed incrementalist planning

Disjointed incrementalist planning has emerged as a major critique of rational comprehensive planning [Braybrooke and Lindblom 1963; Lindblom 1965]. The main areas of criticism are the unattainability of rationality, goal directed action and comprehensiveness in the planners' knowledge and efforts. Indeed, as already discussed above, the assumptions of non-conflicting objectives, consensus of opinion, full understanding and control of the planning field, are extremely weak in complex situations.

Incrementalists attach more importance to the planning process itself, which they see as a political activity which develops through a gradual process, where advocates of particular views compete with others to have their ideas adopted. They recognise the pluralism of various interest groups and the influence they exert to determine outcomes. The approach does not attempt to pre-take all decisions necessary to achieve the required end result, but instead subjects them to continuous adjustment. The test of a"good" policy is agreement on that policy itself, which is claimed [Lindblom 1959] to be possible even when agreement on values is not. Incrementalism favours remedial policies, and choice between alternatives is made in marginal analysis terms. Hence, this approach considers only policies similar to the currently adopted one and attempts gradual change to achieve better results in terms of limited objectives.

Although incrementalism is more practical and acknowledges human limitations, the role of politics and the need for flexibility, it still has considerable weaknesses [Etzioni 1967; Dror 1968; Faludi 1973]. By considering policies close to the current one, it excludes the possibility of radical change which could be advisable in turbulent environments. For the same reason, it has been criticised as favouring the status quo and those who have power. Therefore, although it is more flexible compared to rational comprehensive planning, it still remains a "conservative" approach, inappropriate in many planning situations where the results of existing policies are not satisfactory.

Lindblom has also been criticised for replacing validity as a criterion for decisions with agreement [Faludi 1973]. The incrementalist approach draws from Popper's falsificationist scientific method, in that a theory is never verified; after being tested against the facts, with aim of refuting it, it can become at most well corroborated. In the same way, Lindblom is extremely sceptical about the possibility of basing decisions on valid knowledge since this knowledge can never be verified. Faludi [1973] argues that a complete replacement of valid knowledge by agreement is wrong, and that policy makers who disregard such knowledge are liable to be unsuccessful in achieving their objectives, no matter whether they have achieved agreement on policies or not. This is because agreement between different interest groups to the same policy can be reached for different ends, but not for conflicting ends. He further argues that planning policies cannot be based on analytical knowledge alone; both political agreement and knowledge are important, and neither can be neglected without detriment to success in planning.

2.3.3 *Mixed Scanning*

The mixed scanning planning methodology was developed by Etzioni [1967] as an attempt to circumvent the limitations of rational comprehensive planning and incrementalism while preserving the advantages of both methods. This methodology regards planning as being conducted at two levels, hence the term "mixed". General directions are laid down at the strategic level, whereas specific policies and actions are examined in more detail at the incremental level. In this way, at the strategic level the pitfalls of rational comprehensive analysis can be avoided, but without the restriction to consider only policies similar to that currently adopted, as the incrementalist approach suggests. Separate issues concerning the implementation of the selected policy that need further investigation can be explored at a higher level of specificity, without encumbering the whole of the analysis by considering all aspects in detail. Mixed scanning claims universal applicability, both as a description of the existing situation and as a normative approach. This alleged universality is achieved by being flexible "through changes in the relative investments in scanning in general ... and among the various levels of scanning"[Etzioni 1968].

Camhis [1979] argues that this claim of universality and the apparent flexibility becloud the methodology's inability actually to define the criteria needed to evaluate alternative courses of action and to select the one to be adopted. Etzioni fails to mention how the consequences of various alternatives are derived. Moreover, he contradicts himself by claiming that an alternative must be selected on the basis of an agreed set of values, when the reason he gives for rejecting rational comprehensive planning is that social decision-making centres frequently do not have such an agreed set of values [Etzioni 1968:218]. Camhis further argues that the universality also comes into contradiction with the narrow outlook of the approach: although Etzioni shifts the emphasis towards action, he restricts the meaning of planning to the rather limited context of decision making. It is however, with the decision making part of planning that this thesis is mostly concerned. The methodology which will be proposed in this thesis deals with decision making while bearing in mind the wider issues of the form that planning takes. In this context, Etzioni's approach is quite appropriate.

2.3.4 Required elements of a methodology for planning under uncertainty

The main positions in planning theory and their limitations have been examined in the previous sections. It was argued that mixed scanning is the most promising alternative. In this section we will examine the required elements of a methodology for planning under uncertainty, by drawing on experience from past Operational Research (OR) practice.

Definitions of planning have common elements with definitions given for operational research. Operational Research has been defined as "the application of the methods of science to complex problems arising in the direction and management of large systems...The purpose is to help management determine its policy and actions scientifically" [Eilon 1975]. The purpose of conducting OR analysis is the same as that of planning: to suggest to management a way to achieve its objectives. The use of scientific method is common in both practices. Faludi [1973] writes that "planning is the application of scientific method, however crude, to policy-making", and comments that the same definition has been given for operational research [Beer 1966]. Faludi claims that this underlines the generality of the phenomenon of planning and its wide applicability.

When dealing with ill-formulated social problems, where the information is confusing, there are conflicting values and the ramifications of the whole system are confusing, in short what have been called "wicked" problems [Rittel and Webber 1973], the boundaries of planning and Operational Research become blurred. It can be argued that in these cases, conducting Operational Research is the same as engaging in planning and vice versa. This may be considered by some as an over-ambitious statement; this is because Operational Research tends to be confused with the application of some of its better known techniques. It must be remembered, however, that Operational Research is the use of scientific thought to a problem irrespective of the methods developed to tackle its particular aspects.

The above argument suggests that theory of planning should be of relevance to Operational Research. The dominant paradigm in planning theory, rational comprehensive planning, has many common aspects with the traditional OR paradigm. It can even be argued, as mentioned above, that conducting OR is the same as engaging in planning. Criticisms, therefore, aimed at either paradigm may be relevant to the other as well.

The appropriateness of traditional planning methodologies in situations of high complexity and uncertainty has been extensively questioned [Rosenhead 1978a; Rosenhead 1980a; Rosenhead 1980b; Jackson 1987]. The traditional methodologies usually involve the application of "hard" or "mainstream" Operational Research techniques, which are usually targeted on the optimisation of a single objective or of several objectives transformed into a single one.

However, when planning in the environment of a large organisation, especially in the public sector, the existence of multiple, vague, and often conflicting interests, of political debate, and of different perceptions of the problem situation, must be recognised as an indisputable reality. Even in the case of a single decision-maker, objectives may not be consistent or may change with time; in addition, when dealing with non-trivial problems, multiple decision makers are the rule rather than the exception. The existence of a variety of objectives, some of them in conflict with each other, is also an inherent condition in complex situations. Clearly, an optimising approach requires explicit trading-off between objectives, a procedure often infeasible because of the vagueness of objectives, or simply undesirable. On the other hand, a "satisficing" approach may help to by-pass the need for explicit trade-offs.

Moreover, the traditional methodologies tend to produce models highly dependent on the quantification of qualitative aspects, which therefore both lack in credibility and pose overwhelming data demands. Considerable effort must be devoted to collecting detailed data where rough measures of key factors may well turn out to be more relevant. These methodologies also assume that the decision maker(s) has complete control of all the variables of the problem, they produce "solutions" which ignore the underlying uncertainty, and consequently propose inflexible plans [Best et al. 1986; Rosenhead 1978a].

"Classic" techniques require top-down implementation, in which the lower tiers are expected to comply with higher level decisions. This is a direct consequence of the opacity of the techniques used and the - often mistaken - assumption of the single decision maker with well defined objectives. Top-down implementation results in bureaucracies where the planning process is slow-moving and cumbersome. Sectoral attempts to revise particular decisions are discouraged, and the organisation's response to unexpected changes is slow. On the contrary, a less technically oriented, transparent methodology will facilitate participation of actors internal to the organisation, and the much desired but often wrongly assumed consensus can emerge more easily. Such attempts have taken place recently in many organisational environments. As reported by Ferlie and McKee [1988], there has been a shift in the National Health Service (NHS) towards "local learning" instead of "top-down" implementation of a national change agenda.

A final point for the implementation of techniques which facilitate participation, is that the latter recognise the role of people as active subjects and not as machines. Since OR deals with purposeful systems of human and social activity, such techniques would be beneficial.

Figure 2.4 summarises the above and offers a comparison of the characteristics of the traditional and the alternative paradigms of OR.

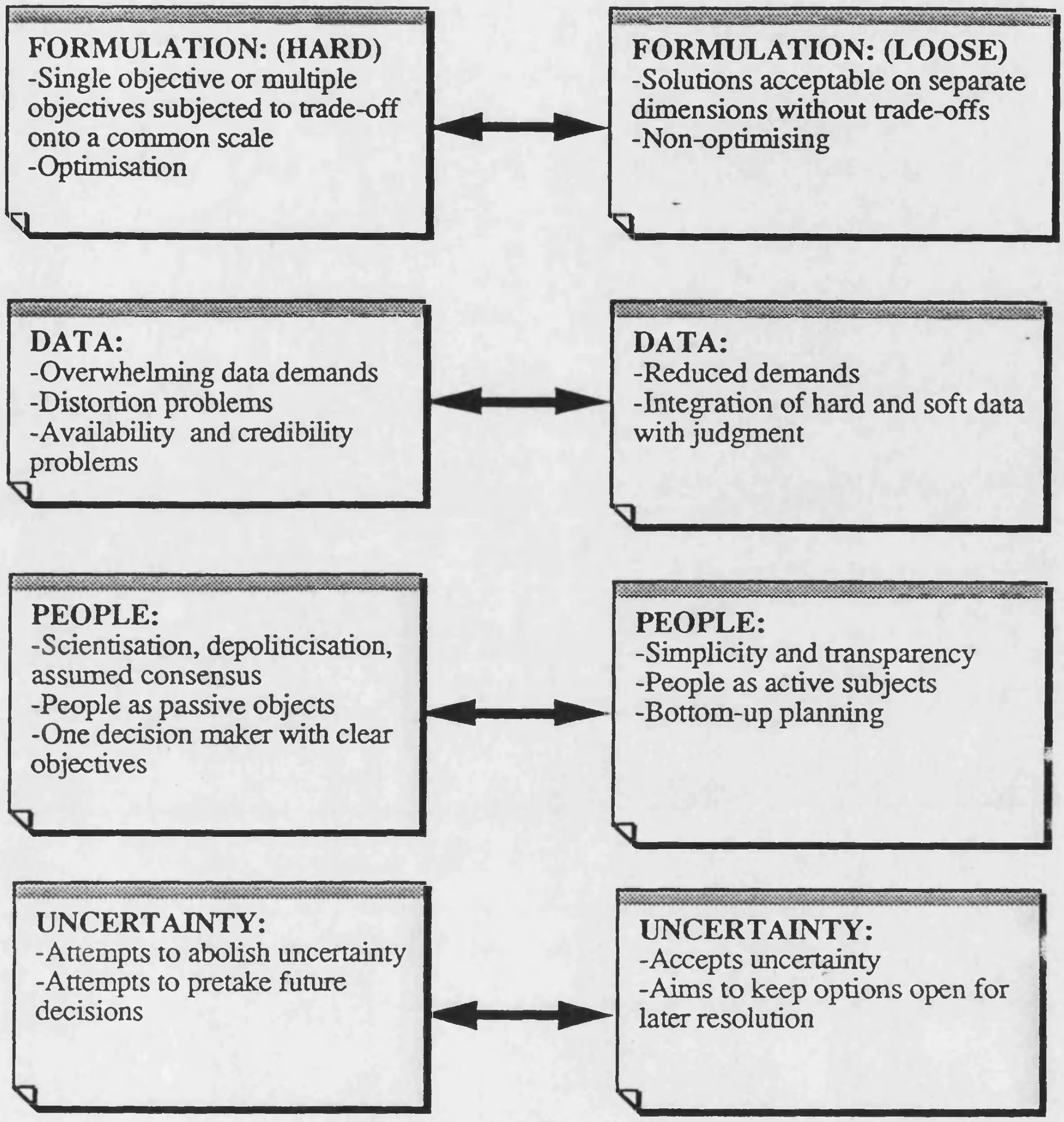

Figure 2.4: Dominant vs an Alternative OR Paradigm

In the absence of uncertainty about the present situation and future developments, problems can still be successfully tackled by using traditional techniques to transform the different objective measures onto a common scale of value. The presence of uncertainty however, calls for the development of alternative methodologies in order to preserve flexibility, which, in contrast to the traditional principal criteria and methodologies, will not aim at the reduction of uncertainty [Rosenhead 1980a]. Uncertainty is an inherent condition in most complex problems and any attempt to abolish it, may well result in irrelevant recommendations, which when implemented can have disastrous consequences. Summarising the above, we can say that a methodology for flexible planning under uncertainty, should be bottom-up, non-optimising, facilitate participation, accept uncertainty, attempt to keep future options open and aim at a loose fit on the planned for activities [Rosenhead 1980b].

2.4 Alternative planning methods

Alternative criteria and methodologies which allow for uncertainty and accept its presence have been proposed. These attempts "to live with uncertainty" include soft systems methodology [Checkland 1981; 1989], cognitive mapping and strategic options development and analysis (SODA) [Eden 1989], the strategic choice approach which incorporates the AIDA technique [Friend and Jessop 1969; Friend and Hickling 1987; Friend 1989], scenario analysis, and robustness analysis [Gupta and Rosenhead 1968; Rosenhead et al 1972; Rosenhead 1980b; Best et al 1986; Rosenhead 1989b]. All of the above are problem structuring methods for situations of complexity and uncertainty. Strategic Choice, Scenario Analysis and Robustness Analysis are methods proposing alternative ways to manage uncertainty in complex situations. Soft Systems Methodology and Cognitive Mapping are focused more on complexity rather than uncertainty. Since, however, complexity can be regarded as a source of uncertainty i.e. uncertainty about the structure and dynamics of the problem, their inclusion in the set of methods which deal with uncertainty is justified. Furthermore, there are other methodologies that apply a game theoretic approach to structuring problems that deal with conflict situations. These are Hypergame [Bennet et al. 1989] and Metagame Analysis [Howard 1971; 1989]. Although situations of conflict are not necessarily characterized by high uncertainty, in many high uncertainty cases conflict causes the prevailing uncertainty. Therefore, both methods can be of interest in uncertainty situations.

The methodology for flexible planning which will be developed and presented on Chapter 4 is based on robustness and scenario analysis using also some elements of metagame theory. Therefore, in the following two sections of this chapter a description of metagame theory and robustness analysis will be presented, while scenario analysis will be presented in more detail in Chapter 4.

2.4.1 *Metagames*

In conflict situations, both strategy and human relations affect the occurrence of a specific future. Metagame analysis is a method which aims to handle both strategic aspects and human relations, within one structured approach. Metagame analysis asks the client questions, by answering which the client educates himself. When answers are analysed, this is not so much to achieve surprising results as to summarise and state clearly what has already been sensed intuitively. The analysis proceeds in the following way: we devise a list of actors and a list of policy options for each actor. By selecting specific policy options for each player, we can generate alternative scenarios. These scenarios are in turn classified and interpreted.

The starting point is to eliminate all the infeasible scenarios. Infeasibility relates to actors' plans and intentions, and therefore one player's intentions may be changed by those of others. We then move to the classification of scenarios. The following categories are of particular interest:

Type 1: The Status Quo as it was before the situation arose

Type 2: The present scenario, incorporating present intentions

Type 3: The positions of different actors, meaning the scenarios they would like others to agree to.

Type 4: Possible compromises between different actors' positions

Type 5: Possible conflict points actors might move to in trying to force others to accept their positions.

Having done so much, we then try to interpret scenarios; that is to answer the question of what would it mean if the players' intentions in each scenario were held to indefinitely. Such insight into possible futures facilitates planning strategies for the interaction.

The next step, analysis of threats and promises, reveals the basic pressures that actors can exert on each other in the given situation. In this part, the first step is to choose a particular scenario to analyse for stability, i.e. acceptance by all actors as the scenario they expect (though this acceptance may be unwilling). Analysis of stability is carried out by finding all unilateral improvements for actors and subsets of actors from the particular scenario, and then by finding all sanctions that exist to deter unilateral improvements. Once the unilateral improvements and sanctions relative to one or more particular scenarios are found, they can be summed up in a strategic map, a diagrammatic way in which to communicate and discuss results. If no scenario is found to be stable, or if there is a stable scenario unwillingly accepted by some players, analysis of the strategic map can be used by the interested player to establish credible threats and promises to the other players s/he has to make to move towards a more preferred scenario.

In the case of type 3 conflict, direct conflict between organizations, metagame analysis can assist not only by clarifying the present situation, but also by assisting the decision maker to make the right moves to bring about the future s/he prefers.

2.4.2 Robustness analysis

The first mention of robustness in the literature has been made by Gupta and Rosenhead [1968], who described the use of robustness in determining the location of new factories producing consumer goods. Subsequent applications include chemical plants [Caplin and Kornbluth 1975], education [Rosenhead 1978b], and health services [Best et al. 1986]. The rest of this section describes briefly the methodology for conducting robustness analysis.

When planning under uncertainty, two things must be borne in mind: first, the acknowledgement of multiple futures, and second, the recognition of a clear distinction between decisions and plans. A decision is a commitment of resources which can only be reversed by a further decision. On the other hand, a plan consists of a foreshadowing of a set of decisions to be taken at some times in the future. The plan, therefore, is a working hypothesis rather than a commitment. Analytic efforts should be focused on getting the decision right, with the plan as a guide to the longer term future. The right decision under uncertainty must be a flexible one. Robustness analysis is a methodology for sequential decision making with the object of preserving future flexibility. It focuses on the alternative immediate commitments which could be made, which will be compared in terms of the range of possible future commitments with which they appear to be compatible.

The robustness of any initial decision is defined as the number of acceptable options at the planning horizon with which it is compatible, expressed as a ratio of the total number of acceptable options at the planning horizon. More formally, the robustness of an initial decision or decision package d_i in future F_j is defined as:

$$r_{ij} = |\hat{S}_{ij}| / |\hat{S}_j| \tag{2.1}$$

where $\hat{S}_j$ is the set of all options acceptable under the conditions of future F_j and $\hat{S}_{ij}$ is the subset of those options which are attainable if decision d_i is taken. It is therefore possible to construct a multi-future robustness matrix $R \equiv (r_{ij})$ (See Figure 2.5).

		Futures			
		F_1	F_2	...	F_m
Initial Decisions	d_1	r_{11}	r_{12}	...	r_{1m}
	d_2	r_{21}	r_{22}	...	r_{1m}
	...	...	...	...	...
	d_n	r_{n1}	r_{n1}	...	r_{nm}

Figure 2.5: Multi-future robustness matrix

Complementary to robustness is the notion of debility [Caplin and Kornbluth 1975]. Debility is defined as the number of unsatisfactory end-states still attainable after an initial decision, expressed as a ratio of all such end-states.

In the case of a single future the choice of the appropriate initial decision presents no problems: as far as the characteristic of flexibility is concerned the appropriate decision to be taken (other things being equal) is the one with the highest robustness (or lowest debility) score. Things are not so simple in the case of multi-future robustness. There is no obvious choice, unless one decision has the best scores under all futures. This, of course is an extreme case, and if a decision proves to be so much better than the other candidates, it is very likely that this fact would have been obvious even before starting the analysis. In most problems however, it is to be expected that a decision which fares well under some futures will perform less well under others. It can be the case that simple observations about the overall performance of a decision are impeded by the sheer size of the matrices; even the extreme case of one decision performing better under all futures may not be immediately obvious in a very big matrix. It can be argued that a useful way of summarizing the information contained on the two matrices is to fashion a single measure of relative decision flexibility. In the next section some possible ways to combine the information contained in the robustness and debility matrices into a single measure will be proposed.

2.4.3 Possible measures of decision flexibility

The contents of the robustness and debility matrices can be combined in several different ways. One such possibility is the use of the robustness-debility criterion (RDC). This criterion is similar to the Hurwicz criterion of decision theory [Hurwicz 1951]. It indicates the choice of the initial decision that maximizes:

$$\frac{\alpha}{n}\sum_{j=1}^{n} r_{ij} - \frac{(1-\alpha)}{n}\sum_{j=1}^{n}\delta_{ij} \qquad (2.2)$$

where n is the number of futures, r_{ij}, and δ_{ij} are the robustness and debility scores for each decision respectively and α is a subjective weight defined by the decision maker to express the trade-off between robustness and debility for each decision, $0 \leq \alpha \leq 1$. A high value of α would describe a risk-seeker decision maker, whereas a low α would be characteristic of a risk-averse decision maker. The values of the expression lie between $\alpha-1$ and α. Thus, for any particular α the criterion has a total range of 1. If $\alpha=1$, in the extreme case where the average robustness is 1 and the average debility is 0, then $\bar{RDC}=1$. At the other extreme where average robustness is 0 and average debility is 1, RDC=0. For $\alpha=0$ the two extreme values become 0 and -1 respectively.

The criterion can be modified to take into account not only the mean robustness of each decision but also the relative concentration of values around the mean:

$$\frac{\alpha}{n}\left(\frac{\sum_{j=1}^{n} r_{ij}}{s_r}\right) - \frac{(1-\alpha)}{n}\left(\frac{\sum_{j=1}^{n} \delta_{ij}}{s_\delta}\right) \qquad (2.3)$$

where s_r , s_δ are the standard deviations of the robustness and debility scores respectively for d_i.

An alternative combined criterion is the minimax criterion:

choose the decision d_i that maximises the minimum r_{ij} (2.4)

Another is the maximax criterion:

choose the decision d_i that maximises the maximum r_{ij} (2.5)

All four criteria have disadvantages. Thus, one weakness of criterion (2.2) is that by using average values for the robustness and debility scores across futures, it implicitly assumes that all futures are equi-probable. The use of simple averages in the criterion can be justified using Laplace's "principle of insufficient reason" where knowing nothing about the true state of nature is equivalent to all states having equal probability [Laplace 1825]. However, assigning subjective probabilities to the alternative futures, would invalidate the whole purpose of conducting robustness analysis: the underlying rationale for opting for this sort of analysis is that under conditions of high uncertainty probabilities become irrelevant or even meaningless.

This weakness is shared by the modified robustness-debility criterion (2.3). In addition, it has the further disadvantage that meaningful upper and lower limits for the expression are hard to calculate, thus rendering comparisons of its value for different decisions difficult.

Both the maximax and the minimax criteria present two major disadvantages :

1) They consider either robustness or debility only

2) Non-extreme values of the scores are not taken into consideration, resulting in the loss of valuable information: opportunities lost or risks suffered are ignored.

In Chapter 7, the robustness-debility criterion (2.2) will be adopted to provide a basis for comparison of the relative flexibility of initial decisions, since it is relatively simple to compute, and does not have the disadvantages of either the modified version (2.3) or the minimax and maximax criteria.

CHAPTER 3

THE NEED FOR FLEXIBILITY

CHAPTER 3

THE NEED FOR FLEXIBILITY

3.1 Introduction

The previous chapter has explored the nature of uncertainty surrounding real life problem situations. It has pointed out that traditional planning methods cannot cope with the presence of uncertainty, and that an appropriate method should attempt, among other things, to preserve flexibility. It has been argued that in many problem situations, where uncertainty concerning the future is dominant, it may be possible for decisions to be made sequentially to benefit from information which is unavailable at the time the first decision is made, but which might become available at a later time. Such an approach provides an opportunity for successive revision of decisions on tactics, strategies, and policies. Tactics, strategies, and policies can be applied successfully in such situations only when they have certain desirable characteristics. In this chapter, some of those characteristics will be presented and discussed. As there are many such characteristics and properties, the discussion will be restricted to those that are most relevant to the decision making process under conditions of uncertainty, and will be focused on flexibility as the central desirable property. Many terms that will be used in this analysis have been employed in different senses by various authors. In order to avoid terminological conflicts, a set of definitions of terms which will be used in a technical sense throughout the analysis will be introduced next, followed by a discussion.

3.2 Definitions

Outcome: The effects that result from the implementation of a decision or a set of decisions. Although in most people's minds outcomes are taken to signify numerical results, an outcome can very well be a change as subjectively perceived by an observer.

Objective: According to Ackoff [1962] an objective is an outcome which has a positive value for the decision maker. The positive value reflects the fact that the outcome is desired by the decision maker. By employing the element of desirability, we can define an objective as the intended result of the implementation of a decision or a set of decisions.

Goal: In situations where a decision or a set of decisions is implemented with a view to achieve multiple objectives, or where there are multiple decision makers with conflicting objectives, or where a decision results in more than one outcome, decision makers may express their objectives in the form of goals, one for each outcome; goals are target levels to be achieved as closely as possible.

Outcomes, objectives and goals describe the "ends" for a decision. To illustrate the relationship between these concepts, consider the following example: When switching on the central heating system of a room, its temperature rises; both the actual temperature measurement and the rise in temperature as perceived by the tenants of the room are considered outcomes of the decision. The objective of the decision makers is to increase the room temperature. This action, however, may result in other outcomes, such as a dry atmosphere unwelcome in various degrees by the decision makers. Moreover, some of the tenants may wish for a further increase, others a slight decrease and some may find the temperature ideal. The tenants of the room can agree upon a specific temperature measurement acceptable to everyone; that measurement constitutes a goal. Thus, even this simple example demonstrates some of the complications associated with a decision problem. One of the necessary and sufficient conditions for the existence of a problem is the existence of an objective [Ackoff 1962]. In real life problem situations, complications arise from the existence of more than one objective, which may not be consistent with each other. Since objectives can also be non-quantifiable abstract concepts which reflect individual values and perceptions, further complications can arise from the existence of multiple decision makers each with their personal values. Goals, in contrast to objectives, are quantitative measures only. This fact facilitates the process of negotiation between decision makers in order to achieve consensus on the level of the goals, since expressing preferences in numerical values makes the results more explicit. Another word which has been used in a similar sense to "objective" is the word "target". In this analysis, however, target will be used as a synonym for goal.

Having considered the "ends", we will now proceed to discuss the "means" to achieve them. These "means" are considered at three different levels: tactics, policies and strategies. (When making a statement applicable to any of the three levels, the term **alternatives** will be used.) The relationships between these levels can be defined either top-down (in which strategies determine tactics) or bottom-up (in which tactics sum to strategies). Since this thesis is mostly concerned with the properties of the alternatives rather than the generating process, it is of little importance, for our purposes, which view is adopted. In this section, we will follow Walker's [1988] terminology, which implicitly adopts the bottom-up view.

Tactic: A tactic is a single possible action to be taken which is intended to contribute towards the achievement of one or more objectives. Tactics are the building blocks of policies and strategies.

Policy: A policy is a combination of tactics describing courses of action relevant to the achievement of one or more objectives which are to be taken at particular points in time.

Plan: A plan describes the way which a policy is to be implemented.

Strategy: A strategy is a policy plus a plan on how to bring about the desired future.

Environment: Both the "means" and the "ends" are considered in a specific context, the environment: A problem's environment consists of all factors which can affect the outcome of implementing an alternative and which are not under the decision maker's control [Ackoff 1962]. The problem environment is also called the problem context.

3.3 Discussion of definitions

A distinction should be made between actions and tactics/policies/strategies. An action produces an outcome. A tactic is an action not yet taken which can, once taken, contribute towards the achievement of an objective. The same applies to policies and strategies: they both specify possible commitments. Unless some of the commitments that they describe have been taken they are in principle fully reversible and can be re-evaluated at any point should the need arise.

Objectives are given certain weights of importance by the decision makers according to their priorities; the more desired an outcome is, the greater the weight it is assigned.

Whereas policy gives broad directions for actions to be taken, a strategy describes also how these actions are going to be implemented. For example, an AIDS prevention policy may be comprised of a variety of tactics, such as screening of all blood donors, staff protection measures, educational campaigns etc. An AIDS prevention strategy should specify not only the set of tactics to be adopted, but also the way in which they will be implemented. That is, how is the blood screening going to be conducted, which bodies are to undertake the educational campaigns aimed at different groups of the population, etc.

3.4 Desirable characteristics of alternatives under consideration by the decision makers

When selecting alternatives for each problem situation, various desirable characteristics of alternatives should be considered. In section 3.5 it will be argued that under conditions of uncertainty a very important such characteristic is flexibility, and consequently the methodology which will be introduced in Chapter 4 is designed to preserve flexibility. Before introducing the concept of flexibility, two types of characteristics will be discussed:

(a) characteristics which facilitate the decision making process

(b) characteristics which relate to environmental uncertainties

Characteristics of the first type are desirable in all decision making situations, whereas characteristics of the second type are particularly relevant in decision making under uncertainty. The properties considered here are by no means mutually exclusive and exhaustive.

3.4.1 Characteristics which facilitate the decision making process

Numerous characteristics that facilitate the decision making process have been discussed by Walker [1988] and Archibald [1979]. These include: *merit, relative advantage, origin, scientific status, etc.* From a very long list the authors select *compatibility with existing norms and procedures, communicability, and simplicity* as the crucial ones to be sought.

Compatibility with existing norms and procedures. In cases of wholesale restructuring, uncertainty as to the reception of the innovations that the alternative introduces is generated. Whether the alternative will be adopted or not depends on the balance of power between interested parties. Compatibility with existing procedures can reduce the opposition to the proposed changes. Maintaining compatibility does not mean giving up significant, visible, large scale changes. To illustrate this, Archibald [1979] gives the example of introducing women as firefighters.

"...This will be seen as a dramatic change, requiring adjustments in just about every phase of firefighting operations and lifestyle. The design of such a program will be better received if compatibility with existing norms, practices, equipment, attitudes, and values can be maintained."

Communicability is the ease with which the alternative can be understood by persons not involved in the analysis; that is the ease with which these persons can visualise the different commitments involved in each step and their respective consequences. Communicability can promote communication between interested parties, enhance understanding of the problem situation and promote participation and support for the project.

Simplicity is a sufficient condition for communicability but not a necessary one. It is difficult to define simplicity: an alternative can be characterized simple only relatively to others. Measures of simplicity can be the number of outcomes in which the alternative may result or the number of separate actions (tactics) that comprise the alternative or the effort needed to implement the alternative. If these measures are low, uncertainty about the approval of an alternative is reduced.

The type of uncertainty that is resolved if the alternatives are communicable and simple, is uncertainty which results from lack of understanding, by some of the individuals involved in the analysis, of how the alternative in question will contribute towards the objective and to what degree. This uncertainty is of the UV type (see Chapter 2). Since the adoption of an alternative may also depend on people other than those designing or proposing it, and decisions to adopt alternatives can be made sequentially, a policy or strategy may run the risk of being abandoned at some future time. This risk is reduced if the alternative is simple and clear at the outset. Moreover, if the alternative is compatible with existing norms and procedures it has a higher chance of being adopted. All these uncertainties fall into the "restricted" uncertainty category, since they can be abolished relatively easily by ensuring that the alternatives in question have the required characteristics.

Clearly, the above characteristics are relevant in all complex decision making situations, not just those where uncertainty is a key factor. For such situations, the characteristics of alternatives which are discussed next are most relevant.

3.4.2 Characteristics which relate to environmental uncertainties

To clearly demonstrate the characteristics which are desirable under conditions of environmental uncertainty, the organization for which the decisions are made will be regarded as an operating system. Obvious characteristics of alternatives that are desired, in the case of an operating system, include *economy*, *effectiveness* and *efficiency*. The key requirement under conditions of environmental uncertainty is the preservation of the satisfactory operation of the system. The characteristics considered by Walker [1988] to contribute towards this requirement include insensitivity, reliability and invulnerability. Archibald [1979], adds that of reversibility and explores the implications of complexity. Other characteristics that merit examination include divisibility, adaptability and flexibility. The remaining part of this section will present and discuss all of the above characteristics, except flexibility which, due to its importance, will be discussed separately in section 3.5.

Insensitivity: the degree to which attainment of the objectives will be sustained despite disturbances encountered in normal operation of the system;

Reliability: the probability that the system is operating at any given time; and

Invulnerability: the degree to which the performance of the system remains unaffected by failure of one of its parts. The performance of the system is its ability to reach the goals.

Reversibility: the degree to which it is possible to return to the conditions that existed before a change if the change does not in practice seem to be contributing towards the achievement of the objectives. In the case of sequential investment decisions under uncertainty, when decisions have to be revised in the light of new information, reversibility is a crucial characteristic. Although alternatives are defined as commitments rather than actions, the psychological effect of commitment should be taken into account. Levin [1976] describes the phenomenon of commitment observed by psychologists as the state of mind associated with the expectation that a person forms, implicit or explicit, that s/he will suffer a psychological or socio-psychological penalty of some kind if s/he goes back on her/his decision:

"...they acquire a disinclination to go back on (their decision) -to negative it- without a plausible cause for doing so, such as the occurrence of a change in circumstances that could not have been foreseen."

Therefore, a reversible alternative would seem more attractive to decision makers since returning to the initial conditions could be easy and less apparent.

Divisibility: A practical way to attempt to achieve reversibility is to design strategies and policies that can be sequentially implemented. Divisibility is a property required for a mixed-scanning strategy [Etzioni 1967], that is one which first covers the problem area holistically but in broad terms, and then focuses in on those areas shown by the first scan to require a more in-depth examination.

A concept negatively related to divisibility and simplicity is that of complexity. A complex policy or strategy is one that is comprised of a variety of undistinguishable parts. This may be either due to the interconnectedness of the decisions about tactics, or to failure of the decision makers to understand the distinction between the individual steps that must be taken. In the first case, however, the alternative is indivisible, and therefore complex, whereas in the second it is complex and as a result cannot be seen as divisible. A policy that affects groups with competing interests, and tries to deal with many factors simultaneously, cannot be anything but complex and thus difficult to comprehend. This can be avoided if the policy can be broken down into smaller identifiable segments to be implemented at different times and sections of subject matter. Avoiding complexity can facilitate the decision making process and achieve divisibility.

Adaptability: the property of a strategy or policy that allows the decision maker to change some of the tactics that comprise it to meet changing circumstances. Adaptability relates to divisibility and risk. Divisibility may be a prerequisite for adaptability; it is easier to change small parts of a policy than its whole. Risk is reduced when the alternative is designed in a way that makes it adaptable to changing circumstances. Adaptability is a requirement in cases where insensitivity - the ability to perform well under changing circumstances- is low. Adaptability is closely related, as will be seen, to *flexibility* which is the concept to be discussed next.

3.5 The concept of flexibility

There are several definitions of flexibility, and although authors agree that in uncertain environments the alternatives under consideration should preserve flexibility, there has been debate about the properties that the term implies. Flexibility is a polymorphous concept [Evans 1988] which adopts different forms depending on its deployment in unique situational contexts. Such contexts include strategic management [Ansoff 1975; Eppink 1978; Krijnen 1979, Harrigan 1985], military strategy [Eccles 1959; Taylor 1959], decision theory [Heimann and Lusk 1976; Merkhofer 1977; Mandelbaum and Buzacott 1990], systems analysis [Collingridge 1983; Holling 1973], economics [Marschak and Nelson 1962; Jones and Ostroy 1984], business [Vives 1986; Carlsson 1989] manufacturing [Buzacott 1982; Brown et al. 1984] etc. Evans [1988] states that despite the different forms which flexibility may require, all studies in the various contexts address a similar problem: that of adjusting available means to better achieve current and anticipated future ends. We will define flexibility as the ability to respond to unforeseen changes. This definition may seem similar to that of adaptability, but there is a fundamental difference: adaptability is a permanent adjustment to a newly transformed environment whereas flexibility is a temporary approximation of this adjustment [Stigler 1939]. The capacity for constant readaptation to meet changing circumstances can be termed flexibility.

Flexibility is not a characteristic of alternatives in the strict sense; instead it can be considered as a property of the decision making process which should be preserved by the selection of alternatives that have certain characteristics. Adaptability is such a characteristic: because an alternative is adaptable, it contributes towards the preservation of flexibility. Other such characteristics are reversibility and divisibility. Alternatives can only be flexible because they have certain characteristics which contribute to flexibility preservation.

Another concept related to flexibility has been introduced by Gupta and Rosenhead [1968], that of *robustness*. Robustness is a measure of the useful flexibility maintained by a decision, and has characteristics which make it a suitable criterion for sequential decision making under conditions of uncertainty. The relationship between flexibility and robustness will be explained in the next section.

3.6 Flexibility and robustness

Although this section deals with flexibility as a property of decisions about tactics, policies and strategies, a distinction should be made between tactical and strategical flexibility. Tactical flexibility could be thought of as micro-flexibility in contrast with strategical flexibility which could be called macro-flexibility. Tactical flexibility is the degree to which a tactic designed to do a certain job can be used with reasonable success for a modified, or even an entirely different, purpose. It should not be confused with adaptability which is the ability to use a different tactic than the one selected initially for achieving the original purpose. Strategical flexibility is the ability to make a series of changes in the strategy to cope with unanticipated contingencies.

Since a tactic is a single thing to be done, devising flexible tactics is a relatively simple task: tactics are clearly specified single measures; it can be relatively straightforward to identify and evaluate their consequences; it may be possible to judge them on the basis of past experience. Past experience, however, cannot be a reliable guide to effectiveness at a strategic level. The consequences of adopting a certain strategy cannot be evaluated in advance, since they depend not only on the performance of the individual tactics on particular areas, but also on the relatively ill-understood relationships between those areas which are interconnected. Although tactical flexibility is relatively easier to maintain than strategic flexibility, its importance should not be ignored: once a decision has been made to implement a tactic, reversing or revising this decision will prove much more expensive in terms of commitment of resources in the absence of tactical flexibility.

Many authors describe flexibility as a criterion for decision making associated with preserving options. Options are the remaining possible alternatives once an initial decision has been made. Mandelbaum and Buzacott [1990] define flexibility as the quality of a system or process which allows it to respond effectively to a change of its environment or to a change in the decision maker's perception of reality. It could be argued however, that this is just another version of adaptability (as we have defined it) and not flexibility. As an attribute of a decision problem the authors argue that one possible way to view flexibility might be the number of options to choose from at a later date once a decision has been made. In a similar way, Merkhofer [1977] states that the flexibility of a decision variable is determined by the size of the choice set associated with that variable. Pye [1978] defines flexibility as the amount of uncertainty which the decision maker retains concerning the future choices s/he will make, and argues that under simple circumstances it may be interpreted as the number of future alternatives from which choice will be made.

All these three "option-preserving" definitions of flexibility presented above, seem to confuse flexibility, a quality, with numbers of remaining options. The concept of robustness can help resolve the ambiguity. The distinction can be made clearly between flexibility as a quality, and robustness as its measure. The ability to change to accommodate a wide range of futures is, despite discrepancies in terminology, a necessary and desirable characteristic of any alternative considered in an uncertain environment. In this thesis, we will use the terms *flexibility* for this property and *robustness* will be regarded as its measure.

CHAPTER 4

SCENARIO-ROBUSTNESS METHODOLOGY

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SCENARIO-ROBUSTNESS METHODOLOGY

4.1 Introduction

In the previous chapter the necessity of maintaining flexibility when planning under uncertainty was discussed. In this chapter a methodology to preserve such flexibility based both on robustness analysis and on scenario analysis will be presented. The multi-future perspective of robustness analysis, as already explained, can provide information on the relative flexibility of alternative initial decisions under different futures. Robustness analysis does not however prescribe how these futures are obtained. Scenario analysis, a planning tool used in decision making under uncertainty to analyse alternative futures will be used in the new methodology to construct these futures.

In developing any such methodology, it is important to define all the terms involved since the terminology in general use fails to cover all aspects of the analysis, while some terms are used in varying senses in the literature. Below, we will first describe some aspects of the decision making environment which will be assumed, and then introduce formal definitions of the terms that will be used in the analysis. Before presenting the methodology itself, both the nature and the purpose of scenario analysis will be discussed.

4.2 The decision making environment

Decision making in an organisational context is a complicated and subtle process. For definitional clarity many of these complexities will be subjected to a robust simplification in what follows. Thus, the decision maker will be referred to as if s/he were a single person or a homogeneous group. No distinction will be made between decision making and the actual implementation of decisions. The reason for making these assumptions is that in this chapter the interest is exclusively focused on the behaviour of the organisation as a single entity in relation to the outside world.

The organisation for which the decision maker acts will in some instances be referred to as the operating system; it follows that the "operating environment" is the context in which the organisation operates. As a simplification, the operating environment will be seen as a responsive one, in which decisions taken by the decision maker are capable of provoking responsive actions by other decision makers in the field. The presence of other factors capable of shaping the future and which are outside the decision maker's control must also be acknowledged. Shifts in general operating conditions do take place over time and factors causing these changes include non-responsive actions, one-off events and accidents. These factors are inherently uncertain, and therefore the decision maker may need to make alternative assumptions about their occurrence.

4.3 The time frame

In any planning exercise, after defining the scope of the analysis, establishing the time horizon is a necessary step which should be taken at an early stage. For clarity, a distinction should be made between the short term and the long term context: The end of the short term, for the purposes of this analysis, will be marked by the **decision horizon.** A number of alternative criteria can be used to identify the decision horizon:

i) The time that the decision maker must take the next decision.

ii) The time span of the immediate attention of the decision maker when making and implementing an initial decision.

iii) Data (both soft and hard) availability. The decision maker must judge up to which time current knowledge permits adequate detailed evaluation of possibilities.

iv) Operational considerations. The decision horizon can be selected to reflect a time-point before which repeating the analysis could be costly both in monetary and manpower terms.

The selection of the criterion to be applied depends on the particular problem situation. Thus using the timing of the next decision as a criterion for the selection of the decision horizon has the advantage of assisting in structuring the problem by identifying those times at which action is required. Its main disadvantage is that it does not define the decision horizon uniquely, since different initial decisions may require subsequent decisions to be taken at different time points. Selecting the time span of the immediate attention of the decision maker as the criterion, also assists in problem structuring, since the decision maker must identify the time-point where specific effects of the implementation of the decision are expected to occur. On the other hand, if this criterion is adopted, the decision horizon is directly dependent on the specific initial decision and consequently cannot be defined uniquely.

Data availability and operational considerations are convenient criteria to use since they solve many practical problems. Data availability is dependent on the initial decision but not as strongly as the first two criteria, whereas operational considerations are totally independent of the initial decision. However, they both offer little help in structuring the problem. Whichever criterion is chosen, either on its own or in conjunction with the other two, the identification of the decision horizon relies ultimately on the decision makers' personal judgement. There is, therefore, no external objective answer to the question of selecting the decision horizon, but use of the above criteria provides useful reference points in the discussion. Whichever alternative formulation is chosen, the short term can be defined as the period that elapses between the decision making point and the decision horizon.

The **planning horizon** delimits the time span beyond which events including the possible performance of the operating system are not and cannot be taken into account in current decision making because of increased uncertainty and lack of relevant data. The location of the planning horizon can be influenced in a general sort of way by the economic life cycle of investment decisions, any explicit or implicit time discounting and by the extent of uncertainty present in the problem situation. Since the general nature of long term planning does not permit a great level of detail, the choice of criterion is not as important as in short-term planning. By "long term" we will denote the latter part of the period between the decision horizon and the planning horizon. The duration of both the short term and the long term varies according to the purpose of the analysis.

4.4 Definitions

A set of mutually consistent definitions of the basic concepts needed to build up the scenario-robustness planning methodology will be now introduced. From this point on the words to be defined will be used in a limited technical sense. All concepts relating to the short term are denoted by lowercase letters, whereas concepts relating to the long term are denoted in capitals.

A single **decision element** is a measure which purposefully modifies the operating system. The changes to the system will occur in the short term but since every decision has a time profile of effects in the future, the effects of the decision will continue to be present in the longer term.

A **decision package** is an integrated set of measures or commitment of resources which modifies the operating system in a coherent way. In many cases the null decision package of no deliberate change to the operating system will be among those to be considered. The concept of decision package includes the concept of decision element as a special case. The set of decision packages is denoted by the set $\mathbf{d} \equiv \{d_i\}$, $i=1,2,\ldots,I$. For simplicity, in what follows the term "initial decision" will be used to denote an initial decision package.

Within the short term, each initial decision can provoke one or more **responsive actions** by other decision makers in the field who share an interest in the situation in question. Let

$$\mathbf{a} \equiv \{a_q\},\ q=0,1,2,\ldots,Q$$

be the set of all responsive actions available to other decision makers. A subset of these, $\mathbf{a}_i$, are potential responses to d_i. The general member of $\mathbf{a}_i$ will be called a_{ik}, $(k=1,2,...,K_i)$. These responsive actions will be assumed to take place in the short term and with effects which will have manifested themselves before the decision horizon. No explicit responsive actions after the decision horizon will be considered. Possible long term responsive actions will instead be incorporated within alternative "scenarios".

The potential responsive decision makers will be treated as a group; no responsive actions will be identified to particular decision makers. The value 0 for the index q corresponds to the case where no responsive action is taken.

The short term consequences of an initial decision are also affected by factors other than responsive actions. These factors may include changes in the parameters of the operating environment and other (non-responsive) decisions up to the decision horizon. The decision maker therefore may need to make alternative assumptions about these factors; alternative assumptions which can be made will be termed **conjectures** and will be denoted by the set $\mathbf{c} \equiv \{c_m\}$, $m = 1,2,...,M$.

The realisation of particular conjectures and responsive actions will together shape the short term setting. Thus, at the decision horizon the decision maker may be operating within alternative possible contexts which will be termed **environments**. The set of possible alternative environments is denoted by $\mathbf{e} \equiv \{e_{ik}^{m}\} \equiv (a_{ik}, c_m)$

Any initial decision can be combined with a compatible environment to form a **situation**. The set of possible situations is denoted by $\mathbf{t} \equiv \{t_{ik}^{m}\} \equiv (d_i, e_{ik}^{m})$

So far, we have only covered the situation in the short term. The long term future may be shaped by a multitude of external factors. The decision maker will need to make assumptions about particular combinations of settings/values of these factors which we will call **scenarios**. A scenario, therefore, is a complete, consistent, and plausible description of a possible long-term future operating environment. Alternative scenarios are denoted by the set $C \equiv \{C_j\}$, j=1, 2,..., J.

The implementation of one of the decision maker's initial decisions will result, *ceteris paribus,* in a specific state of the operating system at the decision horizon. These states will be termed **interim configurations.** The set of possible interim configurations is denoted by $g \equiv \{g_v\}$, v = 1,2, ...,V.

Similarly, the implementation of a series of decisions taken by the decision maker will result *ceteris paribus* in a specific long-term state of the operating system which will be termed a **configuration.** One configuration may be attainable by different decision sequences. The set of possible configurations is denoted by $G \equiv \{G_n\}$, n = 1,2, ...,N.

Thus, an initial decision triggers off one or more responsive actions, which together with the realisation of particular conjectures lead to possible short-term environments. Subsequent decisions of the decision maker can result in a number of alternative system configurations. The performance of any particular configuration will generally depend on the scenario in which it may need to operate.

The definitions presented above will be used as building blocks to construct the new methodology for planning under uncertainty. As mentioned before, this methodology uses robustness analysis (described in Chapter 2), a tool for sequential decision making, to assess the flexibility of alternative configurations under particular scenarios. At this point, therefore, and before introducing the methodology formally, the nature and purpose of scenario analysis will be discussed.

4.5 Scenario analysis

Scenario analysis is a technique applied in decision making under uncertainty for analysing alternative futures in order to develop strategies. Scenario planning techniques are adopted when increased levels of uncertainty are present in the planning environment and consequently traditional forecasting methods become inadequate.

Such high uncertainty situations arise in long-term strategic planning. Scenario analysis is particularly useful in preparing strategic decisions, since these are by nature irreversible and concern the longer-term future. Companies and organisations that need long-term forecasts to develop their strategic plans have found it useful to replace traditional forecasting with scenario analysis.

Most industrial firms which adopted scenario analysis as a strategic planning tool did so after the 1973 oil crisis[1] proved the inadequacy of forecasting by extrapolating past trends. Linneman and Klein [1979] in a survey they conducted in 1977 of the "Fortune 1000" U.S. industrial corporations, found that approximately 15 % had begun using multiple scenario analysis. In a follow-up study [Linnemann and Klein 1983] the same authors found that in 1981 this percentage had risen to 35%. McHale and McHale [1976] found scenario building to be the most widely used internationally, of the structured, non-analytic futures-research techniques. More recent regular users of scenario analysis include the electricity industry [Mobasheri et al. 1989; Hankinson 1986], the oil industry [Galer and Kasper 1982; Leemhuis 1985; Wack 1985a; 1985b; De Geus 1988; Hadfield 1990], the process (paper, fibre and wood products, chemicals, petroleum, glass concrete, abrasive and gypsum) and aerospace industries [Linnemann and Klein 1983] as well as banks, motor and electronics companies [Linneman and Kennell 1977].

Scenario analysis is also particularly relevant in cases where the source of uncertainty is conflict between actors. It is not incidental that such techniques originate in the military sector. The US Pentagon regularly analyses possible scenarios of conflict situations to determine the level of defence required to cope with those eventualities [Guardian

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[1] One company that had developed scenario planning in the late 60's and early 70's is Royal Dutch/Shell. By listening to planners' analysis of the global business environment, Shell's management was prepared for the eventuality-if not the timing- of the 1973 oil crisis. And again, in 1981, when other oil companies stockpiled reserves in the aftermath of the outbreak of the Iran-Iraq war, Shell sold off its excess before the glut became a reality and prices collapsed [Wack 1985a].

1992]. Metagame analysis, a technique for analysing processes of conflict or cooperation between actors by using scenarios, was first developed in the 1960s under a contract with the US Arms Control and Disarmament Agency [Howard 1971].

By creating and analysing scenarios, planners attempt to embrace uncertainty in their strategies; the usefulness of the technique lies not so much in facilitating the selection of the appropriate course of action, as in helping managers to understand the problem situation, to identify the driving forces of uncertainty and to reorganise their mental model of reality.

4.5.1 Scenarios: Definitions

Hadfield [1992] defines scenarios as "alternative views of the future business environment over a long timespan". Similar definitions are given by O'Brien et al [1991] "... distinct snapshots of the environment at a future point in time", by Linneman and Kennell [1977] "...possible future operating environments for the organisation", and Leemhuis [1985] "... descriptions of possible future (business) worlds". Mobasheri et al. [1989] describe a scenario as "a complete, consistent, and plausible description for a possible future state of the world that could occur if one or more major events were to happen". To distinguish scenarios from sets of forecasts of individual variables independently arrived at, Linnemann and Klein [1983] stated in the questionnaire they sent out in the course of their second survey of US industrial firms that a scenario is " a written depiction of a possible external future environment facing the firm and/or its planning units that indicate the interdependencies among the critical issues of variables characterising the future". All of the above definitions agree that a scenario is a static picture of a possible future operating environment. Linnemann and Klein state explicitly that a scenario is also external. This last definition disagrees with the definition given by Howard [1989], who describes a scenario as a combination of actors' plans in cases of conflict between actors. For each actor it is "a possible pathway into the indefinite future, representing the future each actor would anticipate if those plans were carried out".

Howard's definition differs from all previous ones in that it includes the decision maker's actions in the scenario. Since Howard is concerned with situations of conflict, this is a valid assumption as the decision makers' intended actions in such situations will influence the other players' intentions. Whether the decision maker's actions should be included in the scenario generation process or not depends on the situation in question or the purpose of the analysis. For example, if the decision maker wants to develop different scenarios about the state of the world economy, it would be foolish to believe that any of his/her actions would have an influence on the outcome, unless of course, the decision maker happens to be the government of a world leading economic power or an organisation that can exert such influence, as for example OPEC. If, on the other hand, the purpose of the analysis is the launch of a product by a competitor in an oligopoly market, his/her firm's intentions as perceived by the competitor may influence the latter's decisions.

The question arises whether the decision maker's intended actions should be included in the scenarios or not. The dilemma, however, is more a question of formality rather than substance. The purpose of all these analyses is to assist the decision maker in taking the most appropriate decision. Her/his decisions, therefore, are the core of the analysis. Whether they are included in the scenarios, or are examined in conjunction with them, is secondary. Thus, since the question is one of definition, in this thesis we will not include the decision maker's options within the definition of a scenario, in order to remain consistent with the most frequent terminological usage, and so to avoid confusion. Table 4.1 below summarizes the differences between "scenarios" as commonly used in strategic planning and "scenarios" as employed in Metagame theory.

Strategic Planning Approach	Metagame Approach
General	Detailed
External	Internal+External
Few in number	Many

Table 4.1: Differences between scenarios using two approaches

All definitions mentioned above point to four basic characteristics of a scenario:

a) It is hypothetical; the decision maker only hypothesises about the future course of events.

b) It is static; it represents a situation at a specified future point in time.

c) It is uncontrollable (or at most, partially controllable); that is, the decision maker can act in a specific way to influence the course of events, but because of the existing uncertainty, s/he cannot ensure that a particular scenario will become reality.

d) It is self contained; the logic of the particular combination of factors in a scenario describe a feasible future.

Taking these characteristics into consideration we can now define a scenario more formally as a description complete at its level of detail, of a future state of the operating environment of the organisation which results from a series of actions of agents external to the organisation, whose actions the decision maker can only partially influence.

In the strategic planning approach to scenario analysis, emphasis is placed on the long-term horizon, using mostly intuitive methods to assess possible alternative configurations of the environment at that point. These configurations are necessarily small in number (two, three or four usually) since only very broad hypotheses about a very limited number of key issues can reasonably be made for such a long time ahead. In the short run, however, more detailed predictions can be made based on the decision maker's current knowledge of the environment. For these more detailed short-term scenarios the term *conjectures*, as already defined, has been adopted.

4.5.2 Generating scenarios

In the literature there are various guidelines on how to develop and use scenarios [Linneman and Kennell 1977; Nair and Sharin 1979; Huss and Honton 1987; Schnaars 1987; Howard 1989; Hadfield 1991]. O' Brien et al [1991] have combined the various approaches described in the literature into an eight stage scenario generation process:

Stage 1	Define the scope of the analysis
Stage 2	Select key factors
Stage 3	For each key factor, determine a range over which that factor may vary within the time horizon
Stage 4	Combine projections of key factors to form scenarios
Stage 5	Discard internally inconsistent or implausible scenarios
Stage 6	Select a set of distinct scenarios
Stage 7	Produce narratives for each scenario
Stage 8	Use scenarios to create and test plans

Howard [1989] whose metagame analysis investigates situations of potential conflict, proposes the following process for generating scenarios:

The first step is to review the issues to be decided. Proceed by asking who controls the issues: the answers will provide a list of actors. By asking how the actors are controlling the issues, a list of policy options can be produced. A scenario results from a combination of specific choices for each option.

Theoretically, a very large number of scenarios can be generated by using all the available combinations of actors' plans, even if the list of actors and options is relatively small. Even from a list of two actors with two policy options each, we can construct 16 scenarios. Fortunately, some of the scenarios generated in this way can be infeasible[1]. The scenario generation process is followed by the classification and interpretation of scenarios. Five classes of scenarios are of particular interest:

1) The *status quo* as it was before the "situation" arose
2) The *present scenario*, incorporating present intentions
3) The *positions* of different actors, meaning the scenarios they would like others to agree to
4) Possible *compromises* between different actors' positions
5) Possible *conflict points* actors might move to by changing their own plans in trying to force others to accept their positions.

Interpretation of scenarios involves explicit description of the effects that actors' intentions would have if they were all held to indefinitely. Howard continues the process by analysing scenarios using strategic maps and laying out all the threats and promises actors can make to try and stabilise the situation at scenarios they prefer. This process has already been described in Chapter 2. In this section, only the pre-play analysis (i.e. scenario generation) is of interest.

We can summarize Howard's scenario generating process in 8 stages:

Stage 1 Review issues to be decided

Stage 2 Determine list of actors by asking who controls the issues

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[1] Howard maintains that in some combinations the infeasibility could be psychological: "...The infeasibility of A planning to collaborate with an unwilling B is actually psychological, consisting in the fact that A can't form the intention to collaborate without belief in B's corresponding intention. Hence A's intention may be changed by B's." Recognition, however, of the fact that human interactions may change intentions, does not change the infeasibility of the scenario. In Howard's example, only the scenarios "A collaborates with B and B collaborates with A" and "A does not collaborate with B and B does not collaborate with A" are feasible. Actor A may believe the second scenario to be more probable to occur if he considers B unwilling to collaborate, but in that case he does not consider the first scenario as infeasible. He merely considers it very improbable. Therefore, infeasible scenarios in this case are only those where one actor collaborates and the other does not.

Stage 3	Determine list of policy options by asking how actors can control the issues
Stage 4	Combine actors' options to generate scenarios
Stage 5	Discard infeasibilities
Stage 6	Classify scenarios
Stage 7	Interpret scenarios
Stage 8	Analyse threats and promises

It is clear that the two generating processes have a certain relationship in most stages. Stage 2 of O'Brien's process corresponds to both stages 1 and 2 of Howard's procedure. In stages 2 and 3 O'Brien et al. examine the possible changes in key factors without specifying their source, that is the action that caused them, whereas in stages 2 and 3 of Howard's process the actions available to the actors are examined.

Another difference in the two procedures is that O' Brien's does not include the decision maker's options explicitly in the formation of scenarios. These are only considered in the final stage where scenarios are used to test plans. This is consistent with Hadfield's definition of a scenario as a view of the future business environment [Hadfield 1990]. Metagame analysis, however, includes the decision maker's options in the formation of scenarios. In the previous section, we have given reasons for the non-inclusion of the decision maker's options in the scenarios. Although the decision maker's actions will not be included in our scenarios, it is however worthwhile to adopt Howard's way of eliciting options, since in the general case, it is possible that the decision maker's intended actions as perceived by other actors will influence their responses, which in turn will shape the future operating environment. Moreover, by listing the actors (including the decision maker) who are fewer than the available options first, and then proceed to list the corresponding options we can easily avoid to overlook some options.

The following figure shows the relationships between the two procedures. The dashed arrows indicate a weaker correspondence than the plain ones.

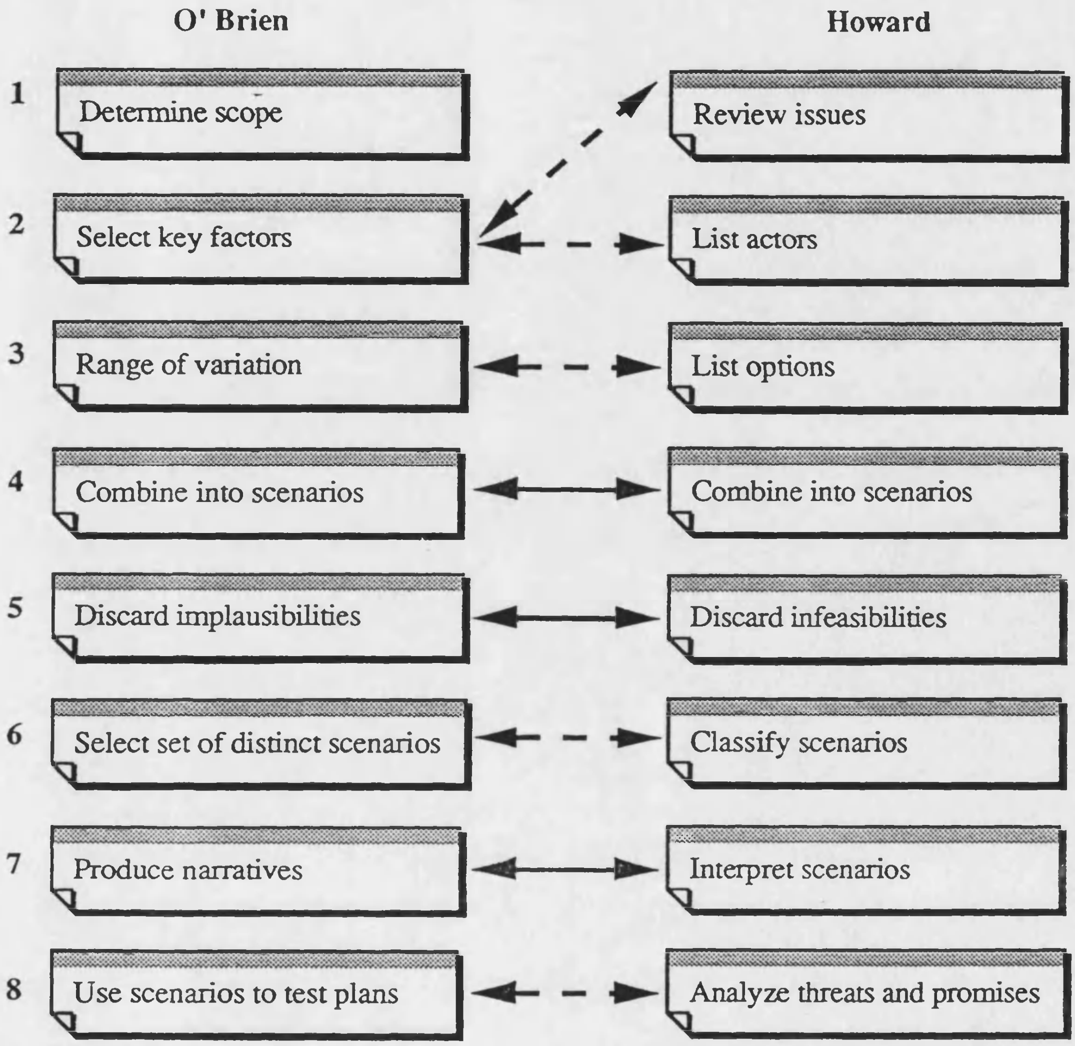

Figure 4.1: Relationships between the stages of the two scenario generating processes

It has been argued that the number of scenarios under consideration must be small enough to be manageable. Authors agree that for business purposes no more than four scenarios must be developed[1] [Linnemann and Klein 1979; Beck 1982; Wack 1985b;

[1] It is difficult to state whether two, three, or four is best. Schnaars [1987] maintains that the number depends on the goals of the analysis and the specific application. Deficiencies in using either two or three scenarios have been pointed out. Two scenarios tend to be classified as "pessimistic" and "optimistic". Managers then believe that the truth is somewhere in between. They split the difference to arrive at an answer not very different from a single-line forecast. A design that includes three scenarios

Schnaars 1987]. This recommendation can be followed since the factors shaping a scenario can be described in very broad terms and consequently their number will be small.

We can use elements of both procedures to generate conjectures and scenarios in the planning methodology which is introduced in the next section.

4.6 The Scenario-robustness methodology

In the previous chapters we have argued that traditional planning methods are inadequate for conducting planning under uncertainty, largely because they aim to abolish it rather than recognize its presence and attempt to keep options open for future resolution. A methodology suitable for planning under uncertainty should aim to preserve flexibility. It has been argued that multiple-future robustness analysis is such a methodology. This methodology however, does not prescribe a specific method to construct these multiple futures. Rosenhead [1980b] suggests, among other methods, the development of alternative scenarios using the Delphi technique [Helmer 1966]. This technique uses a panel of experts, where each member of the panel answers (separately) questions on possible future developments. These answers are processed and re-circulated to the panel to prompt revised responses. Consensus, or stable polarized groups emerge usually after no more than three iterations. Rosenhead states that it is possible to devise a modified approach where a set of distinct positions rather than consensus is encouraged.

Another multi-future approach that Rosenhead considers relevant is the use of "conditional projections" [Sandberg 1976], where answers to "what if" questions

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describing alternative outcomes along a single dimension is dangerous because many managers tend to identify the middle one as a baseline [Wack 1985b]. The same view is shared by Wilson [1978] who prescribes that in such cases the scenarios should be distinctly "themed" to make them appear equally likely. Finally, four scenarios may seem too many.

about the continuation of existing relations, are used to identify those relations whose break-up would lead to more desirable futures. Both Sandberg's conditional projections and scenario analysis constitute option-scanning devices to explore not only alternative decisions but also alternative operating environments.

It is clear that a formal, but not restrictive method to elicit possible futures would offer a valuable assistance to conducting robustness analysis. Scenario analysis is such a method. We have seen however, that there are two approaches to scenario generation: one requires the identification of key factors only, whereas the other requires all options to be explicitly stated. We can, however, use both to exploit their respective advantages. An approach related to Howard's can be used to conduct analysis pertaining to the decision horizon, since there is more information about the short term. Uncertainty grows as we move towards the planning horizon. Since detailed predictions are irrelevant in the long term, the strategic planning approach can be used to identify a small number of distinct scenarios about the longer-term future.

The new planning methodology therefore, consists of two exercises: one analysis at the decision horizon, and one at the planning horizon. Since it borrows elements from both robustness analysis and scenario analysis, Scenario-Robustness Methodology (SRM) would be an appropriate name for it. The steps involved to conduct SRM are listed below:

1. Select decision horizon and planning horizon
2. For decision horizon
   - (i) list all possible responsive actions
   - (ii) make alternative conjectures
   - (iii) combine responsive actions and conjectures to generate feasible environments
   - (iv) identify possible interim configurations
   - (v) conduct robustness analysis to each initial decision under different environments on the

basis of the desirability of interim configurations

(vi) Compute robustness-debility scores

3. For planning horizon
   (i) generate scenarios
   (ii) identify possible configurations
   (iii) for each initial decision check which configurations are attainable under alternative scenarios
   (iv) apply robustness analysis to each initial decision under different scenarios on the basis of the desirability of configurations
   (v) Compute robustness-debility scores

4. Check which initial decision(s) are indicated by both short-term and long-term analysis in terms of highest robustness-debility scores.

The procedures described in the first three steps have all been explained in detail in various previous sections of this thesis. Step 4, however has not yet been discussed. The situation may be relatively straightforward if an initial decision performs reasonably in terms of robustness at both horizons. Problems arise when no such decision can be found. The methodology will not attempt to give a particular answer in this case; the horizon which should have the dominant influence will be determined by the decision makers in the particular problem situation. It would be unrealistic to make a specific recommendation without knowing the details of the problem. Moreover, making specific recommendations is not the purpose of SRM. Its aim is to assist the decision making process by structuring the problem and to identify flexible decisions. However, in addition to flexibility, other factors such as cost, ease of implementation, political pressure etc. will influence the final commitment.

Since SRM is based on both scenario and robustness analysis, it follows that it is particularly relevant when both these methodologies are recommended. In terms of the classification of uncertainty described in Chapter 2, SRM is relevant in cases of "hard" uncertainty, when surprises are expected, and under ignorance. The type of uncertainty it tackles is mostly UE and UR in Friend and Jessop's terms, and uncertainty over consequences of actions in Hopwood's terms. These are the types of uncertainty prevalent in turbulent environments where scenario analysis is indicated.

CHAPTER 5

MEASUREMENT OF UNCERTAINTY USING MEASURES OF SIMILARITY BETWEEN SCENARIOS

CHAPTER 5

MEASUREMENT OF UNCERTAINTY USING MEASURES OF SIMILARITY BETWEEN SCENARIOS

5.1 Introduction

In this chapter an attempt will be made to measure the uncertainty about the future in a decision-making situation by using scenarios. Although this measurement is not incorporated in SRM, it is nevertheless a useful by-product of the analysis. A measurement of the uncertainty about the future prevalent in a planning situation may help to identify possible alternative analytical approaches appropriate to that situation.

The conventional way of measuring uncertainty is to apply probabilities to establish the relative likelihood of certain events occurring. We have argued, however, approaches using probabilities are not appropriate in situations of high uncertainty, where surprises are possible. Surprise events have by definition a very small probability of occurring and consequently, planning techniques based on such probabilities fail to anticipate the unexpected. The problem arises therefore, of how to measure uncertainty in turbulent environments, without applying probabilities. Scenario analysis offers one possible resolution of this difficulty. During the course of conducting SRM, a number of scenarios about the long term future are constructed. In this chapter, we will develop a measure of the uncertainty in a problem situation based on variation in the performance of the system under the different scenarios.

Suppose that the problem situation can be described by the matrix in Figure 5.1[1]:

[1]For simplicity, we consider only the case of single rather than sequential commitments.

	d_1	d_2	...	d_n
C_1	F_{11}	F_{12}	...	F_{1n}
C_2	F_{21}	F_{22}	...	F_{2n}
...	...	...	...	...
C_m	F_{m1}	F_{m2}	...	F_{mn}

Figure 5.1: A matrix of futures

Each element of this matrix (symbolized by F_{ij}) represents the future situation resulting from the implementation of decision i and the occurrence of scenario j. In this chapter these situations will be referred to as "futures". Each of these futures may be evaluated using a subjective qualitative scale according to their desirability. If a measure of similarity between scenarios by using the corresponding futures can be found, it would also be a measure of the prevalent uncertainty. By similarity, we do not imply identical performance, but rather performance which is equally desirable. Thus, we can ascertain the amount of uncertainty present in the problem situation by examining how similarly each decision is treated by the different scenarios. The more similar the treatment, the less it matters which scenario finally materialises (in terms of the desirability of the outcomes), and thus, the less uncertainty surrounds the problem.

The following sections will examine various ways to measure similarity. Section 5.2 attempts to measure similarity between scenarios by using similarity coefficients developed for use in cluster analysis. Section 5.3 examines the use of Gower's index of similarity for the same purpose. In section 5.4 the suitability of the variance-covariance matrix of the scenarios to measure their similarity is examined, while section 5.5 presents the use of the coefficient of concordance (between scenarios) as a measure of uncertainty. Examples of such use are given in section 5.6, followed by a comparison in section 5.7 of the performances of the coefficient of concordance and of the cluster analysis similarity coefficients. The chapter concludes with a discussion in section 5.8 on the use of similarity measures to measure uncertainty.

5.2 Measurement of similarity using cluster analysis similarity coefficients

The raw data to be subjected to cluster analysis consists of a matrix of measurements of individual entities. Similarity coefficients are used to ascertain the degree of similarity between those measurements in order to classify the individuals into particular groups. We will see that if we treat the matrix of futures as a matrix of measurements, where the individuals are the scenarios, and then use similarity coefficients to determine the similarity of those scenarios, we will produce a measure of uncertainty. A brief presentation of cluster analysis similarity coefficients is given below followed by the application of those coefficients to the futures matrix.

Everitt [1980] describes cluster analysis as a set of techniques which seek to separate data into constituent groups[1]. In general, the raw data to be subjected to cluster analysis consists of an n*m matrix of measurements, X, where x_{ij} is the score on the j^{th} variable, character or attribute for the i^{th} individual, entry or object under study. The measurements involved may be quantitative (e.g. age, weight, etc.), qualitative (e.g. the presence or absence of a symptom, eye colour etc.), or, as happens in many cases, the data will involve a mixture of both types of variable.

A range of possible measures of similarity can be applied to determine the degree of similarity between individuals using the information in X, and thus assign those individuals to particular groups. A similarity coefficient measures the relationship between two individuals given their values on a set of variates common to both. In many cases those variates are of the presence or absence type which may be arranged in the familiar two-way association table for binary data :

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[1] Although Kendall and Stuart [1979] propose that the term "cluster analysis" be used for techniques which group variables, and "classification" for those which group individuals, in this thesis we will adopt Everitt's terminology and refer to both types of grouping as cluster analysis.

		Individual i		
		Presence	Absence	
Individual j	Presence	a	b	a+b
	Absence	c	d	c+d
		a+c	b+d	a+b+c+d

Table 5.1: Two-way association table for binary data

In Table 5.1, a represents the number of positive matches, b and c are mismatches, and d is the number of negative matches.

Many similarity coefficients have been suggested for data of this type [Everitt 1980]. These include the following:

(i) (a + d)/(a+b+c+d) (ii) a/(a+b+c) (iii) 2a/(2a+b+c)

(iv) 2(a+d)/[2(a+d)+b+c] (v) a/[a+2(b+c)] (vi) a/(a+b+c+d)

The number of proposed association coefficients is large, mainly because of the uncertainty over how to incorporate negative matches (i.e. d in Table 5.1) into the coefficients. In many situations the absence of a characteristic in two individuals does not automatically guarantee their similarity. For example, the fact that two individuals do not have blue eyes, does not mean that they have the same eye colour. Of the six coefficients presented above, only coefficients (i) and (iv) explicitly take into account both positive and negative matches (a and d respectively), the latter giving more importance to matches over mismatches (b and c). Sneath and Sokal [1973] give a full discussion of similarity coefficients for use with binary data and decide that no hard rule can be made regarding the inclusion or otherwise of negative matches. Each set of data must be considered on its merits by an investigator familiar with the material.

Differences amongst the coefficients also arise over the question of whether or not matched pairs of variables should be weighted equally with, or carry twice the weight of unmatched pairs, or vise-versa. For example in coefficient (iv) matched pairs carry twice the weight that they carry in coefficient (i), where matched and unmatched pairs carry equal weight.

Qualitative data for which the variates may have many levels (as in our problem) may be treated in a similar way to binary data, with each level of a variate regarded as a single binary variable. For example, consider the two individuals 1 and 2 , each measured on variates x and y, each of which can take the three values A, B, C (instead of 0 or 1). Suppose that individual 1 measures A on x and C on y, and that individual 2 measures B on x, and C on Y. The new matrix of measurements is represented in Figure 5.2:

	x			y		
	A	B	C	A	B	C
Individual 1	1	0	0	0	0	1
Individual 2	0	1	0	0	0	1

Figure 5.2: Example of matrix of measurements for qualitative data

The matrix of measurements in Figure 5.2 can be treated as measurements of two individuals on six binary variates, and similarity coefficients for binary data can be applied. This representation generalises easily to larger problems. As will be seen later, evaluations of the performance of the futures will be treated in a similar way.

Let us now consider how similarity coefficients can be applied to our problem. If we have n decisions and m scenarios, each entry x_{ij} of the matrix of futures (Figure 5.1), is a measurement of the performance of the future resulting from the combination of the the i^{th} decision with the j^{th} scenario. That is, each row of the matrix represents a scenario, whereas each column represents the future possibilities for each decision[1]. A possible matrix of measurements, using the qualitative scale of Very Good (V), Good (G), Fair (F), Poor (P), Catastrophic (C) is shown in Figure 5.3. This matrix shows how each decision fares under a particular scenario.

[1]In some cases it would be more convenient to work with the transposed matrix.

	d_1	d_2	...	d_n
C_1	V	G	...	F
C_2	G	P	...	C
...			...	
C_m	F	P	...	C

Figure 5.3: Example of matrix of measurements of scenarios

Scenarios can be seen as the individuals which are being investigated for similarity, and decisions as the variates on which they are measured. Thus, the matrix in Figure 5.3 can be seen as equivalent to the matrix of measurements X. The scale of qualitative measurements of the performance of each future (V, G, F, P, C) can be seen as the five binary variables on which the variates (decisions) are measured. In this way, a matrix of measurements equivalent to that in Figure 5.2 can be produced. If there are only two scenarios under consideration, the cluster analysis similarity coefficients can be used to measure the degree of similarity between those scenarios.

We will illustrate this measurement of similarity with an example of 10 possible decision situations. These situations are presented in Figure 5.4. These 10 cases have been designed in such a way as to produce certain intuitive uncertainty rankings. The suitability of the similarity coefficients will be examined on the basis of verification of these expectations. The intuitive rankings of these cases are discussed below.

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	V	G	F	P

Case 1

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	G	F	P	C

Case 2

	d_1	d_2	d_3	d_4
C_1	V	V	V	V
C_2	G	G	G	G

Case 3

	d_1	d_2	d_3	d_4
C_1	V	V	V	V
C_2	F	F	F	F

Case 4

	d_1	d_2	d_3	d_4
C_1	V	V	V	V
C_2	G	G	F	F

Case 5

	d_1	d_2	d_3	d_4
C_1	V	V	V	V
C_2	G	G	F	C

Case 6

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	P	F	G	V

Case 7

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	P	G	G	V

Case 8

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	V	F	G	P

Case 9

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	V	F	F	P

Case 10

Figure 5.4: An example of 10 possible decision situations

In case 1 both scenarios treat each decision the same way, whereas in case 2, C_2 treats each decision one level worse than C_1. In both cases we would expect a high similarity score.

In case 4, C_2 treats each decision worse than it does in case 3. Case 4 is expected therefore to give a lower similarity score than case 3.

Case 6 differs from case 5 only in one element. It would be interesting to see what difference, if any, this rather small difference has on the similarity scores.

In case 7, C_2 treats each decision in exactly the opposite way than C_1, while case 8 differs from case 7 in one element only. A very low similarity score is expected in both cases; it would be of interest too, to measure the sensitivity of the coefficients to small differences.

Finally, cases 9 and 10 also differ at one element, but in contrast with cases 5 and 6 C_1 treats all decisions differently. In this example we would expect case 10 to give higher similarity scores between the two scenarios.

The results on the six coefficients are given in Table 5.2. Details of the calculations can be found in Appendix II.

	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Case 1	1	1	1	1	1	0.2
Case 2	0.6	0	0	0.75	0	0
Case 3	0.6	0	0	0.75	0	0
Case 4	0.6	0	0	0.75	0	0
Case 5	0.6	0	0	0.75	0	0
Case 6	0.6	0	0	0.75	0	0
Case 7	0.6	0	0	0.75	0	0
Case 8	0.7	0.143	0.25	0.824	0.077	0.05
Case 9	0.8	0.333	0.5	0.889	0.2	0.1
Case 10	0.9	0.6	0.75	0.947	0.428	0.15

Table 5.2: Results on the six coefficients for 10 hypothetical cases

Table 5.2 indicates several disadvantages in using the similarity measures of cluster analysis in comparing scenarios, the basic ones being:

(1) By using two-way association tables, we can only compare two scenarios at a time.

(2) The coefficients do not reflect the degree of dissimilarity adequately. For example, cases 2 to 7 give the same values on all coefficients. It can be argued however, that in case 3 the scenarios are more similar than in case 4 since C_2 in the former gives good futures for every initial decision whereas in the latter gives only fair ones. Similarly, it

can be argued that there is more similarity between the two scenarios in case 2 than in case 7. In case 2, for every decision each scenario gives a rating one grade lower, whereas in case 7 this is true for two decisions only, while for the other two the ratings are three grades lower. This limitation of the coefficients is a result of treating the measurement scale as binary variables: the method distinguishes only between similar and dissimilar ratings but does not accommodate for the degree of dissimilarity.

(3) The selection of the appropriate similarity coefficient. In case 1 where both scenarios are exactly the same, all coefficients except the last take the value 1. The last coefficient, a/(a+b+c+d), takes into account only the positive matches. In our problem, however, negative matches (two zeros) indicate the same similarity as positive matches (two ones). This is because for each decision each scenario can only score one 1 and four 0s. If, therefore, one of the scenarios treats a decision similarly to the other, we will have one pair of 1s and four pairs of zeros which will be equally important. We can therefore discard this particular coefficient as not suitable for our purposes.

For the same reason, we can discard coefficients (ii), (iii) and (v). In all cases, coefficient (iv) is higher than coefficient (i). This is because the former gives matches twice the weight of mismatches. There is no evidence, however, to suggest that it is appropriate to do so in our problem. We can therefore, conclude that if, despite the disadvantages, we proceed to measure uncertainty with the similarity coefficients the most appropriate one to use is (i), the simple matching coefficient.

5.3 Measurement of similarity using Gower's index

So far we have examined cluster analysis similarity coefficients for binary data only. In this section, Gower's index which accommodates mixtures of types of data will be examined as a measure of similarity between scenarios. As in the case of similarity coefficients for binary data, Gower's index can measure similarity between two individuals only.

In many applications of clustering techniques each individual is described by a set of variables which includes binary, qualitative and quantitative measures. In such cases, a similarity coefficient proposed by Gower [1971] can be very useful, since it can deal with such a mixture of variable types. The coefficient is defined as follows:

$$S_{ij} = \frac{\sum_{k=1}^{m} s_{ijk}}{\sum_{k=1}^{m} w_{ijk}} \qquad (5.1)$$

S_{ij} denotes the degree of similarity between individuals i and j. s is a binary variable which takes the value 1 if there is a positive match for individuals i and j on variable k, and equals 0 otherwise. The weight w_{ijk} is set equal to 1 or 0 depending on whether the comparison is considered valid for variable k, and except for the case of dichotomous variables, this weight can only be zero when variable k is unknown for one or both individuals. With dichotomous variables, w_{ijk} is also set to zero when variable k is known to be absent from both individuals. Whenever $w_{ijk} = 0$, then s_{ijk} is set to zero, and if $w_{ijk} = 0$ for all variables S_{ij} is undefined.

If all variables are binary then Gower's index is equivalent to coefficient (ii) of the previous section. In the case of qualitative data, $s_{ijk} = 1$ if the two individuals are the same for the kth variable, and $s_{ijk} = 0$ if they differ. Gower's index can therefore be used in our problem, taking the scenarios as the individuals to be compared, each variable to be the initial decision, and each future to be the measurement of that decision. The values of Gower's index for the ten cases considered in Figure 5.4 are given in Table 5.3 :

Case 1	1
Case 2	0
Case 3	0
Case 4	0
Case 5	0
Case 6	0
Case 7	0
Case 8	0.25
Case 9	0.5
Case 10	0.75

Table 5.3: Values of Gower's index for 10 hypothetical cases

From Table 5.3 it can be seen that in addition to the drawback that only two scenarios can be compared at a time, Gower's index cannot distinguish between levels of dissimilarity. Its merit is principally its relative computational simplicity.

5.4 Measurement of similarity using the variance-covariance matrix

Both similarity coefficients and Gower's index can measure the similarity between two scenarios only. In this section we will examine another possible measure of similarity which will allow more than two futures to be compared.

If the futures were to be measured on a numerical scale, and scenarios were to be treated as random variables, another possible measure of similarity could be devised by calculating the variance-covariance matrix of the scenarios:

	C_1	C_2	...	C_n
C_1	Var (C_1)	Cov(C_1,C_2)	...	Cov(C_1,C_n)
C_2	Cov(C_2,C_1)	Var (C_2)	...	Cov(C_2,C_n)
...			...	
C_n	Cov(C_n,C_1)	Cov(C_n,C_2)	...	Var (C_n)

Figure 5.5: Variance-covariance matrix of the scenarios

The matrix in Figure 5.5 shows the degree of agreement between scenarios and within scenarios. In contrast to the measures presented above, this representation allows the comparison of more than one scenarios. There is not, however, a single measure of this matrix, that is we cannot express it with one number. We could choose to use the trace or the determinant of the matrix, but the meaningfulness of these measures is questionable. Moreover, calculating the variance-covariance matrix of the scenarios assumes that the scenarios can be treated as random variables, which they are not. Therefore, the significance of this matrix is at least dubious.

Finally, another major disadvantage of this method is the requirement of numerical measures for futures. We must therefore assign a numerical value to each grade of the qualitative scale, but these values must be equidistant; otherwise the variation between consecutive grades of the qualitative scale will not be the same. There is a method however, that avoids this problem by ranking the futures in order of preference. This method will be described next.

5.5 Measurement of uncertainty using the coefficient of concordance

This section proposes the use of the coefficient of concordance as a measure of similarity between scenarios, and therefore as a measure of the prevalent uncertainty.

A possible measure of similarity between scenarios can be found by ranking the futures within each scenario according to preference, and calculating Kendall's coefficient of concordance W [Kendall 1975] for m rankings (as there are scenarios). This coefficient measures the degree of agreement between rankings, in our case the degree of similarity of the effects of the scenarios on each decision. Since rankings can be based on some quality or qualities which cannot, for either practical or theoretical reasons, be measured, they do not have to be objective.

The coefficient of concordance W is given by the formula:

$$W = \frac{12\,S}{m^2(n^3 - n)} \qquad (5.2)$$

where m is the number of rankings (in our case scenarios), n the number of objects to be ranked (in our case decisions), and S is the sum of squares of the actual deviations of the totals of ranks from their mean, or more formally

$$S=\sum_{i=1}^{n}\Big[\sum_{j=1}^{m}r_{ij}-\Big(\sum_{i=1}^{n}\sum_{j=1}^{m}r_{ij}\Big)/n\Big]^2 \tag{5.3}$$

where r_{ij} is the ranking of future F_{ij} by comparison with futures in the same row.

Formula (5.2) for W is used in the case of no ties between rankings. W measures, in a sense, the commonality of the treatments of the n decisions by the m scenarios. If those treatments are all the same, then W=1. If the treatments differ very much, the sums of ranks will be more or less equal, and consequently the sum of squares S becomes small compared with the maximum possible value, so that W is small. As the measure of agreement in the rankings increases, W increases from 0 to 1[1].

In the case where there are some ties in the rankings the coefficient W is defined as

$$W=\frac{S}{\frac{1}{12}m^2(n^3-n)-m\frac{1}{12}\sum_{t=2}^{n}n_t\,(t^3-t)} \tag{5.4}$$

---

[1]Although Kendall's rank correlation coefficient τ, which measures the degree of correspondence between two rankings, ranges from -1 which denotes complete disagreement to +1 which denotes complete agreement, the coefficient of concordance W ranges from 0 to 1. This is due to the fact that when more than two scenarios are concerned, agreement and disagreement are not symmetrical opposites. All scenarios can treat all decisions in exactly the same way, but treatment in an exactly opposite way cannot be defined. If, for an example of three scenarios, C_1 disagrees completely with C_2 and also with C_3, C_2 and C_3 must agree. In this case C_1's rankings would be the reverse of those of both C_2 and C_3. Therefore, C_2's and C_3's rankings must be the same. Complete disagreement in cases of more than two scenarios cannot be defined. Consequently, negative values of the coefficient would have no meaning. What can be measured is strong or weak agreement, and this is reflected by values close to 1 or 0 respectively.

where t is the number of consecutive members which are tied and n_t the number of times that a tie of t elements occurs. The method of allocating rank numbers to tied futures is to average the ranks they would possess if they were distinguishable. For instance, if the third and fourth futures are tied, each is allotted the number 3.5, and if the second to the seventh inclusive are tied, then each is allotted the number 1/6(2+3+4+5+6+7) = 4.5.

The formulae for tied and untied ranks seem different, but they are not. They are different expressions of the more general formula :

$$W= S/mS' \tag{5.5}$$

where S' is the sum of squares of deviations of all ranks from their mean, or mathematically

$$S'=\sum_{i=1}^{n}\sum_{j=1}^{m}\left[r_{ij}-\left(\sum_{i=1}^{n}\sum_{j=1}^{m}r_{ij}\right)/n\right]^2 \tag{5.6}$$

The significance of the coefficient W can be tested to reject or accept the hypothesis that the scenarios apply different treatments to the decisions. The actual distribution of W has been worked out by Kendall for lower values of m and n: n=3, m=2 to 10; n=4, m=2 to 6; n=5, m=3. For higher values two approximations can be used:

a) Fisher's z-distribution. We write

$$z=\frac{1}{2}\ln\frac{(m-1)W}{1-W} \tag{5.7}$$

$$v_1=n-1-\frac{2}{m} \text{ and } v_2=(m-1)v_1 \tag{5.8}$$

Then for degrees of freedom v_1 and v_2, z can be tested using the tables of Fisher's distribution.

b) Although the above test is generally valid, a simpler test may be used for n>7. If we write

$$\chi_r^2= m(n-1)W=\frac{S}{\frac{1}{12}\,mn(n+1)} \tag{5.9}$$

then χ_r^2 is distributed in the form χ^2 with $\nu = n-1$ degrees of freedom.

When ties are present, the z-test requires no modification unless the number or extent of ties is large. In the latter case the degrees of freedom are modified as follows:

$$\nu_1 = \frac{2(m-1)}{m^3 \mu_2(W)} - \frac{2}{m} \quad (5.10)$$

$$\nu_2 = (m-1)\nu_1 \quad (5.11)$$

$$\text{where } \mu_2(W) = \frac{4}{m^2(n-1)} \frac{\sum_{i,j} \mu_{2i}\mu_{2j}}{(\sum_i \mu_{2i})^2} \quad (5.12)$$

the summation in the numerator extending over the m(m-1)/2 values $i \neq j$; and μ_{2i} is the variance of the ith ranking typified by

$$\frac{1}{12}(n^2-1) - \frac{1}{12n}\sum(t^3-t) \quad (5.13)$$

χ_r^2 is given by the following formula

$$\chi_r^2 = \frac{S}{\frac{1}{12}\, mn(n+1) - \frac{1}{12(n-1)}\sum(t^3 - t)} \quad (5.14)$$

5.6 Examples

In this section, we will use examples of futures classifications similar to those given in section 5.2. In this section, however, we will use five decisions to allow for all possible classifications (V, G, F, P, C) in a scenario, and three scenarios to demonstrate multi-scenario comparisons.

Consider the eight examples of futures classifications presented in Figure 5.6:

	d_1	d_2	d_3	d_4	d_5
C_1	V	G	F	P	C
C_2	V	G	F	P	C
C_3	V	G	F	P	C

Case 1'

	d_1	d_2	d_3	d_4	d_5
C_1	V	G	F	P	C
C_2	G	F	P	C	C
C_3	F	P	C	C	C

Case 2'

	d_1	d_2	d_3	d_4	d_5
C_1	V	V	V	V	V
C_2	G	G	G	G	G
C_3	F	F	F	F	F

Case 3'

	d_1	d_2	d_3	d_4	d_5
C_1	V	V	V	V	V
C_2	G	G	G	G	G
C_3	C	C	C	C	C

Case 4'

	d_1	d_2	d_3	d_4	d_5
C_1	V	V	V	V	V
C_2	G	G	F	F	F
C_3	F	F	P	P	P

Case 5'

	d_1	d_2	d_3	d_4	d_5
C_1	V	V	V	V	V
C_2	G	G	F	F	F
C_3	F	F	P	P	C

Case 6'

	d_1	d_2	d_3	d_4	d_5
C_1	V	G	F	P	C
C_2	P	C	V	G	F
C_3	P	G	C	F	V

Case 7'

	d_1	d_2	d_3	d_4	d_5
C_1	V	G	F	P	C
C_2	C	G	P	V	F
C_3	F	C	G	P	V

Case 8'

Figure 5.6: Eight examples of decision situations

If we allow rankings to be used, cases 1' and 2' can be transformed as follows:

	d_1	d_2	d_3	d_4	d_5
C_1	1	2	3	4	5
C_2	1	2	3	4	5
C_3	1	2	3	4	5
Σ:	3	6	9	12	15

mean : 9

S : $(3-9)^2+(6-9)^2+(9-9)^2+(12-9)^2+(15-9)^2= 90$

W: 12*90/ 9*120 = 1

	d_1	d_2	d_3	d_4	d_5
C_1	1	2	3	4	5
C_2	1	2	3	4.5	4.5
C_3	1	2	4	4	4
Σ:	3	6	10	12.5	13.5

mean: 9

S: 78.5

W: 78.5/82.5 = 0.95

Formula (5.3) was used to calculate S, and formulae (5.2) and (5.4) were used to calculate W in cases 1' and 2' respectively. The coefficient of concordance shows that in both cases there is low uncertainty. In fact, in case 1' there is no uncertainty at all. If case 2' were to be restricted to the first three decisions only, there would have been no uncertainty at all in this case as well.

Both cases 3' and 4' give W=0/0 which is undefined. This is because the formulae cannot be used when all decisions for each scenario are tied. It could be argued that case 3' is less uncertain than case 4' since in the former the outcomes associated with scenario C_3 are closer to those in the other two scenarios than the corresponding ones in the latter. The question arises of how can we distinguish between the two cases.

Cases 5' and 6' are similar except for the element (3,5). In case 5' W=0.4 and in case 6' W=0.41. We can argue, in a way similar to when comparing cases 3' and 4', that case 5' is less uncertain than case 6' because element (3,5) in the former is closer to the other elements of the matrix than in the latter. Why is then W slightly lower? We can observe that C_2 treats each decision worse than C_1 does, and C_3 worse than C_2. This is more apparent in case 6', and if W is interpreted as measuring the degree of agreement between scenarios, then the result is consistent with this view. The decision maker is interested in the treatments that the scenarios will apply to his/her decision, and in case 6' there is less uncertainty that decision 5 is worse than decision 4.

Cases 7' and 8' translate respectively to:

	d_1	d_2	d_3	d_4	d_5
C_1	1	2	3	4	5
C_2	4	5	1	2	3
C_3	4	2	5	3	1

	d_1	d_2	d_3	d_4	d_5
C_1	1	2	3	4	5
C_2	5	2	4	1	3
C_3	3	5	2	4	1

which both give W=0. Thus these two cases are equally uncertain.

In case 1' it is very easy to predict that the value of W will be 1, since each decision is treated the same way by all scenarios. Generally, in all cases where the elements of each column are the same, W=1 as expected. It must be noted that W can take the value 1 in other cases as well. The condition, therefore is sufficient but not necessary. One such case is case 2 of Figure 5.4 (see also Table 5.4). This happens because although the elements of each column are different both scenarios rank the decisions in exactly the same order. It is not, however, so obvious to recognize a situation where W will equal zero, and no general rule exists. In cases 7' and 8' no comparisons can be made at first sight other than recognizing that the situations differ.

5.7 Comparison of W and the cluster analysis similarity coefficients

Except the obvious (and most important) advantage of W, which is its ability to compare more than two scenarios simultaneously, there is another point in which it is stronger than the cluster analysis coefficients. This is the fact that by definition it takes into account the degree of dissimilarity, something that the other coefficients are not designed to do. We will now use W and compare the results it gives on cases 1 to 10 (see Figure 5.4) with those given by the first similarity coefficient. The results are presented in Table 5.4 .

	(a+d)/(a+b+c+d)	W
Case 1	1	1
Case 2	0.6	1
Case 3	0.6	undefined (0/0)
Case 4	0.6	undefined (0/0)
Case 5	0.6	0.5
Case 6	0.6	0.5
Case 7	0.6	0
Case 8	0.7	0.026
Case 9	0.8	0.9
Case 10	0.9	0.974

Table 5.4: Comparison of similarity coefficient and W in 10 hypothetical cases

In case 1, which is very straightforward, both methods give the value 1 implying complete certainty. In case 2 where the second scenario treats each decision worse than the first the cluster analysis coefficient gives the value 0.6 while W equals 1. It may appear that this is a weakness of W, but since we are trying to measure the degree of difference of the two scenarios in their treatments of the decisions, and C_2 lags one level from C_1 for each decision, we can argue that there is no uncertainty about those treatments. Yet, this is a disadvantage of W if we are trying to measure the level of uncertainty of a situation.

In cases 3 and 4 W cannot be defined (it equals 0/0) since each row has the same entries. However, this translates into the fact that in such cases we no longer have a decision making situation. Our decisions are irrelevant; everything depends on which scenario will become reality. It can be argued that there is no need to measure uncertainty in such cases, since nothing can be done anyway.

In case 7, W has an advantage over the cluster coefficient, since it reflects clearly the fact that the two scenarios are in complete disagreement by giving W=0.

In case 8, the two measures give very different results. Again, W seems to have an advantage, since in half the decisions the two scenarios give opposite results.

Cases 5, 6, 9, 10 give similar values on both coefficients, and therefore do not indicate which one is preferable.

In order to explore further the comparative performance of the two indices, a simple experiment was carried out. We have shown three people the ten cases and asked them to identify a rule for ranking them in order of increasing uncertainty. All three came up with the same intuitive rule: For each decision, measure by how many levels the corresponding futures differ, and add them. The lowest number being the least uncertain case, the highest the most uncertain one. This rule can be applied only in the two-scenario case, and ranks the ten cases in order or increasing uncertainty as follows:

1 10 9 2,3 5 8 4,6,7

the numbers separated by a comma indicating a tie. It is interesting to see how the three methods rank the cases. Table 5.5 shows these rankings. For ease of presentation cases 3 and 4 (which give undefined values for W) have been omitted.

Intuitive rule	1	10	9	2	5	8	6,7	
W	1,2		10	9	5,6		8	7
(a+d)/(a+b+c+d)	1	10	9	8				2,5,6,7

Table 5.5: Rankings of ten hypothetical situations in order of increasing uncertainty

It can be seen from Table 5.5 that the three methods generally agree in ranking the ten cases in terms of increasing uncertainty. In fact, the coefficient of concordance between the three methods is just over 0.8.

From the analysis in this and previous sections, it can be concluded that W is the most appropriate measure of uncertainty, from those considered, since it has two basic advantages: First, it permits measurement when there are more than two scenarios, and second, it takes into account the degree of dissimilarity between futures.

5.8 Measurement of uncertainty using similarity measures: Discussion

The measures of similarity between scenarios presented in the previous section can be used to provide a measure of the prevailing uncertainty. The more similar two or more scenarios are, the less the uncertainty of the situation is. The previous section concluded that the coefficient of concordance W is the most appropriate measure of similarity between those presented. Using this measure, a further question which should be addressed is how to classify situations of uncertainty into different levels. For example, if W=0.4, is the situation in question of high or medium uncertainty? How can this situation be compared with another which has W=0.47? What level of difference in the values of W justifies different treatment of the problem situations?

There can be no general answer to those questions. This is because each situation has its unique features. Moreover, uncertainty about the future is often compounded with other types of uncertainty, for example UV (in terms of Friend and Jessop's classification in Chapter 2). Therefore, it is important to determine the source of uncertainty in each problem situation.

As mentioned before, uncertainty can be of many types. W measures the degree of similarity between scenarios, and thus gives an indication of the level of uncertainty about the future. If a problem is sufficiently complex, (and which planning problem is not?) a significant part of the prevalent uncertainty may stem from the lack of understanding of its structure. A variety of problem structuring methods have been developed to deal with this type of uncertainty. SRM, which is based on robustness analysis provides assistance in problem structuring, in addition to defining future possibilities.

Each problem situation has its own unique features, and therefore, there can be no general rule to determine uncertainty thresholds. Nevertheless, determining the value of W can be a valuable decision-aiding tool, especially in cases where W is relatively high. A high value of W could pinpoint the fact that the prevalent uncertainty is not a result of uncertainty about the future, but of uncertainty about the structural relationships of the elements of the problem. In such a case, effort should concentrate on structuring the present situation.

CHAPTER 6

HIV/AIDS-RELATED PLANNING

CHAPTER 6

HIV/AIDS-RELATED PLANNING

6.1 Introduction

In the next chapter the scenario-robustness methodology will be applied to a problem dealing with the provision of services to people with AIDS and/or HIV infection. In this chapter, background information on HIV/AIDS and problems associated with planning for the care of people with HIV infection will be discussed.

6.2 Definition and epidemiology of AIDS and HIV infection

AIDS is the acronym for Acquired Immune Deficiency Syndrome, a state of suppression of the immune system which is the most severe clinical manifestation of infection with the Human Immunodeficiency Virus (HIV). This virus infects a subset of peripheral blood lymphocytes, the T-cells, which are responsible for many of the functions of the cellular immune system. Infected cells lose their functional capability and die prematurely. This defect of the immune system leads to susceptibility to infection with opportunist agents, and to the development of particular groups of tumours. It has also been recognized that HIV infected patients may also develop a spectrum of other diseases without the presence either of opportunist infection or tumour [Weber and Pinching 1986]. The commonest of these conditions are persistent generalised lymphadenopathy (PGL) and AIDS related complex (ARC). Both are described as a combination of symptoms, signs and laboratory abnormalities, but PGL is less severe than ARC. Moreover, patients with ARC are likely to develop AIDS sooner than those with PGL only.

It is generally believed that an HIV infected person will eventually develop AIDS. However, since the disease is relatively new, and estimates of the incubation period (the time between infection and clinical manifestation of the disease) vary widely, the timing of such progression is uncertain. Estimating progression rates to clinical AIDS in seropositives (people who have been tested positive for HIV) is a matter of following them over a relatively long period of time. As time progresses and evidence from more studies comes to light such estimates are continuously reassessed. Early studies [Goedert et al. 1987, Polk et al. 1987] estimated progression occurring about 5-6 years after infection. More recent studies however, give much longer estimates for the average incubation period; Longini et al.[1989] estimated it as 9.8 years, Lemp et al.[1990] as 11.8 years, Satten et al.[1992] as 10.3 years, whereas Bailey [1994] reports a value of 11.7 years.

The key routes of transmission of HIV are sexual transmission, blood or tissue transmission, and maternofoetal transmission [Piot and Caraël 1988, Institute of Medicine 1986]. In Europe and North America there is greater prevalence of infection in homosexual men, although the prevalence of HIV in the heterosexual population is continuously growing [Slutsker et al 1992]. In central Africa transmission appears to be predominantly through heterosexual intercourse, with an equal number of male and female cases [Quinn et al. 1986, Weber and Pinching 1986, Mann et al.1992]. The major route of blood to blood transmission in developed countries is by the sharing of needles and equipment between injecting drug users (IDUs). In earlier stages of the epidemic where the cause of AIDS was not determined and tests had not been developed, a large number of people suffering from haemophilia, a condition which requires receiving blood products (factor VIII or IX), were infected [Murphy and Dietrich 1992]. The transmission dynamics of HIV infection and the estimation of key epidemiological parameters are the subject of extensive research. Numerous mathematical and statistical models are available for studying various aspects of the HIV/AIDS epidemic [Anderson et al. 1986, Anderson 1988a &b, Jager and Ruitenberg 1988, Isham 1988, Roberts and Dangerfield 1990, Caulkins and Kaplan 1991, Homer and St. Clair 1991, Sexton and Feinstein 1991, Brailsford and Shahani 1994, Williams and Anderson 1994].

6.3 Treatment of HIV/AIDS

At present there is neither a cure nor a vaccine for AIDS. No vaccine is expected to be developed within the next 10 years. However, a large number of drugs which aim at debilitating the virus are currently under development. At present, a number of such drugs are administered to patients to alleviate symptoms and prolong life expectancy. Of these, the most widely used are AZT, ddI and ddC, either on their own or in some combination [Morton 1992]. These drugs are all of the anti-viral type. This means that they attack the HIV lifecycle at some stage, aiming at slowing its replication rate, thus preventing the fast destruction of the immune system. An important problem concerning drug development is HIV's genetic variability: differences in genetic sequence can be observed between variants of a same type of HIV found in different patients, and even in the same patient. HIV variants have appeared during long-term treatments by drugs such as AZT or ddI. As a result, the virus escapes the drug. Therefore, research for more effective drugs is directed towards the development of complex specific treatments using combinations of molecules which could inhibit the viral replication cycle at the same stage or at different stages [Barré-Sinoussi 1992].

Since HIV attacks the immune system, a patient may develop a wide variety of opportunistic infections, which are in turn treated using many different drugs. A distinction should be made therefore, between those drugs which treat the effects of the virus and the antiviral drugs which attack the virus itself. Because the latter are to a greater or lesser extent toxic, only a proportion of patients are able to take them.

6.4 Uncertainties associated with HIV/AIDS

There is a wide variety of uncertainties surrounding the HIV/AIDS problem. These can be classified under three broad headings: uncertainty about the nature of the disease, uncertainty about future demand for services, and uncertainty about the availability of future treatments. Of these we will concentrate on the latter two categories which are of particular interest to planners.

6.4.1 Uncertainty about future demand for HIV/AIDS-related services

Future demand for HIV/AIDS-related services is a function of many factors:

(1) Uncertainty about current prevalence and future incidence. Prevalence generally refers to "the number of persons in a given population with a disease or an attribute at a specific point in time", whereas incidence is defined as "the number of new events (e.g. cases of a disease) in a defined population within a specified period of time" [International Epidemiological Association 1983]. Obviously any future demand on service provision is directly related to both current prevalence and future incidence. A number of alternative estimates have been calculated by epidemiologists, based on a wide range of assumptions. Compulsory testing has been proposed as a means of collecting more information about HIV prevalence but both the usefulness and ethics of such a practice have been strongly questioned. Reliance on voluntary testing has the disadvantage that volunteers cannot be expected to provide proportional representation of all the groups at risk. Currently the AIDS Centre of the Public Health Laboratory Service at the Communicable Disease Surveillance Centre is coordinating the unlinked anonymous HIV prevalence monitoring programme with the support of the Medical Research Council and the Department of Health [PHLS 1993b].

(2) Uncertainty about the accuracy of currently recorded data. Current data is subject to double counting and poor reporting. Estimates of HIV and AIDS prevalence usually take this factor into account and allow for under-reporting or reporting delays [Dept. of

Health 1988, PHLS 1990, PHLS 1993a, De Angelis and Gilks 1994, Evans and McCormick 1994].

(3) Uncertainty about the transmission dynamics of the disease. There is still a high level of uncertainty about the length of the incubation period and the pattern of spread of the disease. Since only longitudinal studies can provide reliable estimates, and the disease is relatively new, a possible way to deal with the problem is the use of alternative assumptions about the growth of the disease. Such alternative forecasts have already been provided by the Cox [Dept. of Health 1988] and both Day reports [PHLS 1990 and 1993a].

(4) Changes in behaviour may affect the spread of the disease and consequently the pattern of demand for services. Therefore, behavioural studies such as the National Survey of Sexual Attitudes and Lifestyles [Johnson et al. 1992] can provide valuable inputs to alternative future projections of AIDS incidence by exposure category, such as those of both Day reports [PHLS 1990, 1993a], which in turn are of particular interest to service providers.

6.4.2 Uncertainty about drugs/treatments

The development of new drugs and treatments will affect the life expectancy of the patients, and consequently the demand of services. This issue is discussed extensively in the next chapter, where different scenarios are built about the type, availability and implications of alternative drug treatments.

6.5 A microcomputer-based system for planning HIV/ AIDS services

6.5.1 Introduction

This section describes the development of a microcomputer-based system to assist planning for HIV/AIDS-related services. Detailed descriptions of the development process, the system's structure and examples of use have can be found in Rizakou et al. [1991] and in Forte et al. [1994]. A detailed description of the system can be found in Appendix I of this thesis. In this section some background information on the planning problems associated with HIV/AIDS in the UK, and a general description of the system will be given.

6.5.2 Planning for HIV/AIDS in the UK context

To date, there have been about 10,000 AIDS cases in the UK and money has been targeted explicitly by the Department of Health for HIV/AIDS-specific services. The complexities of service planning between health authorities and local governments where inputs of both medical and non-medical services are required, are not made any easier by the fact that boundaries between the two agencies are not often co-terminous. The private sector also provides mainly hospital-based services but is not, as yet, a major provider of AIDS services. The voluntary sector is, perhaps, more important, particularly in providing informal support networks (especially in the homosexual community) which can have a bearing on the quantity and type of statutory service provision that is required.

Understanding the way in which earmarked funds can be used is even more significant following the 1991 reform of the NHS, which introduced an "internal market". Health authorities, as purchasers of care for their residents, are expected to assess need and contract with providers (hospital and community units) for appropriate levels of service. In 1993, further legislation introduced similar responsibilities for local authorities, who are now charged with organizing and commissioning long term care for people to be treated in a community rather than institutional setting. This will increasingly include the non-medical care requirements of people with HIV and AIDS.

It is this multi-agency dimension which is the nub of the service planning problem. Certain aspects of the treatment for people with HIV/AIDS - and particularly full-blown AIDS - are very clearly hospital-based, requiring specialized acute treatment, often in specialized units. However, there are large components of care for non-acute phases of the disease which can take place in community health facilities, such as GP surgeries, but may also require inputs from other agencies such as social services, housing departments, and the voluntary and private sectors. The central issue is how much of which service is required for whom, and who pays for it.

This planning problem is recognized, if only implicitly, through the large AIDS planning committees which have been established in most health authorities. These seek to involve the main statutory and voluntary agencies and groups likely to be involved in HIV/AIDS service provision or representation of client groups at the local level. This, in turn, means that there is usually no shortage of ideas as to the needs of people with HIV/AIDS. What is lacking, however, is a suitable vehicle for assessing the resource consequences of possible care policy innovations, particularly where a variety of treatment options exist for a given level of dependency and where these options span a range of different care-providing agencies.

This problem is not unique to the HIV/AIDS arena; similar situations face planners of long-term care services for other client groups, including the elderly and people with long-term mental illness. This means that general planning frameworks developed for these other client groups can also contribute to HIV/AIDS service planning, taking account, of course, of unique characteristics of this client group. In the case of people with HIV/AIDS the planning framework includes the following tasks:

-estimating local level prevalence of HIV/AIDS

-keeping in view the range of agencies, services and local interest groups with a contribution to make

-developing appropriate care plans when "best practice" is constantly changing in response to new drugs and therapies

-establishing contracts between purchasers/ commissioners and providers to supply these services

6.5.3 *The AIDSPLAN system*

In 1988, the Operational Research Service of the Department of Health began work on a planning model to address the issue of local level resource planning for people with HIV/AIDS. In conjunction with with the Operational Research Group at the London School of Economics (LSE), the model was developed into the microcomputer-based decision support system, AIDSPLAN. This system is designed for use, by local managers concerned with planning HIV/AIDS-related services, as an option-scanning device to examine the strategic level consequences of particular policies. The approach was based on the Balance of Care model: a framework developed earlier for long-term care planning for elderly people [Bowen and Forte 1987]. The original version of AIDSPLAN itself is a customized spreadsheet developed in Lotus Symphony.

LSE and ORS worked together to develop the AIDSPLAN system [Bowen et al. 1989]. The then Parkside Health Authority agreed to fund the development of a planning model similar in structure to that proposed by ORS. Work was conducted over a period of one year from autumn 1988 to autumn 1989 when the system was finally delivered. A modified version of the model was made available to other interested health authorities. In 1994 a revised version of the model was introduced to follow the release of new forecasts of HIV/AIDS prevalence for England and Wales [PHLS 1993a].

The format and operation of AIDSPLAN are described in detail in Appendix I. However, it would be appropriate here to summarize the way in which AIDSPLAN works.

Conceptually, AIDSPLAN can be thought of as two submodels, a population submodel and a care options submodel. In the first of these, current data on the patient workload are fed into the model to produce local estimates based on the official Day national forecasts [PHLS 1990] of future patient numbers by patient categories. Three forecasts can be selected: low, medium or high. These patient numbers in turn form the input to the second sub-model, which contains costed care options specified for each patient category. It then calculates estimates of the costs and resources required to treat these numbers of patients using the identified care options.

Figure 6.1 gives an overview of AIDSPLAN. The rounded boxes represent inputs and tasks performed by the user, and the rectangular boxes show the results of calculations carried out by the model.

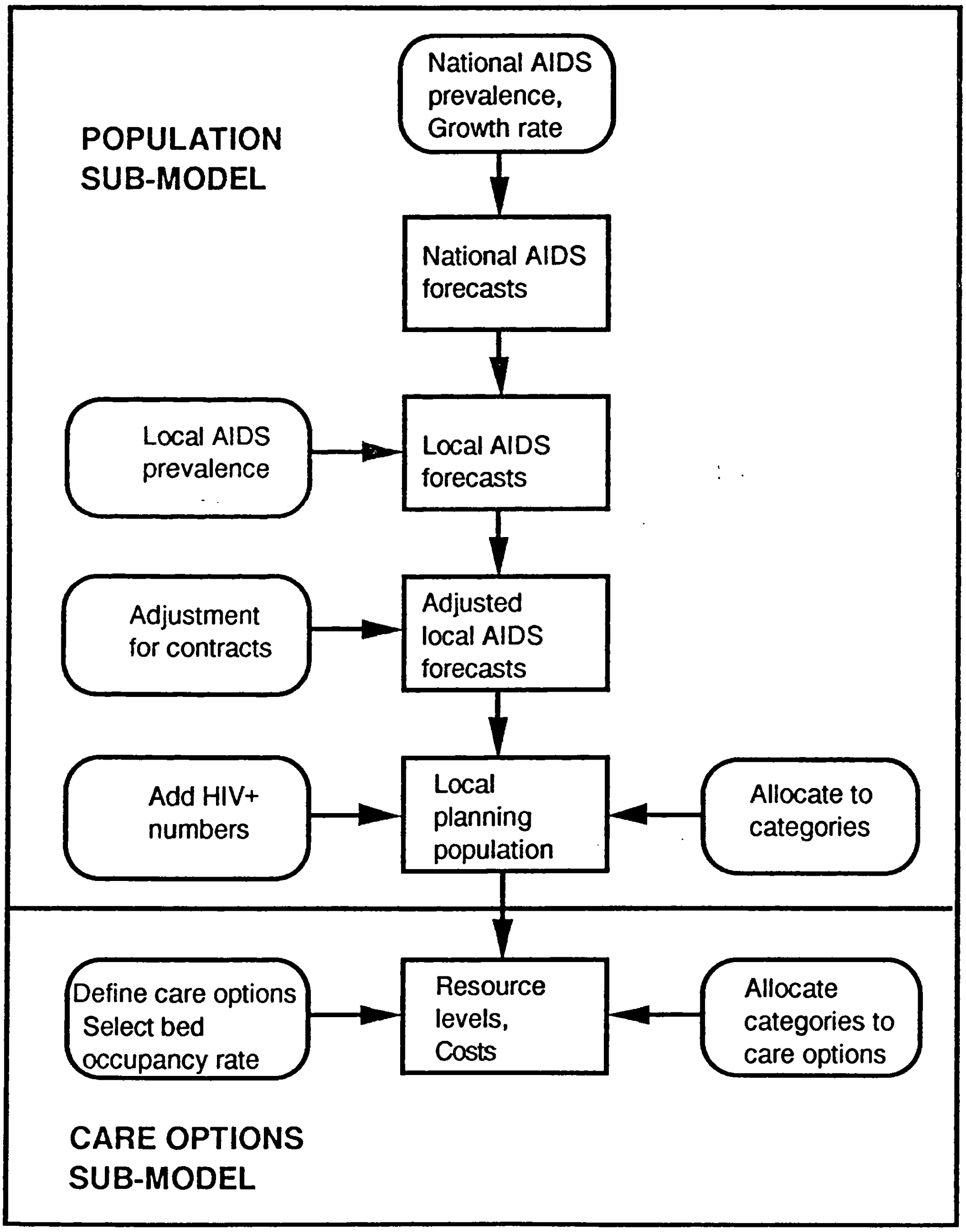

Figure 6.1. AIDSPLAN overview

The next chapter presents the application of SRM to an HIV/AIDS planning problem. AIDSPLAN proved to be a valuable tool in structuring the problem and determining the resource implications of the alternative scenarios.

CHAPTER 7

THE USE OF SRM IN PLANNING FOR HIV/AIDS

CHAPTER 7

THE USE OF SRM IN PLANNING FOR HIV/AIDS

7.1 Introduction

In Chapter 3 the importance of preserving future flexibility when dealing with complex situations of high uncertainty was discussed. By maintaining a high level of flexibility the decision maker(s) may avoid adverse consequences and even benefit from unexpected opportunities. SRM, as an extension of robustness analysis, is a method which assesses the relative flexibility of particular decisions. Moreover, by embodying elements of scenario analysis it attempts to give a structured picture of the uncertainties facing the decision maker(s). SRM, therefore, is designed to assist decision making in two ways: first, by structuring uncertainty and presenting the alternative futures as scenarios, and second, by assessing the relative flexibility of the decision makers' intended commitments. In this chapter SRM will be applied to an HIV/AIDS planning problem to examine its suitability for use in such situations. At first sight, planning for HIV/AIDS may seem an odd choice of area to apply a strategic planning methodology such as SRM; strategic planning is usually associated with business, industry or government. However, scenario analysis has already been used in connection with AIDS [van Druten et al. 1992, Beckmann 1992, Reinking et al. 1992, Leidl et al. 1992, Jager and van den Boom 1994]. Planning for HIV/AIDS has all the required elements of a problem situation which requires a strategic planning approach: it is beset by uncertainty, it is quite complex, and there is a variety of interested parties with different, though not necessarily conflicting objectives.

As discussed previously, planning the provision of services to people with AIDS and HIV associated illness presents problems of quite unusual intensity. The heterogeneity of the client group and the wide variety of associated conditions makes demands across the whole spectrum of hospital-based services. The cycle of acute episodes and periods of remission among a relatively youthful affected population produces calls on a whole range of community services provided by numerous statutory and voluntary agencies. Uncertainty about the current size of the infected group and about the transmission dynamics of HIV infection results in a wide variation in legitimate estimates of demand for services and consequently in estimates of resource requirements. Moreover, uncertainty about future availability of treatment affects not only the level of projected resource requirements but also their pattern.

Under such conditions of complexity and uncertainty, the application of a methodology such as SRM would appear prima facie to have a contribution to make in preserving the necessary flexibility to meet future uncertainties. In the illustration which follows, the microcomputer model AIDSPLAN, presented in the previous chapter, will be used as a decision support tool in conjunction with SRM. As AIDSPLAN is designed to provide answers to "what if..." questions, it can be used to explore the consequences of alternative decisions and scenarios in terms of resources. Thus, AIDSPLAN will be used under various hypotheses concerning future patient numbers and alternative modes of treatment, to produce different sets of resource requirements. These will then be analyzed using SRM to assess the future flexibility of alternative decision commitments which need to be made now. The objectives of this analysis are to examine the suitability of SRM in situations of high uncertainty, to find any other elements that might be incorporated into it, and to pinpoint any aspects where its procedures need strengthening.

There is no formal test for the suitability of methodologies such as SRM for particular problems. A possible way to assess the success of the analysis might be to judge retrospectively whether the choices indicated by SRM analysis were appropriate. Even then, it is very difficult to assess whether any particular choice was justified. For example, a risk averse decision maker might choose the commitment which avoids an outcome perceived as catastrophic over another commitment with many desirable outcomes but including a possible catastrophic result under a particular future. If this future fails to materialize, it does not necessarily follow that the decision maker was wrong in taking the particular decision.

It must be emphasized at this point, that all methodologies within the family of problem structuring methods (which includes SRM) do not attempt to prescribe solutions: rather, they assist decision makers to understand the problem situation and the implications of their decisions. It is they who ultimately decide, after careful consideration of the available information.

The decision making bodies which have an interest in planning the provision of HIV/AIDS-related services include the Department of Health, health authorities, GPs, hospitals, various voluntary and private organizations, and local government through housing and social service departments. Of these, health authorities and hospitals would benefit most from the use of SRM, for a number of reasons. The AIDS services provided by health authorities and hospitals tend to be much more expensive than those provided by other agencies. Moreover, health authority and hospital decisions with respect to HIV/AIDS are interconnected, thus increasing the complexity of the problem.

It has not proved possible to conduct a "live" use of the methodology on HIV/AIDS material. However, we have constructed a plausible, if simplified, version of an HIV/AIDS-related planning context by using information obtained during the development of AIDSPLAN, more recent interviews with health authority and hospital staff, and the published literature[1]. The following section describes this context.

7.2 The problem situation

Consider an NHS trust hospital which treats a number of AIDS patients in a dedicated ward. The hospital's objectives with respect to the HIV/AIDS problem include: to

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[1]Some of the information used in this example was obtained during the development of AIDSPLAN a few years ago. However, its purpose is as an example of SRM, not as a model of current NHS arrangements.

contain or reduce the average cost of treatment per patient per annum while maintaining their ability to secure and fulfil their contracts for treatment of HIV/AIDS patients at a bed occupancy rate of between 90% and 95%. The management believes that they may be able to bid successfully for funds to expand their AIDS services. These funds could be used for opening a second ward dedicated to AIDS patients and for expanding the day and outpatient facilities. The size of this new ward, if decided on, may lie between 11 and 36 beds -the precise number would need to be recommended. A second possibility is that the funds could be used to expand the existing ward and outpatient facilities -with a maximum level of expansion of 16 extra beds. Alternatively, the management may decide not to bid, leaving the situation as it is. Yet another possible initial decision could be to reduce the number of AIDS dedicated beds[1], by a maximum of 6 beds.

In responding to the hospital's decision to open a new AIDS ward or expand the day and outpatient facilities, district health authorities and GP fundholders may increase the number of patients for whom they make contracts for treatment with the hospital; or contracts could remain essentially unaffected[2]. A fall in the number of patients for whom contracts are made is not expected. If, however, no expansion or a reduction in facilities takes place, contracts are expected either to stay unaffected or decrease.

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[1] Since the number of AIDS patients treated in the hospital has been increasing steadily, it was felt initially that such a decision should not be considered. However, subsequent analysis using AIDSPLAN showed that under certain future conditions, an initial decision resulting in a reduction of resources could be appropriate.

[2] Currently, in most cases, the HIV/AIDS budget is ringfenced. This means that patients are not accepted for treatment on a basis of a contract between the care provider and the purchasing authority. Instead, the hospital receives from the health authority an amount based on expected caseload and activity levels. This practice, however, will be eventually phased out and replaced with the internal market system. Since the analysis focuses on 1999, it is reasonable to expect that by then the contracts system will have been well established.

7.3 Modelling the problem situation

The previous section describes the hospital's decision situation only in very general terms. In order to represent the situation in a way which makes it tractable by SRM, further details or assumptions are needed. If the hospital decides to expand the outpatient facilities and either to open the new ward or to expand the existing one, a decision horizon of two years seems justified, since by then the implementation of the decisions will have been completed and the management will be able to evaluate the initial results.

The planning horizon will be determined both by the nature of the uncertainties for which the scenarios must be built, and by operational considerations. Significant elements of the uncertainties under consideration, such as the future availability of new drug treatments for example, will not appear for at least another three years. On the other hand, AIDSPLAN can make predictions for up to five years[1]. The planning horizon, therefore, must lie between these two figures. The selection of the planning horizon as five years ahead seems reasonable, since by then the possible effects of a new drug treatment available after the first three years would have a better chance to become evident.

In addition to patients treated in the hospital under contracts, patients can also be admitted to the hospital as emergency cases, or can use the hospital's walk-in GUM clinic. The number of patients who do so is thought to be directly related to the number of HIV+ people resident in the districts which have contracts with the hospital. In the absence of data on local HIV+ prevalence, the only possible assumption, though rather

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[1]AIDSPLAN can actually be used to make predictions for as many years as required. However, it assumes that the pattern of growth in AIDS cases for the second and subsequent five year periods, is similar to that for the first. If the user has accurate predictions of numbers of AIDS cases from external sources, s/he can input them to the model directly and then calculate the corresponding resource implications. However, official data on future AIDS cases is available for the next five years only.

crude, is that the growth in the number of such patients is proportional to the number of AIDS cases nationally.

7.4 The Scenarios

In addition to uncertainty about the likely workload, there is also uncertainty about the mode of treatment of the patients. Any new drug that may be introduced is expected to have the same characteristics as the drugs currently administered to patients (AZT, ddI and ddC): it would offer alleviation of symptoms rather than a complete cure, and would be toxic to some degree. The introduction of a new drug may affect seriously both the amount and the type of resources needed to provide treatment. Relevant factors needing consideration include[1]:

Side-effects: Because of AZT's toxicity, some patients need blood transfusions. The percentage of patients who need transfusions has dropped since 1988 from 50% (the figure used in the care options devised for AIDSPLAN) to around 5%-10%, due to reduced dosages. It will be assumed that the new drug will be less toxic than AZT, thus reducing the number of transfusions needed.

Cost: The price of the new drug is generally expected to be similar to that of AZT or cheaper. To calculate the cost of treatment the cost of other drugs used to alleviate the side-effects of the antiviral drug must also be considered. For example, ddI and ddC cause side effects that can be reduced using cheaper drugs than those used for AZT's side effects.

Effectiveness: The new drug could prolong either the asymptomatic phase, or the patient's life expectancy after full-blown AIDS has been diagnosed, or both. The drug under consideration in this illustration will be appropriate to symptomatic patients only.

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[1] Many of the assumptions made about the introduction of a new drug have been suggested by Anthony Pinching, Professor of Immunology at St. Bartholomew's Hospital, London.

In the case of patients with full-blown AIDS, a reasonable assumption is that the new drug will double life expectancy.

Eligibility: We need to determine to which patient category/ies the drug will be administered, and to what proportion of patients in each category. An indication of a patient's eligibility for antiviral therapy with a drug of AZT's type is a low CD4 count. The CD4 count measures the number of CD4 (or T4) cells in the blood. The lower this number, the less immune the patient becomes. The CD4 count-however, is an expensive test: to monitor the patient's eligibility for the drug properly the test needs to be carried out every three months at a cost of £25 per test. It is expected that around 70% of the total caseload may not be eligible for the new drug.

Length of hospitalization: One of the possible effects of the introduction of a new drug on the pattern of care is reduced hospitalization. A working hypothesis could be that the new drug may reduce the annual number of days spent in hospital per patient by 50%. It is unlikely that any new drug will be given intravenously- therefore, we can assume that no extra resources will be required for its administration.

All of the above factors can be combined to produce three possible scenarios related to the introduction of a new drug. The first is a projection of the status quo, that is AZT is administered in combination with other drugs to symptomatic patients only. Some 10% of those who take it need transfusions. The costs of both AZT and other drugs administered to the patients to alleviate side effects remain at their present high levels. Patients who receive this treatment have less illness episodes requiring hospitalization than those who do not, and consequently consume less of the corresponding resources.

The second scenario explores the possibility of a new more effective antiviral drug taken on its own. Any other drugs administered to the patients would treat or alleviate the symptoms of secondary infections. This scenario is not very realistic, since current practice has moved towards treatments with combinations of antiviral drugs[1]. However, we will consider the scenario for illustrative purposes.

It will be assumed that this drug will have a price similar to AZT, will be less toxic and will work on its own even after prolonged treatment. It will be administered to AIDS patients only, but at a higher proportion than that for AZT. The drugs bill per patient will be slightly reduced due to the lower dosages of other drugs needed to combat its side effects. Hospitalization rates will be similar to those of patients who are currently receiving AZT. Thus, the total hospitalization cost per patient (excluding the cost of the drug) will fall.

The third scenario describes the possibility of the discovery of a new drug that can be administered in combination with already existing drugs, such as ddI or ddC. This drug will be assumed to be suitable for all symptomatic patients. It will delay the progression to AIDS and the number of acute episodes after AIDS. Its cost per dose will be similar to AZT, but is expected to fall two years after its introduction. For these first two years, the drugs bill per patient treated with this drug will be similar to that in the second scenario. This drug is expected to lead to lower hospitalization rates through the reduction in the number of episodes requiring hospital admission.

7.5 The parameters

We will now translate the problem situation and scenarios described in the previous section into terms compatible with SRM. It should be recalled that with SRM, the decision maker is seen as facing a number of alternative decision packages, which may be followed by a set of responsive actions. Conjectures must be made about factors

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[1] There are two reasons for this: First, after prolonged treatment with one drug, the virus becomes resistant to it, and therefore a switch is recommended. Secondly, patients react differently to the same drugs. For some patients, a combination of drugs is more beneficial than corresponding dosages of a single drug, and results in less serious side effects.

other than responsive actions affecting the consequences of the initial decision packages in the short term. For the long term, alternative scenarios must be constructed. Configurations of the operating system both in the short and long terms must be identified, and choices are required about the length of both the short and long terms.

The decision packages[1] available to the management are as follows:

d_1: Open new ward and expand out-patient facilities

d_2: Expand existing ward and out-patient facilities

d_3: Do nothing

d_4: Reduce number of beds and associated staff

There are three possible responsive actions[2]: The number of contracts increases, remains unaffected or decreases. Table 7.1 lists the initial decisions and the possible responsive actions. (It should be noted that responsive actions of a particular type may be of different magnitude.) The empty cells of the table indicate that the particular responsive action is incompatible with the initial decision.

		Responsive action (j) Contracts		
		1. Increase	2. Unaffected	3. Decrease
Initial Decision (i)	1. New ward	√	√	
	2. Expand	√	√	
	3. No change		√	√
	4. Reduce		√	√

Table 7.1: Initial decisions and responsive actions

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[1] Throughout this chapter, decision packages will be referred to as "decisions" for simplicity.

[2] In the responsive action a_{ij} the first index i refers to the decision d_i to which the jth action is taken as a response.

According to a Department of Health report [PHLS 1993a], three AIDS growth rates can be considered: Low, medium and high. Therefore the three conjectures are:

c_1: AIDS growth rate is low

c_2: AIDS growth rate medium

c_3: AIDS growth rate high

By combining responsive actions and conjectures, nine possible future operating environments can be identified:

1. AIDS growth rate is low and contracts increase.
2. AIDS growth rate is low and contracts remain unaffected.
3. AIDS growth rate is low and contracts decrease.
4. AIDS growth rate is medium and contracts increase.
5. AIDS growth rate is medium and contracts remain unaffected.
6. AIDS growth rate is medium and contracts decrease.
7. AIDS growth rate is high and contracts increase.
8. AIDS growth rate is high and contracts remain unaffected.
9. AIDS growth rate is high and contracts decrease.

Each situation (initial decision plus environment) must be evaluated under the following three scenarios:

C_1: AZT in combination with other drugs

C_2: A new stronger drug which works on its own

C_3: A new drug in combination with other drugs

7.6 Specification of AIDSPLAN runs

Since there are nine possible operating environments and three scenarios, there must be at least 27 configurations, each of which performs well under each combination of environments and scenarios. AIDSPLAN was used to identify these configurations.

By inputting various hypotheses about patient demand, mode of treatment, and bed occupancy rate, the model produced the corresponding resource requirements and costs. These results were used to formulate desirable configurations. Some variations from the desirable format were also considered. The assumptions that needed to be made to use AIDSPLAN are listed below:

<u>National forecasts of AIDS cases</u>: Three levels were considered; low, medium, and high using data from the Day 2 report [PHLS 1993a]. This report gives annual projections of national AIDS cases by risk group. A most likely estimate and its upper and lower limits are given for each risk group. To keep the analysis manageable, it was decided to exclude combinations of different levels of risk group estimates. The three estimates were taken to represent the three different levels of forecast.

<u>Local forecasts of AIDS cases</u>: These were calculated pro-rata to the national cases, using the proportion of the national caseload that was treated in Parkside in 1992. This calculation assumes no change in contract levels. Separate forecasts were needed to reflect any changes in contract levels. According to the 1992 AIDS (Control) Act Report for Parkside, only one third of HIV or AIDS cases treated in Parkside were also resident there, and since it was assumed that only non-residents were affected by changes in the contracts, either an increase or a decrease in the level of contracts would affect two thirds of the estimated caseload. The level of the change was taken as 20%. Setting up the AIDSPLAN runs to reflect changes in contracts was achieved by using the facility provided by the model to calculate cross-boundary flows.

<u>Local forecast of HIV+ cases (excluding AIDS)</u>: Since no future estimates of the national HIV+ numbers were available, to estimate the future number of HIV+ cases locally, an extrapolation based on an assumption of a constant proportion of HIV+ to AIDS cases given in the Parkside was made.

A set of different estimates of patient numbers for 1996 (decision horizon) and 1999 (planning horizon) based on the above assumptions is presented in Tables 7.2a and 7.2b below.

Level of demand	Contracts	HIV+	ARC	AIDS
Low	Decrease	775	365	327
Low	Unaffected	895	421	378
Low	Increase	1013	477	428
Medium	Decrease	897	422	379
Medium	Unaffected	1035	488	437
Medium	Increase	1175	553	496
High	Decrease	983	462	415
High	Unaffected	1137	535	480
High	Increase	1286	605	543

Table 7.2a: Expected patient numbers for 1996

Level of demand	Contracts	HIV+	ARC	AIDS
Low	Decrease	819	385	346
Low	Unaffected	948	446	400
Low	Increase	1072	504	453
Medium	Decrease	990	466	418
Medium	Unaffected	1142	538	482
Medium	Increase	1293	608	546
High	Decrease	1205	567	509
High	Unaffected	1390	654	587
High	Increase	1576	741	665

Table 7.2b: Expected patient numbers for 1999

Care Options: Three alternative care options were developed to reflect the three different drug treatment scenarios. It was assumed that due to general ill health, injecting drug users (IDUs) would not be eligible to be treated either with AZT or with the two new drugs. It was also assumed that the reduction in hospitalization by 50% resulting from the administration of the new drug treatments would be reflected in a corresponding increase in out-patient or day patient visits. The reduction of hospitalization would be due to the drug's effect in reducing the number of illness episodes requiring hospitalization. For this to happen, it was assumed that patients would need more visits to the outpatient clinic to get their prescriptions and to be properly monitored. As can be seen from Table 7.3, at the time of data collection, the average AIDS patient visited the outpatients clinic 16 times per annum and spent 27 days p.a. as an inpatient. The 27 inpatient days corresponded to an average of three episodes requiring hospital admission. It is therefore reasonable to assume that the patient would visit the OP clinic once a month plus once after each episode. If the administration of the new drug reduces the number of episodes and thus hospitalization by 50%, the average number of follow-up visits would drop to 1.5. Assuming that under the new drug regime the patient would need to visit the OP clinic twice a month, the OP visits increase to approximately 25. Using the same logic, the figure for OP visits of ARC patients becomes 19. Since HIV+ asymptomatic patients are not eligible for any of the drugs under consideration, it will be assumed that no change in their visiting pattern occurs. The following table summarizes the information used to calculate the increase in OP visits resulting from a 50% decrease in hospitalization.

	HIV+	ARC	AIDS	Total
Current patient number	829	390	350	1569
IP days per patient per annum	0	7	27	n/a
OP visits per patient per annum	4	10	16	n/a
OP visits per patient taking drug p.a.	4	19	25	n/a

Table 7.3: Outpatient visits resulting from a 50% decrease in hospitalization

A summary of the assumptions concerning the effects of the new drug treatments is given in Table 7.4:

	Scenario 1	Scenario 2	Scenario 3
Cost of drug	As before	As before	20% less
Cost of other drugs	As before	20% less	As before
Transfusions	As before	50% less	50% less
Hospitalization	As before	50% less	50% less
OP visits	As before	more	more
Eligibility	AIDS	AIDS	ARC, AIDS
Proportion of category taking drug	50%	60%	50%, 70%

Table 7.4: Summary of the effects of the three drug treatment scenarios

Bed occupancy rate: Since the hospital considers a bed occupancy rate of between 90% and 95% acceptable, the model was run for both these figures, to identify corresponding upper and lower bounds for the number of beds required. This was achieved by setting the conversion factors provided by the model to transform resources from the units in which they are expressed in the care options (e.g. annual in-patient days) to meaningful annual resource units (e.g. number of beds).

Cost per case: to compare the cost per case figures, the cost of treatment for AIDS non-IDU cases was used. The average over-all cost was considered not representative, since the vast majority of patients are HIV+ asymptomatic who would not take any of the three drugs described in the scenarios. For the same reason, IDUs were excluded. Moreover, it was felt that a reduction in the cost of the most expensive category to treat (AIDS non-IDU) would be an advantage in establishing future contracts, since care purchasers would be attracted by the reduced cost offered.

7.7 AIDSPLAN Output

The information and assumptions listed in the previous section were used to run AIDSPLAN with contrasting formulations. For the decision horizon, each formulation represents a possible future operating environment, and for the planning horizon each formulation represents a possible future operating environment and mode of drug treatment. Thus, in each run, the following parameters could be varied:

i) The rate of growth of HIV+ and AIDS cases (Low, Medium, High) - for both horizons
ii) The level of contracts (Decrease, Unaffected, Increase) - for both horizons
iii) The mode of drug treatment (Scenarios 1, 2 and 3) - for the planning horizon only

Moreover, for each formulation, an upper and a lower limit for the number of beds were produced: the upper limit representing a bed occupancy rate of 90% and the lower limit one of 95%.

In this specific application of AIDSPLAN, the model produces for each run the level of resources, and their associated costs, needed for the hospital to function under the particular specifications at both the decision and planning horizons (in this case 1996 and 1999 respectively). For simplicity in what follows information on only a limited number of input resources has been recorded and reproduced; other resources consumed which are not explicitly presented here, such as transfusions, counselling etc. are included in the annual cost figures per patient. Table 7.5 shows the level of hospital resources required at the end of 1994 (assumed to be the current year). These were generated by running AIDSPLAN with the latest local figures for HIV+ and AIDS cases and current mode of treatment (Scenario 1). The output from AIDSPLAN shows that the hospital should have 39 AIDS beds attended by 42 Whole Time Equivalent (WTE) nurses and 10 WTE doctors. Two WTE nurses and four WTE doctors should be employed in the out-patients department.

Beds	39
Number of nurses for in-patients	42
Number of nurses for out-patients	2
Number of doctors for in-patients	10
Number of doctors for out-patients	4
Total cost of AZT (£'000s)	938
Total cost of other drugs (£'000s)	773
Cost per AIDS patient per annum	£8,111

Table 7.5: Current level of resources

The output from the series of runs of AIDSPLAN carried out for 1996 is presented in Table 7.6a, and the output for 1999 is presented in Table 7.6b. Table 7.6b is divided into three sections, one for each scenario, whereas Table 7.6a represents the scenario 1 only (Status Quo), since at the decision horizon no new drugs (scenarios 2 and 3) are expected to have been developed. Each row of the tables shows the results of two runs of the model, one for each rate of bed occupancy. The first two columns describe the operating environment. The third column gives two figures for the number of beds required; the lower corresponding to a bed occupancy rate of 95% and the higher to one of 90%. Columns 4 to 7 give the required number of in-patient nursing staff (IPN), out-patient nursing staff (OPN), in-patient medical staff (IPD) and out-patient medical staff (OPD), respectively. The eighth column gives the total cost of drugs other than AZT or those that will replace it under scenarios 2 and 3. The ninth column gives the cost of AZT or the new antiviral drugs in scenarios 2 and 3. Finally, the last column gives the total cost af treatment for all patients. The information in both tables will be used in the next section as a guide to construct alternative future configurations of the hospital, which will then be evaluated, and used to apply robustness analysis to assess the relative flexibility of the initial decisions.

One of the factors to be used to evaluate the performance of the system at the planning horizon is the cost per AIDS (non-IDU) patient per annum for each of the three scenarios. These figures are:

Scenario 1: £8,111
Scenario 2: £8,365
Scenario 3: £8,140

For each scenario there is only one annual cost figure per AIDS patient. All cost figures are marginal costs, in the sense that they do not include overheads. Since the uncertainty in this problem relates to the size and mix of the caseload and the mode of treatment, any costs that are not dependent on these factors may be treated as irrelevant, at least as a first approximation. For the reasons explained at the end of section 7.6, it was decided to record the annual cost of treatment per AIDS patient. Since the differences in these costs for the three scenarios are trivial[1], they were not taken into account in the evaluation of the performance of the system. Instead, it was decided to consider the level of non-expendable resources required to treat patients under each future.

INPUT		OUTPUT							
1	2	3	4	5	6	7	8	9	10
Level of demand	Contracts	Beds	IPN	OPN	IPD	OPD	OD (£000's)	AZT (£000's)	Total Cost (£000's)
Low	Decrease	35/37	39	2	9	3	726	865	2758
Low	Unaffected	41/43	46	2	10	4	838	1000	3184
Low	Increase	46/48	51	2	12	4	948	1129	3597
Medium	Decrease	41/43	46	2	10	4	838	1005	3187
Medium	Unaffected	47/49	53	2	12	5	969	1162	3686
Medium	Increase	53/56	60	3	14	5	1099	1320	4182
High	Decrease	44/47	50	2	11	4	920	1089	3485
High	Unaffected	52/54	58	2	13	5	1065	1264	4039
High	Increase	58/61	65	3	15	6	1203	1426	4557

Table 7.6a: Output of AIDSPLAN runs for 1996

[1] Since Scenario 1 is a projection of the status quo as far as treatment is concerned, it follows that this figure for 1999 will be the same as the current one. Under scenario 2 the cost per patient is about 3% higher, although the cost of the drug that replaces AZT is the same and the cost of other drugs is 20% lower. The increase in the cost per patient is due to the fact that under scenario 2 an extra 10% of the caseload can take the new drug. Under scenario 3, the difference in the cost per patient is trivial. This is because although the cost per dose of the drug is now 20% less, it can be administered to an extra 20% of the caseload. In the context of the magnitude of overall costs and the prevailing uncertainties, these differences are all negligible.

Scenario 1

INPUT		OUTPUT							
1	2	3	4	5	6	7	8	9	10
Level of demand	Contracts	Beds	IPN	OPN	IPD	OPD	OD (£000's)	AZT (£000's)	Total Cost (£000's)
Low	Decrease	37/39	42	2	9	4	767	904	3909
Low	Unaffected	43/45	48	2	11	4	888	1045	4515
Low	Increase	49/51	55	2	12	5	1004	1185	5111
Medium	Decrease	45/47	50	2	11	4	928	1101	4731
Medium	Unaffected	52/55	58	2	13	5	1070	1269	5456
Medium	Increase	59/62	66	3	15	6	1210	1438	6176
High	Decrease	55/58	61	3	14	5	1130	1337	5755
High	Unaffected	63/66	71	3	16	6	1301	1539	6628
High	Increase	71/75	80	3	18	7	1476	1747	7518

Scenario 2

Level of demand	Contracts	Beds	IPN	OPN	IPD	OPD	OD (£000's)	Drug 2 (£000's)	Total Cost (£000's)
Low	Decrease	35/37	40	2	9	4	768	1084	3985
Low	Unaffected	41/43	46	2	10	4	831	1252	4609
Low	Increase	46/49	52	2	12	5	939	1421	5218
Medium	Decrease	43/45	48	2	11	4	867	1320	4824
Medium	Unaffected	49/52	55	3	13	5	1000	1522	5564
Medium	Increase	56/59	63	3	14	6	1131	1724	6300
High	Decrease	52/55	59	3	13	5	1056	1601	5868
High	Unaffected	60/63	67	3	15	6	1217	1848	6769
High	Increase	68/72	76	3	17	7	1474	2095	7670

Scenario 3

Level of demand	Contracts	Beds	IPN	OPN	IPD	OPD	OD (£000's)	Drug 3 (£000's)	Total Cost (£000's)
Low	Decrease	32/34	36	2	8	4	767	1689	4553
Low	Unaffected	37/39	42	2	9	5	888	1950	5261
Low	Increase	42/44	47	3	11	6	1004	2211	5956
Medium	Decrease	39/41	43	3	10	5	927	2049	5505
Medium	Unaffected	45/47	50	3	11	6	1069	2363	6351
Medium	Increase	50/53	57	3	13	7	1210	2678	7193
High	Decrease	47/50	53	3	12	6	1130	2494	6710
High	Unaffected	54/57	61	4	14	7	1301	2875	7731
High	Increase	62/65	69	4	16	8	1474	3257	8759

Table 7.6b: Output of AIDSPLAN runs for 1999

7.8 Configurations

Producing alternative configurations of the system is an essential task of SRM; each configuration represents a possible and potentially valuable future state of the operating system. By evaluating the performance of the configurations under each set of possible future conditions and linking them to the initial decisions, we can apply robustness analysis, and thus assess the relative flexibility of alternative initial decisions.

Configurations are evaluated on the basis of the desirability of their performance. The measures of desirability used in this application are the extents to which resources avoid either over- or underprovision. AIDSPLAN has provided us with the levels of resources required for desirable performance under each operating environment and mode of treatment[1], and this output will be used to construct configurations (i.e. combinations of resources) that perform desirably under particular futures. Their performance under other futures will be evaluated according to the extent to which they deviate from the level of resources produced by AIDSPLAN for those futures. Then, the attainability of the configurations from the particular initial decisions will be established. Next, robustness and debility scores of each initial decision under each future will be calculated. Finally, by using the information contained in the robustness and debility matrices we will analyse the relative flexibility of each initial decision.

Tables 7.6a&b were used as a source of the data needed to construct the interim and final configurations. It was decided to define the configurations in terms of combinations of beds and staff, and to ignore drug costs. This was done to reflect the fact that commitments of resources such as beds and staff are less reversible and thus more inflexible than those involving money.

In the calculations which are reported below, increases in numbers of beds and of in-patient nursing staff are treated as if they can occur only in multiples of five, whereas increases in numbers of in-patient medical staff and out-patient staff are permitted in single units. Using a reduced number of discrete alternatives for nurses and bed numbers was necessary to avoid producing a very large number of essentially similar

[1] For simplicity, from now on, each combination of operating environment and drug treatment scenario will be called a "future".

configurations. A range of nursing staff (rather than a single figure as in Tables 7.6a&b) provides an approximation of the balance of resources from which adaptations can be made in practice. For example, the deviation from the "ideal" figure can be accommodated by either overtime in case of understaffing or reallocation of the extra staff to other specialties, in case of overstaffing.

The initial assumption was that all configurations would feature at least the level of resources produced by AIDSPLAN for the end of 1994, taken to represent the current configuration. For beds and in-patient nurses the range between the maximum level needed under any future and this minimum level was divided into intervals of five. Each range of beds was matched with alternative ranges of in-patient nursing staff using Tables 7.6a&b as a guide. To each combination of beds and nurses, compatible numbers of in-patient medical staff were then attached. The procedure was repeated attaching one resource each time. This procedure resulted in 10 configurations for the decision horizon and 32 configurations for the planning horizon.

One very surprising outcome of the initial runs of AIDSPLAN was the observation that under scenarios 2 and 3, the hospital might need to consider an initial decision that had not been considered up to this point in the analysis: to somewhat decrease the number of beds and associated in-patient staff. This would be indicated under low AIDS growth and decreased contracts under scenarios 2 and 3, and unaffected contracts under scenario 3. Methodologically, this observation is a classic example of the common Operational Research experience that subsequent analysis leads to the reformulation of the initial problem. On the practical side, it can be argued that since the amounts of resources required under these conditions do not deviate significantly from the current ones, any decision about reducing these resources can be deferred until it becomes apparent that it must be implemented. Since the scale of hospital resources to reallocate would then be at most 7 beds and 6 nurses, such a change does not present any significant practical problems. However, for the sake of completeness it was decided to revise the initial decisions to include, as already mentioned, one representing a reduction in in-patient facilities.

This revision of the initial decisions was evidently inconsistent with the assumption that all configurations would feature at least the current level of resources. Therefore, it was necessary to construct a further set of configurations representing reduction of resources. Another configuration was added for the decision horizon and another three were added to the existing 32 for the planning horizon, each appropriate to one of the operating conditions which would justify a reduction in resources, as suggested by Tables 7.6a&b. The resulting 11 and 35 configurations respectively are recorded in Tables 7.8a&b. The first 6 columns describe the resource components of the configurations, while the remaining columns provide information on the evaluation of the configurations under each set of future conditions. The basis for this evaluation is described in the next section.

7.9 Evaluation of configurations

To apply robustness analysis we need to assess the performance of each configuration under each future, and also to link the configurations to the initial decisions. This section describes the method used to evaluate the configurations. (The "linking" process will be discussed in the next section.)

The measures of desirability used in the evaluation of the configurations were the availability of resources to meet demand, and the minimisation of resource wastage. The configurations were evaluated using the following method: As mentioned before, each configuration consists of a range of beds and nurses and exact figures for the remaining resources. If the figure prescribed by the "ideal" configuration suggested by AIDSPLAN (in Table 7.6) for the particular future falls within the range of beds and IP nursing staff in a configuration, and the other resources are exactly as required, then the configuration is considered desirable (denoted by "D" in Table 7.8). If the figures for beds and nurses in the "ideal" configuration deviate by no more than two from the extreme points of the range of beds and IP nursing staff in a configuration, and if the other resources deviate by no more than one unit, the configuration is considered acceptable ("A" in Table 7.8). Under the same conditions for beds and IP nursing staff but the other resources deviating by no more than two units, the configuration is considered of questionable merit ("Q"). All configurations that satisfy none of the above conditions are considered undesirable ("U"). In the calculation of the deviations of the "ideal" figures for beds from the extreme points in the particular configuration, figures for both occupancy rates (located in column 3 of Table 7.6) were considered "ideal".

Table 7.7 summarizes the above rules. The last 9 columns of Table 7.8a and the last 27 columns of Table 7.8b present the evaluation of the configurations on the basis of these rules. It should be stressed at this point that the particular evaluation scheme employed to determine configuration desirability is arbitrary; other sets of rules can be applied to evaluate the configurations. The general rationale for this particular set of rules is that the closer a configuration is to the "ideal" one, the more desirable it is.

Beds	IPN	OPN	IPD	OPD	Desirability
range includes "ideal" no.	range includes "ideal" no.	same as "ideal" no.	same as "ideal" no.	same as "ideal" no.	Desirable
± 2 from "ideal" no.	± 2 from "ideal" no.	± 1 from "ideal" no.	± 1 from "ideal" no.	± 1 from "ideal" no.	Acceptable
± 2 from "ideal" no.	± 2 from "ideal" no.	± 2 from "ideal" no.	± 2 from "ideal" no.	± 2 from "ideal" no.	Questionable
Any other case					Undesirable

Table 7.7: Rules for configuration evaluation

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Configuration	Beds	IPN	OPN	IPD	OPD	LD	LU	LI	MD	MU	MI	HD	HU	HI
1	35-39	39-44	2	9	3	D	A	U	A	U	U	U	U	U
2	40-44	39-44	2	10	4	U	A	U	A	U	U	U	U	U
3	40-44	45-49	2	10	4	U	D	Q	D	U	U	A	U	U
4	40-44	45-49	2	11	4	U	A	A	A	U	U	A	U	U
5	40-44	50-54	2	11	4	U	U	A	U	U	U	D	U	U
6	45-49	50-54	2	11	4	U	U	A	U	A	U	D	U	U
7	45-49	50-54	2	12	4	U	U	D	U	A	U	A	U	U
8	45-49	50-54	2	12	5	U	U	A	U	D	U	A	U	U
9	50-54	55-59	2	13	5	U	U	U	U	A	A	U	D	U
10	50-54	60-65	3	14	5	U	U	U	U	U	D	U	A	U
11	55-61	60-65	3	15	6	U	U	U	U	U	A	U	Q	D

Table 7.8a: Evaluation of interim configurations

						SCENARIO 1									SCENARIO 2									SCENARIO 3								
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
Configuration	Beds	IPN	OPN	IPD	OPD	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
1	33-38	36-41	2	8	4	A	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	D	A	U	Q	U	U	U	U	U
2	33-38	36-41	2	9	4	A	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	A	A	U	A	U	U	U	U	U
3	33-38	42-47	2	9	4	D	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	U	A	U	A	U	U	U	U	U
4	39-44	42-47	2	9	5	A	Q	U	U	U	U	U	U	U	A	A	U	Q	U	U	U	U	U	U	D	Q	A	U	U	U	U	U
5	39-44	42-47	2	9	4	D	Q	U	U	U	U	U	U	U	A	A	U	Q	U	U	U	U	U	U	A	Q	A	U	U	U	U	U
6	39-44	42-47	2	9	5	A	Q	U	U	U	U	U	U	U	A	A	U	Q	U	U	U	U	U	U	D	Q	A	U	U	U	U	U
7	39-44	42-47	2	10	4	A	A	U	U	U	U	U	U	U	A	D	U	A	U	U	U	U	U	U	A	Q	A	U	U	U	U	U
8	39-44	42-47	3	10	5	A	A	U	U	U	U	U	U	U	A	A	U	A	U	U	U	U	U	U	A	A	D	U	U	U	U	U
9	39-44	42-47	3	11	6	Q	Q	U	U	U	U	U	U	U	Q	Q	U	Q	U	U	U	U	U	U	Q	D	A	U	U	U	U	U
10	39-44	48-53	2	11	4	U	D	U	A	U	U	U	U	U	U	A	A	D	U	U	U	U	U	U	U	U	Q	Q	U	U	U	U
11	45-49	48-53	2	11	4	U	D	A	D	U	U	U	U	U	U	A	A	D	Q	U	U	U	U	U	U	Q	U	Q	U	Q	U	U
12	45-49	48-53	2	12	5	U	A	A	A	U	U	U	U	U	U	Q	D	A	A	U	U	U	U	U	U	A	U	A	U	A	U	U
13	45-49	48-53	3	11	6	U	Q	A	Q	U	U	U	U	U	Q	Q	A	Q	Q	U	U	U	U	U	U	A	U	D	U	A	U	U
14	45-49	48-53	3	12	6	U	Q	A	Q	U	U	U	U	U	U	Q	A	Q	A	U	U	U	U	U	U	A	U	A	U	D	U	U
15	45-49	54-59	2	12	5	U	U	D	U	U	U	U	U	U	U	U	A	U	A	U	U	U	U	U	U	U	U	U	Q	A	U	U
16	45-49	54-59	3	13	5	U	U	A	U	U	U	U	U	U	U	U	A	U	D	U	U	U	U	U	U	U	U	U	Q	A	U	U
17	50-54	54-59	2	12	5	U	U	D	U	A	U	Q	U	U	U	U	A	U	A	U	A	U	U	U	U	U	U	U	Q	A	Q	U
18	50-54	54-59	2	13	5	U	U	A	U	D	U	A	U	U	U	U	A	U	A	U	A	U	U	U	U	U	U	U	Q	A	Q	U
19	50-54	54-59	3	13	5	U	U	A	U	A	U	A	U	U	U	U	A	U	D	U	D	U	U	U	U	U	U	U	Q	A	Q	U
20	50-54	54-59	3	13	7	U	U	Q	U	Q	U	Q	U	U	U	U	Q	U	Q	U	Q	U	U	U	U	U	U	U	D	A	A	U
21	50-54	60-64	4	14	7	U	U	U	U	Q	U	Q	U	U	U	U	U	U	U	A	Q	U	U	U	U	U	U	U	U	U	D	U
22	55-59	54-59	2	13	5	U	U	U	U	D	U	A	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	Q	U	Q	U
23	55-59	54-59	3	13	5	U	U	U	U	A	U	A	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	Q	U	Q	U
24	55-59	60-64	3	14	5	U	U	U	U	A	A	D	U	U	U	U	U	U	U	A	Q	U	U	U	U	U	U	U	U	U	Q	U
25	55-59	60-64	3	14	6	U	U	U	U	A	A	A	U	U	U	U	U	U	U	D	U	U	U	U	U	U	U	U	U	U	A	U
26	55-59	60-64	4	14	7	U	U	U	U	U	Q	Q	U	U	U	U	U	U	U	A	Q	U	U	U	U	U	U	U	U	U	D	U
27	55-59	65-69	3	15	6	U	U	U	U	U	D	U	U	U	U	U	U	U	U	A	D	D	U	U	U	U	U	U	U	U	U	U
28	60-64	65-69	3	15	6	U	U	U	U	U	D	U	A	U	U	U	U	U	U	A	U	D	U	U	U	U	U	U	U	U	U	Q
29	60-64	70-74	3	16	6	U	U	U	U	U	U	U	D	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	Q
30	60-64	65-69	4	16	8	U	U	U	U	U	Q	U	Q	U	U	U	U	U	U	Q	U	Q	U	U	U	U	U	U	U	U	U	D
31	65-69	65-69	3	15	6	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	U	Q
32	65-69	65-69	4	16	8	U	U	U	U	U	U	U	Q	U	U	U	U	U	U	U	U	Q	U	U	U	U	U	U	U	U	U	D
33	65-69	70-74	3	16	6	U	U	U	U	U	U	U	D	U	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	Q
34	70-75	75-80	3	17	7	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	D	U	U	U	U	U	U	U	U	U
35	70-75	75-80	3	18	7	U	U	U	U	U	U	U	U	D	U	U	U	U	U	U	U	U	A	U	U	U	U	U	U	U	U	U

Key
D: Desirable
A: Accepatable
Q: Questionable
U: Undesirable

Table 7.8b: Evaluation of configurations

7.10 Measurement of uncertainty in the AIDS example

In this section an attempt will be made to measure the uncertainty of the problem situation using the coefficient of concordance W. This measurement will refer to the planning horizon only, where uncertainty is higher. In the AIDS example, some modifications to the general formulation will be made to use all the available information. In Chapter 5, the uncertainty of the problem is assessed by using a matrix which has scenarios as rows and decisions as columns. The cell entries represent the performance of the outcomes of each decision under each scenario. The coefficient of concordance then measures the degree of similarity of the effects of the scenarios on the outcomes of each decision.

In the AIDS example two modifications will be made. First, the rows represent futures rather than scenarios, since in this example the information on performance of future outcomes is classified by future, a richer concept than a scenario. Secondly, the columns of the matrix represent configurations rather than decisions, since configurations can be taken to represent the outcomes of decisions. The matrix of futures consists of the last 27 columns of Table 7.8b, where the configurations are evaluated. The coefficient of concordance W now measures the similarity of treatment of the configurations by the futures.

The value of the coefficient of concordance can assist the analysis in many ways. A high value of W indicates a high similarity of treatment of the configurations by the futures: the more similar this treatment is, the less important the materialization of a particular future becomes. As the computation of W gives a measurement of the prevalent uncertainty, its value could influence the choice of α (the relative preference of robustness vs debility-see formula 2.2) by the decision maker. For example, if there are futures with particularly beneficial effects in the problem, and W shows that there is high uncertainty in the situation, the decision maker might feel inclined to choose a value for α which gives preference to robustness. Similarly, if there are futures with particularly disastrous effects and high uncertainty, the choice of α could favour debility.

The method described in Chapter 5 is now used to compute the value of W. For each future, the configuration performances will be ranked using the evaluations of Table 7.8b where the configuration performances are assessed. Desirable performances will be ranked first, acceptable ones second and so on. Since there are only four possible classifications of performance (D, A, Q, U), the presence of a great number of tied rankings is inevitable[1]. Therefore, in computing W, the formula for tied rankings (5.4) is used.

Of the following tables, Table 7.9 is a modified version of Table 7.8b, where the qualitative assessments have been replaced by their rankings, and Table 7.10 is a modification of Table 7.9, where tied performances have been allocated the average of the rank they would have if they were distinguishable (mid-rank method). Both tables represent the transposed matrix for ease of presentation.

For n=35 (configurations) and m=27 (futures) a value of W of 0.051 can be calculated from Table 7.10. The statistical significance of W may be tested by computing χ^2 and compare it with the value given by the corresponding statistical table. Thus χ^2=46.79 which is significant at the 0.1 level. The value of W = 0.051 indicates that there is a high disagreement between futures, and therefore the problem situation is highly uncertain.

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[1] In general, in realistic problems the presence of ties is inevitable unless there are as many performance classifications as there are futures. In the AIDS example it would be implausible to attempt to evaluate the configuration performances using a classification with a range of 27.

1	SCENARIO 1									SCENARIO 2									SCENARIO 3								
Configuration	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
1	2	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	1	2	4	3	4	4	4	4	4
2	2	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	2	2	4	2	4	4	4	4	4
3	1	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	2	4	2	4	4	4	4	4
4	2	3	4	4	4	4	4	4	4	2	2	4	3	4	4	4	4	4	4	1	3	2	4	4	4	4	4
5	1	3	4	4	4	4	4	4	4	2	2	4	3	4	4	4	4	4	4	2	3	2	4	4	4	4	4
6	2	3	4	4	4	4	4	4	4	2	2	4	3	4	4	4	4	4	4	1	3	2	4	4	4	4	4
7	2	2	4	4	4	4	4	4	4	2	1	4	2	4	4	4	4	4	4	2	3	2	4	4	4	4	4
8	2	2	4	4	4	4	4	4	4	2	2	4	2	4	4	4	4	4	4	2	2	1	4	4	4	4	4
9	3	3	4	4	4	4	4	4	4	3	3	4	3	4	4	4	4	4	4	3	1	2	4	4	4	4	4
10	4	1	4	2	4	4	4	4	4	4	2	2	1	4	4	4	4	4	4	4	4	3	3	4	4	4	4
11	4	1	2	1	4	4	4	4	4	4	2	2	1	3	4	4	4	4	4	4	3	4	3	4	3	4	4
12	4	2	2	2	4	4	4	4	4	4	3	1	2	2	4	4	4	4	4	4	2	4	2	4	2	4	4
13	4	3	2	3	4	4	4	4	4	3	3	2	3	3	4	4	4	4	4	4	2	4	1	4	2	4	4
14	4	3	2	3	4	4	4	4	4	4	3	2	3	2	4	4	4	4	4	4	2	4	2	4	1	4	4
15	4	4	1	4	4	4	4	4	4	4	4	2	4	2	4	4	4	4	4	4	4	4	4	3	2	4	4
16	4	4	2	4	4	4	4	4	4	4	4	2	4	1	4	4	4	4	4	4	4	4	4	3	2	4	4
17	4	4	1	4	2	4	3	4	4	4	4	2	4	2	4	2	4	4	4	4	4	4	4	3	2	3	4
18	4	4	2	4	1	4	2	4	4	4	4	2	4	2	4	2	4	4	4	4	4	4	4	3	2	3	4
19	4	4	2	4	2	4	2	4	4	4	4	2	4	1	4	1	4	4	4	4	4	4	4	3	2	3	4
20	4	4	3	4	3	4	3	4	4	4	4	3	4	3	4	3	4	4	4	4	4	4	4	1	2	2	4
21	4	4	4	4	3	4	3	4	4	4	4	4	4	4	2	3	4	4	4	4	4	4	4	4	4	1	4
22	4	4	4	4	1	4	2	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	3	4	3	4
23	4	4	4	4	2	4	2	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3	4	3	4
24	4	4	4	4	2	2	1	4	4	4	4	4	4	4	2	3	4	4	4	4	4	4	4	4	4	3	4
25	4	4	4	4	2	2	2	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	4	2	4
26	4	4	4	4	4	3	3	4	4	4	4	4	4	4	2	3	4	4	4	4	4	4	4	4	4	1	4
27	4	4	4	4	4	1	4	4	4	4	4	4	4	4	2	1	1	4	4	4	4	4	4	4	4	4	4
28	4	4	4	4	4	1	4	2	4	4	4	4	4	4	2	4	1	4	4	4	4	4	4	4	4	4	3
29	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
30	4	4	4	4	4	3	4	3	4	4	4	4	4	4	3	4	3	4	4	4	4	4	4	4	4	4	1
31	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4	3
32	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	3	4	4	4	4	4	4	4	4	4	1
33	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	3
34	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	4
35	4	4	4	4	4	4	4	4	1	4	4	4	4	4	4	4	4	2	4	4	4	4	4	4	4	4	4

Table 7.9: Ranked configuration performances

	SCENARIO 1									SCENARIO 2									SCENARIO 3								
Configuration	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
1	5.5	23.5	23	20.5	22.5	21	23	21	19	4.5	23.5	23.5	23.5	23	21.5	22.5	20.5	19.5	1	5.5	23	9.5	20.5	22	23	23	21
2	5.5	23.5	23	20.5	22.5	21	23	21	19	4.5	23.5	23.5	23.5	23	21.5	22.5	20.5	19.5	2	5.5	23	5	20.5	22	23	23	21
3	1.5	23.5	23	20.5	22.5	21	23	21	19	4.5	23.5	23.5	23.5	23	21.5	22.5	20.5	19.5	19	5.5	23	5	20.5	22	23	23	21
4	5.5	8.5	23	20.5	22.5	21	23	21	19	4.5	4.5	23.5	8.5	23	21.5	22.5	20.5	19.5	19	1.5	8	5	20.5	22	23	23	21
5	1.5	8.5	23	20.5	22.5	21	23	21	19	4.5	4.5	23.5	8.5	23	21.5	22.5	20.5	19.5	19	5.5	8	5	20.5	22	23	23	21
6	5.5	8.5	23	20.5	22.5	21	23	21	19	4.5	4.5	23.5	8.5	23	21.5	22.5	20.5	19.5	19	1.5	8	5	20.5	22	23	23	21
7	5.5	4	23	20.5	22.5	21	23	21	19	4.5	1	23.5	4	23	21.5	22.5	20.5	19.5	19	5.5	8	5	20.5	22	23	23	21
8	5.5	4	23	20.5	22.5	21	23	21	19	4.5	4.5	23.5	4	23	21.5	22.5	20.5	19.5	19	5.5	3.5	1	20.5	22	23	23	21
9	9	8.5	23	20.5	22.5	21	23	21	19	9.5	9.5	23.5	8.5	23	21.5	22.5	20.5	19.5	19	9	1	5	20.5	22	23	23	21
10	22.5	1.5	23	2.5	22.5	21	23	21	19	23	4.5	6	1.5	23	21.5	22.5	20.5	19.5	19	22.5	23	9.5	4.5	22	23	23	21
11	22.5	1.5	6	1	22.5	21	23	21	19	23	4.5	6	1.5	9	21.5	22.5	20.5	19.5	19	22.5	8	23	4.5	22	10	23	21
12	22.5	4	6	2.5	22.5	21	23	21	19	23	9.5	1	4	5	21.5	22.5	20.5	19.5	19	22.5	3.5	23	2.5	22	5.5	23	21
13	22.5	8.5	6	4.5	22.5	21	23	21	19	9.5	9.5	6	8.5	9	21.5	22.5	20.5	19.5	19	22.5	3.5	23	1	22	5.5	23	21
14	22.5	8.5	6	4.5	22.5	21	23	21	19	23	9.5	6	8.5	5	21.5	22.5	20.5	19.5	19	22.5	3.5	23	2.5	22	1	23	21
15	22.5	23.5	1.5	20.5	22.5	21	23	21	19	23	23.5	6	23.5	5	21.5	22.5	20.5	19.5	19	22.5	23	23	20.5	5	5.5	23	21
16	22.5	23.5	6	20.5	22.5	21	23	21	19	23	23.5	6	23.5	1.5	21.5	22.5	20.5	19.5	19	22.5	23	23	20.5	5	5.5	23	21
17	22.5	23.5	1.5	20.5	5	21	8.5	21	19	23	23.5	6	23.5	5	21.5	4	20.5	19.5	19	22.5	23	23	20.5	5	5.5	7.5	21
18	22.5	23.5	6	20.5	1.5	21	4	21	19	23	23.5	6	23.5	5	21.5	4	20.5	19.5	19	22.5	23	23	20.5	5	5.5	7.5	21
19	22.5	23.5	6	20.5	5	21	4	21	19	23	23.5	6	23.5	1.5	21.5	1.5	20.5	19.5	19	22.5	23	23	20.5	5	5.5	7.5	21
20	22.5	23.5	10	20.5	8.5	21	8.5	21	19	23	23.5	11	23.5	9	21.5	7.5	20.5	19.5	19	22.5	23	23	20.5	1	5.5	3.5	21
21	22.5	23.5	23	20.5	8.5	21	8.5	21	19	23	23.5	23.5	23.5	23	4	7.5	20.5	19.5	19	22.5	23	23	20.5	22	23	1.5	21
22	22.5	23.5	23	20.5	1.5	21	4	21	19	23	23.5	23.5	23.5	23	21.5	4	20.5	19.5	19	22.5	23	23	20.5	5	23	7.5	21
23	22.5	23.5	23	20.5	5	21	4	21	19	23	23.5	23.5	23.5	23	21.5	22.5	20.5	19.5	19	22.5	23	23	20.5	5	23	7.5	21
24	22.5	23.5	23	20.5	5	3.5	1	21	19	23	23.5	23.5	23.5	23	4	7.5	20.5	19.5	19	22.5	23	23	20.5	22	23	7.5	21
25	22.5	23.5	23	20.5	5	3.5	4	21	19	23	23.5	23.5	23.5	23	1	22.5	20.5	19.5	19	22.5	23	23	20.5	22	23	3.5	21
26	22.5	23.5	23	20.5	22.5	5.5	8.5	21	19	23	23.5	23.5	23.5	23	4	7.5	20.5	19.5	19	22.5	23	23	20.5	22	23	1.5	21
27	22.5	23.5	23	20.5	22.5	1.5	23	21	19	23	23.5	23.5	23.5	23	4	1.5	1.5	19.5	19	22.5	23	23	20.5	22	23	23	21
28	22.5	23.5	23	20.5	22.5	1.5	23	3.5	19	23	23.5	23.5	23.5	23	4	22.5	1.5	19.5	19	22.5	23	23	20.5	22	23	23	4.5
29	22.5	23.5	23	20.5	22.5	21	23	1.5	19	23	23.5	23.5	23.5	23	21.5	22.5	20.5	19.5	19	22.5	23	23	20.5	22	23	23	4.5
30	22.5	23.5	23	20.5	22.5	5.5	23	5.5	19	23	23.5	23.5	23.5	23	7	22.5	4.5	19.5	19	22.5	23	23	20.5	22	23	23	1.5
31	22.5	23.5	23	20.5	22.5	21	23	3.5	19	23	23.5	23.5	23.5	23	21.5	22.5	4.5	19.5	19	22.5	23	23	20.5	22	23	23	4.5
32	22.5	23.5	23	20.5	22.5	21	23	5.5	19	23	23.5	23.5	23.5	23	21.5	22.5	4.5	19.5	19	22.5	23	23	20.5	22	23	23	1.5
33	22.5	23.5	23	20.5	22.5	21	23	1.5	19	23	23.5	23.5	23.5	23	21.5	22.5	20.5	2.5	19	22.5	23	23	20.5	22	23	23	4.5
34	22.5	23.5	23	20.5	22.5	21	23	21	2	23	23.5	23.5	23.5	23	21.5	22.5	20.5	1	19	22.5	23	23	20.5	22	23	23	21
35	22.5	23.5	23	20.5	22.5	21	23	21	1	23	23.5	23.5	23.5	23	21.5	22.5	20.5	2.5	19	22.5	23	23	20.5	22	23	23	21

Table 7.10: Configuration performances allowing for tied rankings

7.11 Robustness Analysis

The next step in the analysis after developing the configurations, and assessing for each the desirability of its performance under each future (not only that for which it was designed), is to establish the attainability of the configurations from the initial decisions. This is the final step which enables us to calculate the robustness and debility scores for each initial decision.

First, however, some incompatibilities between certain decisions and futures must be eliminated from Tables 7.8a&b. It was mentioned earlier that contracts are regarded as responsive decisions and are not expected to fall in case of facility expansion, or to increase in case of a reduction or no change in resources. This means that taking a particular decision prevents the materialization of some futures. Therefore, all futures which include a decrease in contracts (labelled LD, MD, and HD) are incompatible with decisions d_1 and d_2 (new ward or expansion). Similarly, all futures which include an increase in contracts (labelled LI, MI, and HI) are incompatible with decisions d_3 and d_4 (Do nothing or reduce).

The possibility of incompatibility of initial decisions and futures has not been discussed so far. There is nothing, however, in SRM itself to prevent the use of different sets of futures for each decision. The question will be discussed in more detail in the next chapter, where ideas for further development of SRM will be proposed.

7.11.1 Linking initial decisions and configurations

The next step is to establish which configurations are attainable from which decisions. As described previously, the initial decisions are:

d_1: Open new ward and expand out-patient facilities

d_2: Expand existing ward and out-patient facilities

d_3: Do nothing

d_4: Reduce number of beds and associated staff

In general, establishing connections between initial decisions and configurations depends on the decision maker's perceptions about the availability of possible intermediate actions. At the planning horizon, three possibilities about such subsequent decisions will be considered. First, we will consider a rigid formulation where there are no subsequent decisions, so that only configurations which effectively result from the implementation of the initial decision will be compatible with that decision. Secondly, a relaxed formulation will be considered, where subsequent decisions may broaden the spectrum of attainable configurations somewhat. Finally, a third still more relaxed formulation will assume that subsequent decisions will not necessarily be of a minor nature, and therefore an even broader range of configurations can be reached from each initial decision. For the initial decisions to have any meaning, and since the subsequent decisions will not be explicitly stated, it will be assumed that the latter will be able to only partially modify the direction implicit in the former. For the decision horizon, a formulation similar to the second one for the planning horizon will be considered.

Tables 7.11a&b summarize these posited conditions of attainability (of configurations from initial decisions) for the decision horizon and the three formulations of the planning horizon.

Initial decision	Attainable interim configurations
d_1	6-11
d_2	2-8
d_3	2-4
d_4	1-2

Table 7.11a: Interim configurations attainable from the initial decisions

Initial decision	Attainable configurations under formulation 1	Attainable configurations under formulation 2	Attainable configurations under formulation 3
d_1	17-35	17-35	17-35
d_2	9-20	9-20, 22, 23	7-20, 22, 23
d_3	3-9	3-14	1-14
d_4	1-3	1-7	1-9

Table 7.11b: Configurations attainable from initial decisions under three formulations

It can be seen from Table 7.11b that under formulation 1, only 6 out of 35 configurations are attainable from more than one initial decisions. Under formulation 2 this number rises to 17 and under formulation 3 it reaches 20. Attainability of configurations from more than one initial decision is a desirable characteristic in robustness analysis; in its absence we will end up with consistently low robustness scores.

7.11.2 Computation of the robustness and debility matrices

The next step in the analysis is to compute the robustness and debility matrices. Three alternative policies for dealing with "questionable" performances will be considered. In the first, to calculate the robustness scores both "desirable" and "acceptable" configuration performances will be considered as being above the acceptable threshold, and to calculate the debility scores both "questionable" and "undesirable" performances will be considered as being below the threshold. The second policy treats "desirable", "acceptable" and "questionable" configuration performances as being above the acceptable threshold, and "undesirable" ones as being below it. Finally, the third policy excludes questionable performances from the calculation of both robustness and debility scores.

There could of course, be other threshold levels. The choice of both scale of evaluation of configuration performances and of threshold level depends in practice on the particular problem and decision maker.

Tables 7.12 to 7.15 show the robustness and debility matrices which result from the three alternative policies for treating "questionable" performances. Table 7.12 shows the robustness and debility matrices at the decision horizon. Tables 7.13, 7.14 and 7.15 show the robustness and debility matrices for each formulation at the planning horizon, with each table representing one formulation. The X's in some cells denote the incompatibility of the particular future and initial decision. The last row of each matrix shows the total number of acceptable options in the case of a robustness matrix, or the total number of unacceptable options in the case of a debility matrix, for the particular future.

The robustness and debility scores in Table 7.12 (decision horizon) are calculated using the information in Tables 7.8a and 7.11a; the robustness and debility scores in Tables 7.13 to 7.15 (planning horizon) are calculated using the information in Tables 7.8b and 7.11b. The way in which the scores are calculated for the decision horizon will now be explained. (The scores at the planning horizon are calculated in a similar way.) For each initial decision, we check Table 7.11a, to determine which configurations are attainable from that decision. Then, for each future, we check Table 7.8a to determine how many of these configurations are above the acceptable threshold (or below it in the case of debility). The robustness score of the initial decision for that particular future is calculated as the ratio of the number of these configurations to the number of all configurations above the acceptable threshold under that future. Similarly, the debility score is the ratio of the number of configurations below the acceptable threshold attainable from that decision to the number of all configurations below the acceptable threshold in the particular future.

Consider, for example, initial decision d_4, if the acceptability level is set with Q as unacceptable. For this decision interim configurations 1-2 are attainable (Table 7.11a). Of these two configurations, for future LD, only one is above the acceptability threshold. The total number of acceptable options in this future is one. Therefore the robustness score for d_4 in future LD is 1/1=1. Similarly, the total number of unacceptable options under future LD is 10. Of these, only one is attainable from decision d_4. Therefore, the debility score for d_4 under LD is 1/10=0.1.

Q UNACCEPTABLE

ROBUSTNESS MATRIX

	LD	LU	LI	MD	MU	MI	HD	HU	HI
d_4	1	0.5	X	0.5	0	X	0	0	X
d_3	0	0.75	X	0.75	0	X	0.33	0	X
d_2	X	0.75	1	X	0.75	0	X	0	0
d_1	X	0	0.6	X	1	1	X	1	1
n	1	4	5	4	4	3	6	2	1

DEBILITY MATRIX

	LD	LU	LI	MD	MU	MI	HD	HU	HI
d_4	0.1	0	X	0	0.29	X	0.4	0.22	X
d_3	0.3	0	X	0	0.43	X	0.2	0.33	X
d_2	X	0.57	0.33	X	0.57	0.88	X	0.78	0.7
d_1	X	0.86	0.5	X	0.29	0.38	X	0.44	0.5
n	10	7	6	7	7	8	5	9	10

Q ACCEPTABLE

ROBUSTNESS MATRIX

	LD	LU	LI	MD	MU	MI	HD	HU	HI
d_4	1	0.5	X	0.5	0	X	0	0	X
d_3	0	0.75	X	0.75	0	X	0.33	0	X
d_2	X	0.75	0.75	X	0.75	0	X	0	0
d_1	X	0	0.5	X	1	1	X	1	1
n	1	4	6	4	4	3	6	3	1

DEBILITY MATRIX

	LD	LU	LI	MD	MU	MI	HD	HU	HI
d_4	0.1	0	X	0	0.29	X	0.4	0.25	X
d_3	0.3	0	X	0	0.43	X	0.2	0.38	X
d_2	X	0.57	0.2	X	0.57	0.88	X	0.88	0.7
d_1	X	0.86	0.6	X	0.29	0.38	X	0.38	0.5
n	10	7	5	7	7	8	5	8	10

Q EXCLUDED

ROBUSTNESS MATRIX

	LD	LU	LI	MD	MU	MI	HD	HU	HI
d_4	1	0.5	X	0.5	0	X	0	0	X
d_3	0	0.75	X	0.75	0	X	0.33	0	X
d_2	X	0.75	1	X	0.75	0	X	0	0
d_1	X	0	0.6	X	1	1	X	1	1
n	1	4	5	4	4	3	6	2	1

DEBILITY MATRIX

	LD	LU	LI	MD	MU	MI	HD	HU	HI
d_4	0.1	0	X	0	0.29	X	0.4	0.25	X
d_3	0.3	0	X	0	0.43	X	0.2	0.38	X
d_2	X	0.57	0.2	X	0.57	0.88	X	0.88	0.7
d_1	X	0.86	0.6	X	0.29	0.38	X	0.38	0.5
n	10	7	5	7	7	8	5	8	10

Table 7.12: Robustness and debility matrices at the decision horizon

	Scenario 1									Scenario 2									Scenario 3								
Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
	ROBUSTNESS MATRIX																										
d4	0.38	0	X	0	0	X	0	0	X	0.38	0	X	0	0	X	0	0	X	1	0.38	X	0.25	0	X	0	0	X
d3	0.75	0.4	X	0	0	X	0	0	X	0.75	0.71	X	0.4	0	X	0	0	X	0	0.75	X	0.88	0	X	0	0	X
d2	X	0.6	1	X	0.43	0	X	0	0	X	0.29	1	X	1	0	X	0	0	X	0	0.8	X	1	1	X	0.25	0
d1	X	0	0.33	X	1	1	X	1	1	X	0	0.3	X	0.43	1	X	1	1	X	0	0	X	0	1	X	1	1
n	8	5	9	3	7	4	6	4	2	8	7	10	5	7	6	5	3	3	2	8	5	8	3	1	9	4	2
	DEBILITY MATRIX																										
d4	0	0.1	X	0.09	0.11	X	0.1	0.1	X	0	0.11	X	0.1	0.11	X	0.1	0.09	X	0.03	0	X	0.04	0.09	X	0.12	0.1	X
d3	0.04	0.17	X	0.22	0.25	X	0.24	0.23	X	0.04	0.07	X	0.17	0.25	X	0.23	0.22	X	0.21	0.04	X	0	0.22	X	0.27	0.23	X
d2	X	0.30	0.12	X	0.32	0.39	X	0.39	0.36	X	0.36	0.08	X	0.18	0.41	X	0.38	0.38	X	0.44	0.27	X	0.28	0.32	X	0.35	0.36
d1	X	0.63	0.62	X	0.43	0.48	X	0.48	0.52	X	0.68	0.64	X	0.57	0.45	X	0.5	0.5	X	0.7	0.63	X	0.59	0.53	X	0.48	0.52
n	27	30	26	32	28	31	29	31	33	27	28	25	30	28	29	30	32	32	33	27	30	27	32	34	26	31	33

Questionable performances taken as unacceptable

Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
	ROBUSTNESS MATRIX																										
d4	0.33	0	X	0	0	X	0	0	X	0.3	0	X	0	0	X	0	0	X	1	0.33	X	0.3	0	X	0	0	X
d3	0.78	0.55	X	0	0	X	0	0	X	0.7	0.55	X	0.55	0	X	0	0	X	0	0.78	X	0.7	0	X	0	0	X
d2	X	0.55	1	X	0.44	0	X	0	0	X	0.55	1	X	1	0	X	0	0	X	0.11	0.5	X	1	0.75	X	0.4	0
d1	X	0	0.4	X	1	1	X	1	1	X	0	0.36	X	0.4	1	X	1	1	X	0	0	X	0	0.75	X	1	1
n	9	11	10	5	9	6	10	6	2	10	11	11	11	10	7	9	5	3	2	9	10	10	5	8	10	10	6
	DEBILITY MATRIX																										
d4	0	0.13	X	0.10	0.12	X	0.12	0.1	X	0	0.13	X	0.13	0.12	X	0.12	0.1	X	0.03	0	X	0	0.1	X	0.12	0.12	X
d3	0	0.04	X	0.23	0.27	X	0.28	0.24	X	0	0.04	X	0.04	0.28	X	0.27	0.23	X	0.21	0	X	0	0.23	X	0.28	0.28	X
d2	X	0.25	0.08	X	0.31	0.41	X	0.41	0.36	X	0.25	0.04	X	0.08	0.43	X	0.4	0.38	X	0.42	0.28	X	0.23	0.22	X	0.32	0.41
d1	X	0.79	0.6	X	0.38	0.45	X	0.45	0.52	X	0.79	0.63	X	0.6	0.43	X	0.47	0.5	X	0.73	0.76	X	0.63	0.48	X	0.36	0.45
n	26	24	25	30	26	29	25	29	33	25	24	24	24	25	28	26	30	32	33	26	25	25	30	27	25	25	29

Questionable performances taken as acceptable

Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
	ROBUSTNESS MATRIX																										
d4	0.38	0	X	0	0	X	0	0	X	0.38	0	X	0	0	X	0	0	X	1	0.38	X	0.25	0	X	0	0	X
d3	0.75	0.4	X	0	0	X	0	0	X	0.75	0.71	X	0.4	0	X	0	0	X	0	0.75	X	0.88	0	X	0	0	X
d2	X	0.6	1	X	0.43	0	X	0	0	X	0.29	1	X	1	0	X	0	0	X	0	0.8	X	1	1	X	0.25	0
d1	X	0	0.33	X	1	1	X	1	1	X	0	0.3	X	0.43	1	X	1	1	X	0	0	X	0	1	X	1	1
n	8	5	9	3	7	4	6	4	2	8	7	10	5	7	6	5	3	3	2	8	5	8	3	1	9	4	2
	DEBILITY MATRIX																										
d4	0	0.13	X	0.10	0.12	X	0.12	0.1	X	0	0.13	X	0.13	0.12	X	0.12	0.1	X	0.03	0	X	0	0.1	X	0.12	0.12	X
d3	0	0.04	X	0.23	0.27	X	0.28	0.24	X	0	0.04	X	0.04	0.28	X	0.27	0.23	X	0.21	0	X	0	0.23	X	0.28	0.28	X
d2	X	0.25	0.08	X	0.31	0.41	X	0.41	0.36	X	0.25	0.04	X	0.08	0.43	X	0.4	0.38	X	0.42	0.28	X	0.23	0.22	X	0.32	0.41
d1	X	0.79	0.6	X	0.38	0.45	X	0.45	0.52	X	0.79	0.63	X	0.6	0.43	X	0.47	0.5	X	0.73	0.76	X	0.63	0.48	X	0.36	0.45
n	26	24	25	30	26	29	25	29	33	25	24	24	24	25	28	26	30	32	33	26	25	25	30	27	25	25	29

Questionable performances not considered in calculations

Table 7.13: Robustness and debility matrices under formulation 1

Decision	Scenario 1									Scenario 2									Scenario 3								
	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
ROBUSTNESS MATRIX																											
d4	0.88	0.2	X	0	0	X	0	0	X	0.88	0.57	X	0.2	0	X	0	0	X	1	0.88	X	0.75	0	X	0	0	X
d3	0.75	1	X	1	0	X	0	0	X	0.75	1	X	1	0.29	X	0	0	X	0	0.75	X	0.88	1	X	0.33	0	X
d2	X	0.6	1	X	0.71	0	X	0	0	X	0.29	1	X	1	0	X	0	0	X	0	0.8	X	1	1	X	0.25	0
d1	X	0	0.33	X	1	1	X	1	1	X	0	0.3	X	0.43	1	X	1	1	X	0	0	X	0	1	X	1	1
n	8	5	9	3	7	4	6	4	2	8	7	10	5	7	6	5	3	3	2	8	5	8	3	1	9	4	2
DEBILITY MATRIX																											
d4	0	0.2	X	0.22	0.25	X	0.24	0.23	X	0	0.11	X	0.2	0.25	X	0.23	0.22	X	0.15	0	X	0.04	0.22	X	0.27	0.23	X
d3	0.22	0.23	X	0.28	0.43	X	0.41	0.39	X	0.22	0.18	X	0.23	0.36	X	0.4	0.38	X	0.36	0.22	X	0.19	0.28	X	0.35	0.39	X
d2	X	0.37	0.19	X	0.32	0.45	X	0.45	0.42	X	0.43	0.16	X	0.25	0.48	X	0.44	0.44	X	0.52	0.33	X	0.34	0.38	X	0.42	0.42
d1	X	0.63	0.62	X	0.43	0.48	X	0.48	0.52	X	0.68	0.64	X	0.57	0.45	X	0.5	0.5	X	0.7	0.63	X	0.59	0.53	X	0.48	0.52
n	27	30	26	32	28	31	29	31	33	27	28	25	30	28	29	30	32	32	33	27	30	27	32	34	26	31	33

Questionable performances taken as unacceptable

Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
ROBUSTNESS MATRIX																											
d4	0.78	0.36	X	0	0	X	0	0	X	0.7	0.36	X	0.36	0	X	0	0	X	1	0.78	X	0.7	0	X	0	0	X
d3	0.78	1	X	1	0	X	0	0	X	0.8	1	X	1	0.4	X	0	0	X	0	0.78	X	0.8	1	X	0.4	0	X
d2	X	0.55	1	X	0.67	0	X	0	0	X	0.55	1	X	1	0	X	0	0	X	0.11	0.5	X	1	1	X	0.6	0
d1	X	0	0.4	X	1	1	X	1	1	X	0	0.36	X	0.4	1	X	1	1	X	0	0	X	0	0.75	X	1	1
n	9	11	10	5	9	6	10	6	2	10	11	11	11	10	7	9	5	3	2	9	10	10	5	8	10	10	6
DEBILITY MATRIX																											
d4	0	0.13	X	0.23	0.27	X	0.28	0.24	X	0	0.13	X	0.13	0.28	X	0.27	0.23	X	0.15	0	X	0	0.23	X	0.28	0.28	X
d3	0.19	0.13	X	0.23	0.46	X	0.48	0.41	X	0.16	0.04	X	0.04	0.32	X	0.46	0.4	X	0.36	0.19	X	0.16	0.23	X	0.32	0.48	X
d2	X	0.33	0.16	X	0.31	0.48	X	0.48	0.42	X	0.33	0.13	X	0.16	0.5	X	0.47	0.44	X	0.5	0.36	X	0.3	0.22	X	0.32	0.48
d1	X	0.79	0.6	X	0.38	0.45	X	0.45	0.52	X	0.79	0.63	X	0.6	0.43	X	0.47	0.5	X	0.73	0.76	X	0.63	0.48	X	0.36	0.45
n	26	24	25	30	26	29	25	29	33	25	24	24	24	25	28	26	30	32	33	26	25	25	30	27	25	25	29

Questionable performances taken as acceptable

Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
ROBUSTNESS MATRIX																											
d4	0.88	0.2	X	0	0	X	0	0	X	0.88	0.57	X	0.2	0	X	0	0	X	1	0.88	X	0.75	0	X	0	0	X
d3	0.75	1	X	1	0	X	0	0	X	0.75	1	X	1	0.29	X	0	0	X	0	0.75	X	0.88	1	X	0.33	0	X
d2	X	0.6	1	X	0.71	0	X	0	0	X	0.29	1	X	1	0	X	0	0	X	0	0.8	X	1	1	X	0.25	0
d1	X	0	0.33	X	1	1	X	1	1	X	0	0.3	X	0.43	1	X	1	1	X	0	0	X	0	1	X	1	1
n	8	5	9	3	7	4	6	4	2	8	7	10	5	7	6	5	3	3	2	8	5	8	3	1	9	4	2
DEBILITY MATRIX																											
d4	0	0.13	X	0.23	0.27	X	0.28	0.24	X	0	0.13	X	0.13	0.28	X	0.27	0.23	X	0.15	0	X	0	0.23	X	0.28	0.28	X
d3	0.19	0.13	X	0.23	0.46	X	0.48	0.41	X	0.16	0.04	X	0.04	0.32	X	0.46	0.4	X	0.36	0.19	X	0.16	0.23	X	0.32	0.48	X
d2	X	0.33	0.16	X	0.31	0.48	X	0.48	0.42	X	0.33	0.13	X	0.16	0.5	X	0.47	0.44	X	0.5	0.36	X	0.3	0.22	X	0.32	0.48
d1	X	0.79	0.6	X	0.38	0.45	X	0.45	0.52	X	0.79	0.63	X	0.6	0.43	X	0.47	0.5	X	0.73	0.76	X	0.63	0.48	X	0.36	0.45
n	26	24	25	30	26	29	25	29	33	25	24	24	24	25	28	26	30	32	33	26	25	25	30	27	25	25	29

Questionable performances not considered in calculations

Table 7.14: Robustness and debility matrices under formulation 2

Decision	Scenario 1									Scenario 2									Scenario 3								
	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
	ROBUSTNESS MATRIX																										
d4	1	0.4	X	0	0	X	0	0	X	1	0.71	X	0.4	0	X	0	0	X	1	1	X	1	0	X	0	0	X
d3	1	1	X	1	0	X	0	0	X	1	1	X	1	0.29	X	0	0	X	1	1	X	1	1	X	0.33	0	X
d2	X	1	1	X	0.71	0	X	0	0	X	0.57	1	X	1	0	X	0	0	X	0.25	1	X	1	1	X	0.25	0
d1	X	0	0.33	X	1	1	X	1	1	X	0	0.3	X	0.43	1	X	1	1	X	0	0	X	0	1	X	1	1
n	8	5	9	3	7	4	6	4	2	8	7	10	5	7	6	5	3	3	2	8	5	8	3	1	9	4	2
	DEBILITY MATRIX																										
d4	0.04	0.23	X	0.28	0.32	X	0.31	0.29	X	0.04	0.14	X	0.23	0.32	X	0.3	0.28	X	0.21	0.04	X	0.04	0.28	X	0.35	0.29	X
d3	0.22	0.3	X	0.34	0.5	X	0.48	0.45	X	0.22	0.25	X	0.3	0.43	X	0.47	0.44	X	0.36	0.22	X	0.22	0.34	X	0.42	0.45	X
d2	X	0.37	0.27	X	0.39	0.52	X	0.52	0.48	X	0.43	0.24	X	0.32	0.55	X	0.5	0.5	X	0.52	0.37	X	0.41	0.44	X	0.48	0.48
d1	X	0.63	0.62	X	0.43	0.48	X	0.48	0.52	X	0.68	0.64	X	0.57	0.45	X	0.5	0.5	X	0.7	0.63	X	0.59	0.53	X	0.48	0.52
n	27	30	26	32	28	31	29	31	33	27	28	25	30	28	29	30	32	32	33	27	30	27	32	34	26	31	33

Questionable performances taken as unacceptable

Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
	ROBUSTNESS MATRIX																										
d4	1	0.55	X	0	0	X	0	0	X	0.9	0.55	X	0.55	0	X	0	0	X	1	1	X	0.9	0	X	0	0	X
d3	1	1	X	1	0	X	0	0	X	1	1	X	1	0.4	X	0	0	X	1	1	X	1	1	X	0.4	0	X
d2	X	0.73	1	X	0.67	0	X	0	0	X	0.73	1	X	1	0	X	0	0	X	0.33	0.7	X	1	1	X	0.6	0
d1	X	0	0.4	X	1	1	X	1	1	X	0	0.36	X	0.4	1	X	1	1	X	0	0	X	0	0.75	X	1	1
n	9	11	10	5	9	6	10	6	2	10	11	11	11	10	7	9	5	3	2	9	10	10	5	8	10	10	6
	DEBILITY MATRIX																										
d4	0	0.13	X	0.30	0.35	X	0.36	0.31	X	0	0.13	X	0.13	0.36	X	0.35	0.3	X	0.21	0	X	0	0.3	X	0.36	0.36	X
d3	0.19	0.13	X	0.3	0.54	X	0.56	0.48	X	0.16	0.13	X	0.13	0.4	X	0.54	0.47	X	0.36	0.19	X	0.16	0.3	X	0.4	0.56	X
d2	X	0.33	0.24	X	0.38	0.55	X	0.55	0.48	X	0.33	0.21	X	0.24	0.57	X	0.53	0.5	X	0.5	0.36	X	0.37	0.3	X	0.4	0.55
d1	X	0.79	0.6	X	0.38	0.45	X	0.45	0.52	X	0.79	0.63	X	0.6	0.43	X	0.47	0.5	X	0.73	0.76	X	0.63	0.48	X	0.36	0.45
n	26	24	25	30	26	29	25	29	33	25	24	24	24	25	28	26	30	32	33	26	25	25	30	27	25	25	29

Questionable performances taken as acceptable

Decision	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI	LD	LU	LI	MD	MU	MI	HD	HU	HI
	ROBUSTNESS MATRIX																										
d4	1	0.4	X	0	0	X	0	0	X	1	0.71	X	0.4	0	X	0	0	X	1	1	X	1	0	X	0	0	X
d3	1	1	X	1	0	X	0	0	X	1	1	X	1	0.29	X	0	0	X	1	1	X	1	1	X	0.33	0	X
d2	X	1	1	X	0.71	0	X	0	0	X	0.57	1	X	1	0	X	0	0	X	0.25	1	X	1	1	X	0.25	0
d1	X	0	0.33	X	1	1	X	1	1	X	0	0.3	X	0.43	1	X	1	1	X	0	0	X	0	1	X	1	1
n	8	5	9	3	7	4	6	4	2	8	7	10	5	7	6	5	3	3	2	8	5	8	3	1	9	4	2
	DEBILITY MATRIX																										
d4	0	0.13	X	0.30	0.35	X	0.36	0.31	X	0	0.13	X	0.13	0.36	X	0.35	0.3	X	0.21	0	X	0	0.3	X	0.36	0.36	X
d3	0.19	0.13	X	0.3	0.54	X	0.56	0.48	X	0.16	0.13	X	0.13	0.4	X	0.54	0.47	X	0.36	0.19	X	0.16	0.3	X	0.4	0.56	X
d2	X	0.33	0.24	X	0.38	0.55	X	0.55	0.48	X	0.33	0.21	X	0.24	0.57	X	0.53	0.5	X	0.5	0.36	X	0.37	0.3	X	0.4	0.55
d1	X	0.79	0.6	X	0.38	0.45	X	0.45	0.52	X	0.79	0.63	X	0.6	0.43	X	0.47	0.5	X	0.73	0.76	X	0.63	0.48	X	0.36	0.45
n	26	24	25	30	26	29	25	29	33	25	24	24	24	25	28	26	30	32	33	26	25	25	30	27	25	25	29

Questionable performances not considered in calculations

Table 7.15: Robustness and debility matrices under formulation 3

7.12 Analysis of the robustness and debility matrices

In the following analysis the robustness-debility criterion (Formula 2.2 in Chapter 2) will be used to provide a basis for comparison of the relative flexibility of initial decisions.

Table 7.16 gives the value of the robustness-debility criterion (RDC) at the decision horizon, and Tables 7.17 to 7.19 give the values of RDC at the planning horizon for the three formulations about subsequent decisions. All tables consider different values of α, and three alternative policies for the inclusion or exclusion in the computations of questionable performances of the configurations. Where α=0, the values of the criterion represent the negative of the debility scores. Where α=1, the values of the criterion are the robustness scores.

Decision: d_1 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.494	-0.242	0.01	0.136	0.262	0.515	0.767
Q acceptable	-0.499	-0.249	0.001	0.125	0.25	0.5	0.75
Q excluded	-0.499	-0.246	0.001	0.134	0.26	0.513	0.767

Decision: d_2 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.638	-0.427	-0.216	-0.11	-0.01	0.205	0.417
Q acceptable	-0.632	-0.431	-0.229	-0.13	-0.03	0.173	0.375
Q excluded	-0.632	-0.422	-0.213	-0.11	-0.01	0.207	0.417

Decision: d_3 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.21	-0.107	-0.004	0.048	0.099	0.202	0.306
Q acceptable	-0.217	-0.113	-0.008	0.044	0.096	0.201	0.306
Q excluded	-0.217	-0.113	-0.008	0.044	0.096	0.201	0.306

Decision: d_4 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.168	-0.068	0.032	0.082	0.133	0.233	0.333
Q acceptable	-0.173	-0.071	0.03	0.08	0.131	0.232	0.333
Q excluded	-0.173	-0.071	0.03	0.08	0.131	0.232	0.333

Table 7.16: Values of the robustness-debility criterion at the decision horizon

Formulation 1

Decision: d_1 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.553	-0.32	-0.086	0.031	0.147	0.381	0.614
Q acceptable	-0.556	-0.324	-0.091	0.025	0.141	0.374	0.606
Q excluded	-0.556	-0.322	-0.088	0.029	0.146	0.38	0.614

Decision: d_2 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.316	-0.171	-0.026	0.047	0.119	0.264	0.409
Q acceptable	-0.294	-0.154	-0.014	0.055	0.125	0.265	0.405
Q excluded	-0.294	-0.154	-0.013	0.057	0.128	0.268	0.409

Decision: d_3 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.171	-0.085	0.00	0.043	0.086	0.172	0.258
Q acceptable	-0.163	-0.079	0.004	0.046	0.088	0.171	0.255
Q excluded	-0.163	-0.079	0.005	0.047	0.089	0.173	0.258

Decision: d_4 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.077	-0.035	0.007	0.027	0.048	0.09	0.132
Q acceptable	-0.084	-0.042	0.00	0.021	0.042	0.084	0.126
Q excluded	-0.084	-0.041	0.002	0.024	0.045	0.089	0.132

Table 7.17: Values of RDC at the planning horizon under formulation 1

Formulation 2

Decision: d_1 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.553	-0.32	-0.086	0.031	0.147	0.381	0.614
Q acceptable	-0.556	-0.324	-0.091	0.025	0.141	0.374	0.606
Q excluded	-0.556	-0.322	-0.088	0.029	0.146	0.38	0.614

Decision: d_2 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.379	-0.218	-0.058	0.023	0.103	0.264	0.425
Q acceptable	-0.355	-0.196	-0.036	0.044	0.123	0.283	0.443
Q excluded	-0.355	-0.199	-0.043	0.035	0.113	0.27	0.425

Decision: d_3 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.307	-0.148	0.01	0.09	0.169	0.327	0.486
Q acceptable	-0.282	-0.126	0.03	0.108	0.186	0.341	0.497
Q excluded	-0.282	-0.129	0.025	0.102	0.178	0.332	0.486

Decision: d_4 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.169	-0.076	0.017	0.064	0.11	0.204	0.297
Q acceptable	-0.174	-0.083	0.008	0.053	0.099	0.189	0.28
Q excluded	-0.174	-0.08	0.014	0.062	0.109	0.203	0.297

Table 7.18: Values of RDC at the planning horizon under formulation 2

Formulation 3

Decision: d_1 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.553	-0.32	-0.086	0.031	0.147	0.381	0.614
Q acceptable	-0.556	-0.324	-0.091	0.025	0.141	0.374	0.606
Q excluded	-0.556	-0.322	-0.088	0.029	0.146	0.38	0.614

Decision: d_2 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.433	-0.248	-0.064	0.028	0.12	0.304	0.488
Q acceptable	-0.412	-0.232	-0.052	0.037	0.127	0.307	0.486
Q excluded	-0.412	-0.231	-0.052	0.038	0.128	0.308	0.488

Decision: d_3 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.357	-0.168	0.022	0.116	0.211	0.4	0.59
Q acceptable	-0.333	-0.146	0.04	0.134	0.227	0.413	0.6
Q excluded	-0.333	-0.148	0.036	0.129	0.221	0.405	0.59

Decision: d_4 Robustness-debility criterion

Q performance policy	α=0	α=0.2	α=0.4	α=0.5	α=0.6	α=0.8	α=1
Q unacceptable	-0.222	-0.105	0.012	0.07	0.128	0.245	0.362
Q acceptable	-0.218	-0.103	0.012	0.07	0.127	0.242	0.357
Q excluded	-0.218	-0.102	0.014	0.072	0.13	0.246	0.362

Table 7.19: Values of RDC at the planning horizon under formulation 3

All four tables show that the choice of threshold does not alter the scores significantly, i.e. the policy for the questionable performances has a negligible effect on the results. Table 7.16 suggests that at the decision horizon the most flexible decision is d_1, since it has by far the highest pure robustness score. From the same table it can also be observed that decision d_1 "dominates" d_2 since it gives consistently higher scores for all values of α. The same is true for d_4 compared to d_3. Therefore, the problem reduces to the selection of either d_1 or d_4.

We will now examine the problem at the planning horizon, starting with the first formulation. From Table 7.17 it can be observed that if the decision maker is more concerned about robustness than debility, decisions d_1 and d_2 (new ward and expansion, respectively) seem indicated. On the other hand, if the main concern of the decision maker is debility, decisions d_4 and d_3 have the advantage. In the case of relative indifference between robustness and debility, the differences in the values of the criterion are too small to justify a clear favourite. The results for the other two formulations may give further clarification.

Under the second formulation, the values in Table 7.18 suggest that where robustness is concerned decisions d_1 and d_3 have an advantage. If low debility is the main concern, the decisions having an advantage are d_4 and d_3. In both cases, however, d_3 has not much advantage over d_2. If the decision maker wants to ensure satisfactory scores for both robustness and debility, decision d_3 although second best at both extremes, offers reasonable performances at both.

Similar advantages can be observed in Table 7.19 which deals with formulation 3. In this case however, the robustness scores of the second best decision (d_3) are very close to those of the first one (d_1), while its debility scores are about 40% lower. Moreover, in the case of indifference between robustness and debility, the values of the criterion for d_3, although low, are appreciably higher than those for the other decisions. Under this formulation therefore, d_3 seems to have a clear advantage.

Table 7.20 shows the "best" two decisions (in descending order) under each formulation from three viewpoints: Robustness, debility and indifference between the two. It must be stressed though, that in some cases the differences are too small for a clear favourite to emerge.

Preference	Formulation 1	Formulation 2	Formulation 3
Robustness	d_1, d_2	d_1, d_3	d_1, d_3
Debility	d_4, d_3	d_4, d_3	d_4, d_3
Indifference	d_2, d_3	d_3, d_4	d_3, d_4

Table 7.20: Decision ranking under the three formulations

Decision d_3 is present in 8 out of 9 cells of Table 7.20; this means that this decision produces adequate performances under all formulations from most viewpoints. It could be justified, therefore, to say that as far as flexibility is concerned d_3 is the "safest" decision.

The short term analysis (at the decision horizon) has shown that the choice is limited between reduction of resources or opening a new ward. These two decisions recommend two opposing courses of action. The explanation for this apparently paradoxical result lies in the different set of futures which occur in response to these alternative initial decisions. Each of these sets of futures excludes a proportion of those situations in which poor performances would occur. Consequently, both decisions give relatively high robustness scores.

The long-term analysis has pointed out that the safest decision is to do nothing, therefore opening a new ward at the moment seems rather risky. On the other hand, reduction of resources does not require capital investment, and can be effected relatively quickly when the need arises. Thus, one reasonable course of action would be to do nothing for the moment and repeat the analysis when more information about demand and possible treatments becomes available. This particular choice privileges the long term over the short term. Which time-scale should determine the final decision, however, is dependent on the particular problem situation and decision maker. SRM does not attempt to make a recommendation in this matter; its function is to identify alternative courses of action which are satisfactory in terms of preservation of flexibility, as a contribution to a decision making process which must also encompass other factors.

7.13 Discussion

In concrete situations, flexibility will be only one of a number of considerations which influence the choice of initial decision. Such factors may include cost of implementation, short-run performance, political considerations etc. SRM, like other methodologies used in strategic planning is not meant to replace the decision maker's judgement; its aim is to complement it.

In general, SRM is a methodology to assist planning by helping to identify initial decisions which selectively preserve the flexibility necessary in uncertain situations. As such, in this case study it has pinpointed a possible initial decision which satisfies the flexibility considerations under a certain formulation of the problem. More importantly, it has helped to clarify the problem situation in a number of ways. First, during the course of the analysis, it became apparent that a course of action initially considered to be inappropriate to the problem (i.e. reduction of in-patient beds), could be indicated under certain future conditions. Secondly, it has provided a method to specify what type of information should be sought and used. Finally, it has assisted in structuring the information and eliciting some conclusions about the appropriate decision to be taken.

Perhaps the most useful aspect of SRM is the production of the robustness and debility matrices: rather than prescribing the "right" solution, they form the basis of a discussion between the participants, and thus enhance their understanding of the problem situation. In this case, before the analysis, it was felt that the hospital should consider expanding its facilities since demand in the past has been constantly rising and was expected to continue to do so. What was not clear, was the effect that possible future treatment policies would have on the level of required resources. The methodology pinpointed the making of no major commitment as the most flexible alternative. At first sight, this came as a surprise; however, with hindsight, such a choice seems reasonable. Possible new treatment policies will lead to a reduction in the resources consumed per patient, and should a mild expansion of facilities be required in the future, such a commitment can be implemented as an intermediate decision. A recommendation for not making any major commitment could be seen by some as an argument for inaction. In this case, it is not so. It is an argument for delaying action until the right moment.

It also became apparent that the threshold of acceptability/unacceptability did not have a significant effect on the results. This of course, may be due to the level of detail chosen for classifying the performances of the configurations. A less refined scale might have identified an effect, since the number of "intermediate" (questionable) performances would be rather high.

The results of the analysis are dependent on the assumptions made at the outset. Changes in these assumptions could result in different recommendations. For example, we have taken the level of change in the contracts to be around 20%. Sensitivity analysis on this dimension might identify different solutions. Since, however, this is not a "live" application, and the 20% figure is arbitrary, the value of the analysis of other arbitrary figures would be questionable. In a real-life problem, though, where realistic alternative assumptions can be made, such sensitivity analyses are essential to establish credibility of the results of SRM.

This example is a simplification of a real problem. In a realistic problem, however, it is broad directions of action rather than detailed specifications which are sought. In this light, SRM seems to have an advantage over the laying out and exploration of complex and detailed plans. It provides valuable clarification and sets the direction to which actions should be focused.

CHAPTER 8

CONCLUDING REMARKS

CHAPTER 8

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8.1 Summary

This thesis has introduced a new methodology, Scenario-Robustness Methodology (SRM), for planning under uncertainty. SRM is particularly relevant under conditions of uncertainty when a set of initial decisions is being considered by the planners. It gives a measure of the useful flexibility retained after an initial commitment is made, and thus provides a guide to the selection of the appropriate initial decision. Furthermore, by requiring the explicit statement of the available options and the evaluation of their consequences, it provides useful clarification of the problem situation and points out areas where more information should be obtained or further research is required. SRM uses the principles of robustness analysis but differs from it in two aspects: one, in contrast to robustness analysis, SRM offers a formal procedure to generate alternative futures, and two, SRM considers implications for both the short and long term. The field of application of the methodology is theoretically very wide, but it could be of particular interest in cases of strategic planning, as it incorporates elements of scenario analysis, an approach extensively used in such situations. To illustrate the wide applicability of the methodology, an AIDS-related resource allocation case study has been presented.

In Chapter 2 the issue of planning under uncertainty was discussed. First, the notion of uncertainty was examined, and several classifications of uncertainty were given. Then both the form and content of planning were discussed. An examination of the three main positions revealed the weaknesses of both rational comprehensive planning and disjointed incrementalism in handling uncertainty, and we argued that mixed scanning is the most promising alternative. (Indeed, the method for planning under uncertainty proposed in Chapter 4 can best be seen as an example of the mixed scanning approach). Then the elements of an alternative methodology suitable for planning under conditions of uncertainty were presented. A short introduction to existing methodologies which feature these required elements was presented, with particular emphasis on metagames and robustness analysis. At the end of the chapter a number of different criteria to interpret and summarize the elements of the robustness matrix were introduced. It was concluded that the Robustness-Debility Criterion is the most appropriate.

Chapter 3 explored the issue of flexibility. Definitions of flexibility were discussed as well as the relationship of robustness and flexibility. We argued that flexibility is a quality which should be preserved when planning under uncertainty, and that robustness is a measure of flexibility.

Scenario-Robustness Methodology (SRM) was presented in Chapter 4, following a discussion of scenario analysis. The methodology involves the construction of plausible futures for both the medium and long term. In the case of the long term such construction constitutes scenario analysis. Then, robustness analysis for both the medium and long term is conducted.

In Chapter 5 several alternative measures were developed which can be used to quantify the uncertainty of a situation when a number of initial decisions are under consideration and a number of scenarios about the future are available. It was argued that Kendall's coefficient of concordance W is the most appropriate of these measures, since it is the only one which can handle cases where more than two scenarios exist.

In order to proceed to demonstrate the application of SRM to an HIV/AIDS-related resource allocation problem in Chapter 7, some background information on the nature of AIDS and the associated planning problems was given in Chapter 6. In the same chapter an introduction to AIDSPLAN, a decision support tool for planning HIV/AIDS related services, was provided. A detailed description of AIDSPLAN together with information on its development is given in Appendix I.

Finally, in Chapter 7 SRM was illustrated by application to a hypothetical AIDS-related planning situation. The decision maker in this case is a hospital facing a number of alternative possible investment commitments. The way in which SRM can be used to identify an appropriate course of action was demonstrated. In that chapter we also measured the uncertainty present in the problem situation using the coefficient of concordance, concluding that the situation is indeed highly uncertain, and therefore the application of SRM was justified.

8.2 Further research

There are a number of issues discussed in this work which could offer interesting starting points for further research. The principal ones are listed below.

1. SRM is a new methodology, and as such it has not yet been applied in practice, except as described in Chapter 7. It would be interesting, therefore, to apply the methodology to other real problems. Feedback from clients could offer opportunities for further development or enhancement of SRM's component parts.

2. During the analysis in Chapter 7, it became clear that conducting robustness analysis for large problems (and the majority of realistic applications could be classified as such) would become substantially easier if a piece of software was available, to calculate robustness scores and produce the robustness matrix. Computation times would be reduced significantly, and thus the analysts could concentrate their efforts on experimenting with alternative assumptions about the acceptability thresholds, the attainability of configurations from initial decisions, etc. The development of such software is currently being undertaken by researchers at the London School of Economics [Wong 1993].

Currently there are a number of software tools available for producing scenarios. A discussion of their relative merits is given by Lewis [1994]. These tools, however, use simulation, mathematical models, and even assign probabilities for the relative likelihood of the occurrence of certain events, and consequently are inappropriate for use towards conducting SRM analysis. Therefore, any future software for generating scenarios for use by SRM will need to be relatively simple, non-mathematical and certainly non-probabilistic. Its output will provide inputs for the robustness part of the analysis.

3. The Robustness-Debility Criterion has been proposed as the most appropriate way to summarize the information contained both in the robustness and debility matrices. However, there may be scope for the development of more such criteria. For example, multi-temporal robustness criteria, will be able to combine the information from both the short and long term analysis, by combining robustness (and debility) scores on different time frames.

4. Finally, the development of a measure for the prevalent uncertainty about the future (the coefficient of concordance) is a very useful by-product of this work. However, as shown in Chapter 2, uncertainty can be characterized in other ways than high and low. Further work in this area will help to identify forms of analysis appropriate to each category of uncertainty.

APPENDIX I

AIDSPLAN: THE AIDS PLANNING MODEL

APPENDIX I

AIDSPLAN: THE AIDS PLANNING MODEL

AI.1 Introduction

This Appendix describes the structure of AIDSPLAN, as well as the development of the model for the specific context of Parkside Health Authority. The following section gives some background information on the development of the model. Section AI.3 gives a model overview, whereas section AI.4 describes the formulation of the model for Parkside. Finally, section AI.5 gives a list of the possible uses of the model. The account given in this appendix draws significantly from previously published work on AIDSPLAN [Rosenhead et al. 1989, Rizakou et al. 1991].

AI.2 Background

The development of AIDSPLAN was a joint effort of the department of Operational Research at the London School of Economics (LSE) and the Operational Research Service (ORS) of the Department of Health. When LSE first became involved in AIDS/HIV-related issues, the characteristics of the AIDS planning problem had also been identified by ORS. ORS had previously developed a model to support the planning of long term care provision for elderly people [Bowen and Forte 1987] and it recognised that elements of the approach could be adapted for planning services for people with HIV/AIDS. Extensive discussions with health service managers and community physicians revealed that the major areas of concern were

-to develop estimates of future local prevalence

-to assess the service and cost implications.

The model subsequently developed was implemented as a customised spreadsheet system (using Lotus Symphony software) running on industry-standard microcomputers, to allow widest possible dissemination.

In the meantime, LSE had already made contact with Parkside Health Authority, which agreed to fund the development of a planning model similar in structure to that proposed by ORS. It was decided to link the two projects. The work was conducted over a period of one year from autumn 1988 to autumn 1989.

Parkside is no longer a District Health Authority on its own. It is now part of the Kensington Chelsea and Westminster Health Authority. At the time of the development of AIDSPLAN, Parkside was a health district formed out of the merger in the summer of 1988 of the two former districts of Paddington and North Kensington, and Brent. It occupied some 28 square miles of London, and about 377,000 people lived then within its boundaries.

The principal hospital within Parkside was St. Mary's, an internationally renowned teaching hospital. Significantly for our purposes, clinicians within it had been among the first to face up to the challenge of caring for patients with AIDS. At the time, it was one of the three main London centres for treating AIDS patients (and the disease was in Britain initially largely confined to the London area). People with AIDS came to be treated at St. Mary's from all over the country, and even abroad. Although its percentage of the national total has now declined somewhat from its peak, in 1988 Parkside was treating about 160 AIDS patients, some 17.5% of the national total. A further 855 HIV+ patients who had not yet developed AIDS were also on the books. In 1992, these figures had increased to 350 and 1219 respectively.

The purpose for which the model was developed is as a decision support tool to help in predicting the call on hospital- and community-based services by persons with HIV or AIDS treated in Parkside. It is designed to provide answers to *what if...* type of questions - that is, it can be used to explore the consequences of alternative strategies or investments in resources, for particular assumptions about uncontrollable and unpredictable factors. This permits the analysis of likely overload, of possible need for further resources, and of flexibility to meet future uncertainties, corresponding to any given strategy. The model enables calculations to be made of the possible utilisation of resources with corresponding itemised costs.

Evidently, future demand on services is influenced by a wide variety of factors, many of which are inherently uncertain. The strength of these uncertainties indicated a need to restrict the time focus of the model to a period no more than two to five years ahead. It also militated against any attempt to estimate a single "most likely" demand on resources in any particular future year. Instead, it seemed more appropriate to produce a system which would enable repeated forward predictions of demand to be made without undue effort for any future combinations of factors which might prove to be of interest. This requirement could be best met by a computer-based model, and the existence of a range of possible users suggested that a micro-computer be used for portability and accessibility.

AI.3 Model overview

Conceptually, AIDSPLAN can be thought of as two sub-models. In the first, current data on the patient workload are fed into the model to produce estimates of future patient numbers by patient categories. These numbers in turn form the input to the second sub-model, where costed care options are specified for each patient category.

Estimates of the costs and resources required to treat these numbers of patients by the identified care options are then calculated, and can be aggregated by hospital budget head or other (external) agency. The system incorporates graphics and printing facilities to produce concise reports of the results for easy reference. Figure AI.1 provides an overview of the model and the relationship between its two sub-models.

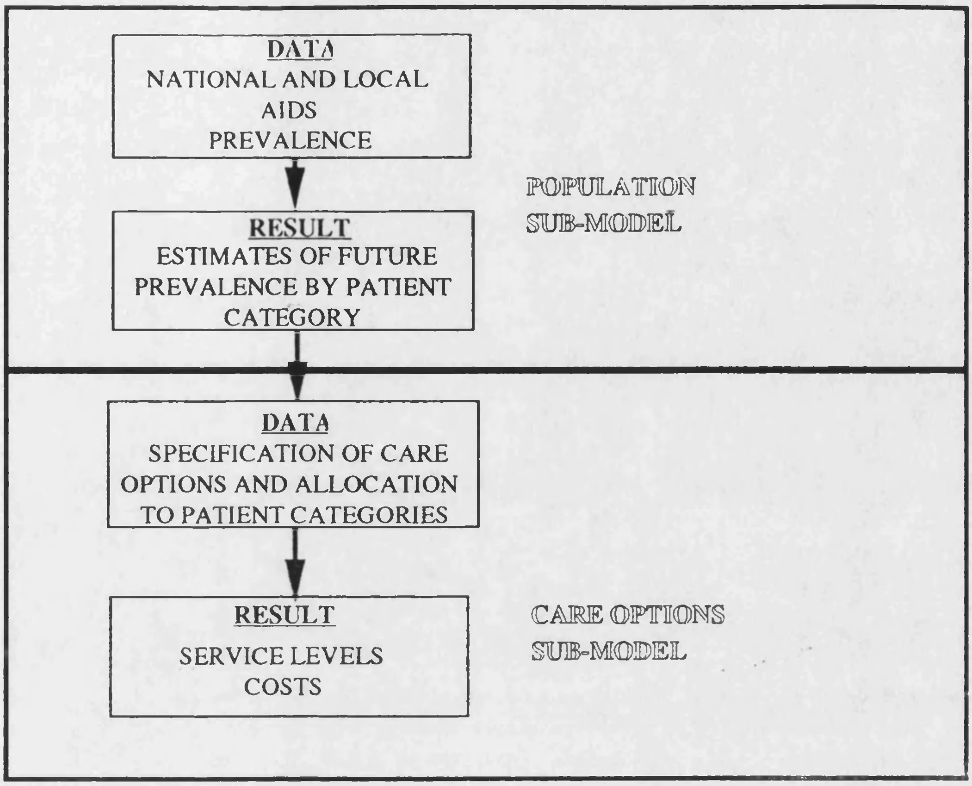

Figure AI.1: Model overview

AI.3.1 Population sub-model

AIDSPLAN starts with a range of national forecasts of AIDS prevalence which are based on the Day Report estimates [PHLS 1990]. These are entered as three separate forecasts - Low, Medium, High - from which the forecast to be used in the current planning scenario can then be selected. This forecast is disaggregated based on local data to give a 5 year local forecast by 4 major sub-groups. These sub-groups are then further analysed into a maximum of 14 detailed patient categories for which care options can be entered. However, the model offers a facility to override the forecasts, and enter manually any required estimates of population category size.

The analysis is based on a division of patients into categories which, for planning purposes, can be considered relatively homogeneous in their demand for services. This classification must enable the model to distinguish between types of patients making significantly different demands for service (but without being so fine-grained as to overstrain the limited data available for calibration). The criteria which can be used for such a classification include clinical state, possible drug use, age, dependency, and housing situation. Evidently, patients who are at different stages of the disease, or homeless, or who are children, will have different care requirements. There is also evidence to suggest that drug users are "difficult" patients: they take up more counselling time, and due to their generally poor health are more prone to infections. Another relevant factor is that patients who have some kind of informal support may make different demands on services from those who do not. For example, a patient who has a carer at home may take up less community nursing time. The categories actually used in the Parkside Model are described in section AI.3.1 later.

AI.3.2 Care options sub-model

The model requires that for each of the categories, appropriate care options are identified. Either a single, or multiple alternative care options can be specified for a given patient category. A care option is a costed combination of Health or Local Authority or other agency's service inputs which constitutes a clinically acceptable method of treating or supporting a member of the client group.

A care option is defined in terms of the basic resources needed to supply appropriate care and treatment. The user may either use the list of resources provided in the model as it stands, or may change it according to his or her special interests. For example, certain resources could be grouped together under a single heading, giving scope for others to be disaggregated into their components. Up to 32 different resources can be accommodated in the model. Once a list of such resources has been established, any given care option can be expressed as a particular combination of resources from the list in specified amounts. Figure AI.2 gives a simplified example of care option construction. The details of the care options developed for Parkside are described in section AI.3.4.

Category: AIDS, Supportive home environment				
Resource	Care Option 1	Care Option 2	Care Option 3	Care Option 4
In-patient (acute)	x			x
Out-patient		x	x	
Home care team		x	x	
District nurse		x		
Therapist			x	x
Drugs	x	x	x	x
etc.				

Figure AI.2: A simplified care option

AI.3.3 Model output

For any particular assumptions made about future demand, AIDSPLAN computes the resource and cost consequences of the identified care strategy. The results section of the menu gives various displays which summarise at different levels the effect of the input assumptions, and so allows the user to identify where further analysis may be needed. The print options on the menu allow the printing of various reports from the model such as population forecasts, details of resources and their units, allocations to care options for all patient categories, as well as results summaries.

AI.4 Formulation of the model for Parkside

The process of specifying the model involved accessing available data on the resources devoted to persons with HIV/AIDS, and also tapping the judgment of those with a wide variety of specialist knowledge. Cooperation was received from a very large number of people, including not only those working within Parkside, but also many from outside with relevant additional expertise, or whose agencies provide services complementary to those of the Authority. A Project Steering Group was established to provide guidance and liaison for the project.

Developing the model was an iterative process involving exposing the incomplete model at a number of different stages to potential users, with either clinical, management or planning responsibilities. This was to ensure both that its contents were consistent with their knowledge of Parkside and of the nature of HIV/AIDS and its treatment, and also that the level of detail incorporated was appropriate to their needs.

This process of interaction produced significant changes in the model. For example, the number of patient categories was reduced successively from 19 to 14 (and this latter number in fact incorporates some distinctions not present in the original version). These reductions - with consequent combination of categories - were made for a variety of reasons: low numerical significance of the category, lack of difference in treatment, difficulty in defining the category operationally. While the current set of patient categories was accepted as reasonable by the project steering group and by those others we have consulted, it should not be regarded as definitive.

To make the model operational it was necessary to specify:

(i) the type of patient category classification to be used;

(ii) the resources needed to construct care options, together with units of measurement;

(iii) care options for each patient category, made up of specified quantities of the input resources;

(iv) costs of each resource.

The relations between these tasks are shown in Figure AI.3

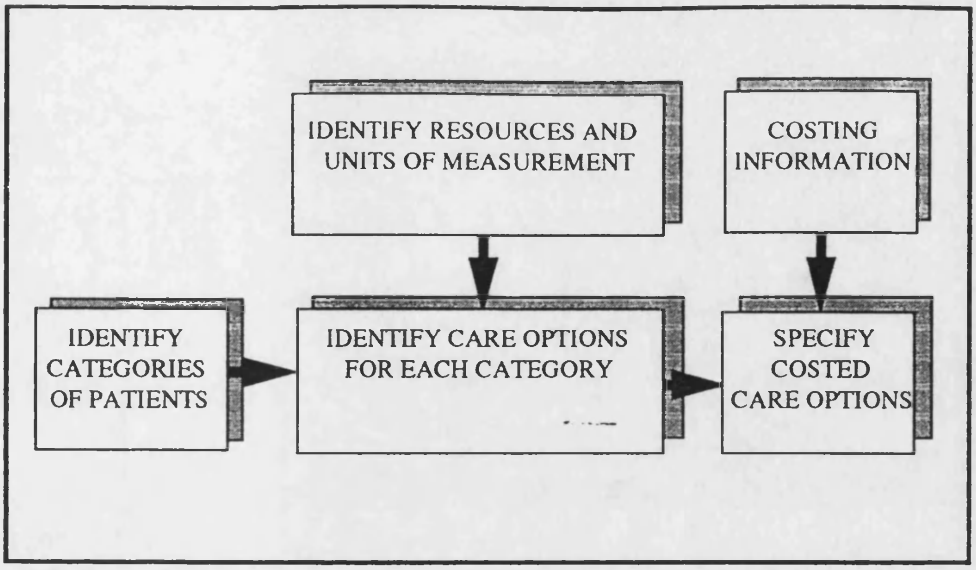

Figure AI.3: Research tasks

Specifying the model for use in Parkside involved accessing a wide range of databases, information, expertise and informed opinion.

The sources of data used to develop dependency categories were:

- -ward books
- -the patient administration service data base
- -questionnaires sent to senior house officers
- -out-patient records
- -records of the drug dependency unit
- -press releases issued by the national Communicable Diseases Surveillance Centre

The sources of data used to identify care options were:

- -the patient administration service data base
- -in-patient and out-patient medical records
- -costings from the Parkside finance department and elsewhere in the UK
- -other relevant literature [Bebbington and Warren 1988; Rees et al 1988; Rees 1989]

We also used the judgments of:

- -medical and nursing staff
- -administrative staff in the Authority's planning and finance departments

-general practitioners

-local authority staff

-workers in voluntary agencies.

These information flows together with the research tasks are indicated in Figure AI.4

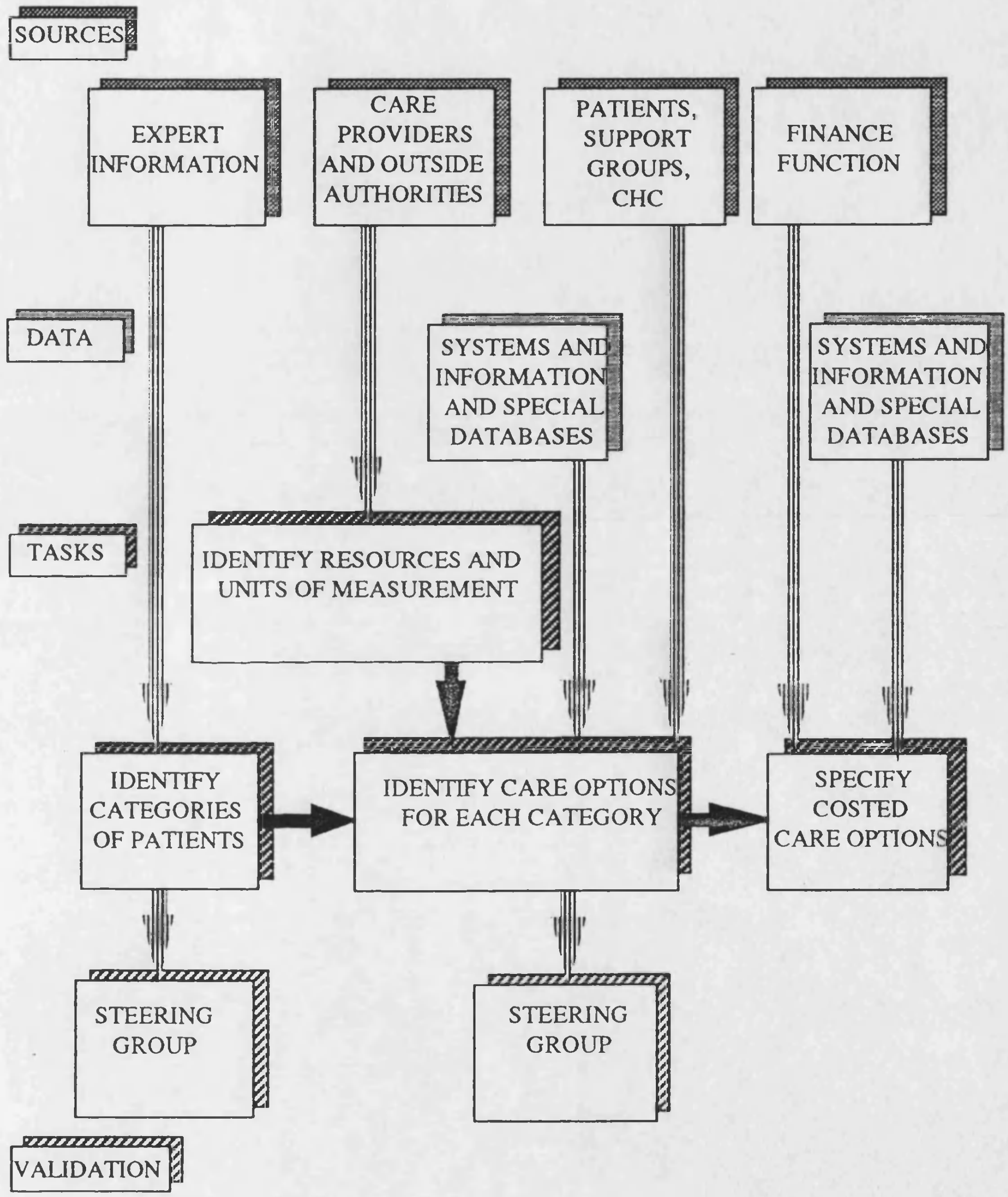

Figure AI.4: Tasks and information flows

Each of the four tasks, with some explanation of the more significant decisions which have shaped the development of AIDSPLAN, will now be described in turn.

AI.4.1 Patient categories

After extensive discussions, a set of fourteen patient categories were agreed as appropriate for use in Parkside. These are displayed graphically in Figure AI.5. Factors affecting this choice of categories included the current or anticipated numerical size of the category, the relative significance of resource inputs to different types of patients, and the way in which data was collected in Parkside.

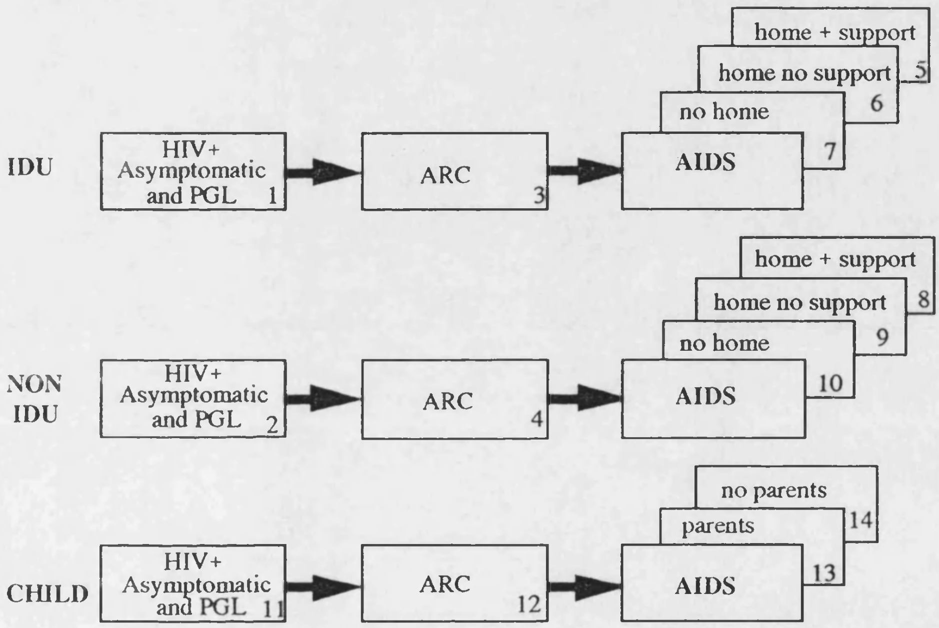

Figure AI.5: Patient categories

It is evident that this is not the the only classification of HIV/AIDS patients which could be made. For example, other health status characteristics (for example, haemophilia) could well be included, while others might be omitted. There is no difficulty in principle in modifying the categories displayed in Figure AI.5. However, further data collection and analysis would then be necessary to specify corresponding care options.

AI.4.2 Resources

Twenty eight resources were identified as contributing actually or potentially to the care and treatment of HIV/AIDS patients in Parkside. These resources are listed in Figure AI.6 and have been grouped by agency, or (within Parkside) budget heading through which they are provided. Within Parkside, the majority of resources were hospital-rather than community-based. Other organisations which provided complementary services without which extra call on Parkside resources would have been generated included local authorities, family practitioner committees, and voluntary agencies. However, for reasons of data availability and managerial relevance, the resources provided by these agencies were treated less fully than those provided by Parkside.

AGENCY	RESOURCE	UNITS
Hospital	IP STAYS	DAYS
Hospital	DIRECT NURSING	HRS
Hospital	MEDICAL STAFF-DIRECT	SESSIONS
Hospital	OTHER MEDICAL STAFF	SESSIONS
Hospital	COUNSELLING	HRS
Hospital	THERAPY (PHYSIO./OCCUP.)	HRS
Hospital	INVESTIGATIONS/ TESTS	NUMBER
Hospital	SURGERY	NUMBER
Hospital	DRUGS	£s
Hospital	OTHER TREATMENTS	NO.
Community	HOME SUPPORT TEAM	HRS
Community	COMMUNITY NURSES	HRS
Community	CHILD SERVICES	HRS
Community	COMMUNITY DAY CARE	HRS
Community	TRANSPORT	TRIPS
Community	HOSPICE CARE	DAYS
L. authority	DOMESTIC CARE	HRS
L. authority	SOCIAL WORKER	HRS
L. authority	HOUSING	£s
L. authority	LIVING AIDS	£s
L. authority	FOSTERING/ADOPTION	£s
L. authority	OCCUPATIONAL THERAPY	HRS
L. authority	DAY CARE - ADULT	DAYS
L. authority	DAY CARE - CHILD	DAYS
FHSA	GP / PRIMARY CARE TEAM	HRS
FHSA	DRUGS	£s
Voluntary	HOSPICE BED	DAYS
Voluntary	VOLUNTARY SUPPORT	HRS

Figure AI.6: List of resources

Resources could be identified at other levels of detail than that of the list in Figure AI.6. For example, different grades of nursing or medical staff could be included, investigations could be separated from tests, different tasks of community nurses or counsellors could be distinguished, etc. However, the level of detail in any listing of resources must correspond to the intended use of the model. The level incorporated in the current version of AIDSPLAN was that appropriate to a managerial use of the model for strategic planning purposes - it was designed to aid discussion about acquisition of resources, rather than to assist in detailed operational deployment of resources. Other versions could in principle be developed to help with the latter task. However, this would entail a considerable task of data collection and analysis; further system programming work; an increase in computer memory requirement; and appreciable problems for managers in manipulating and comprehending resource lists an order of magnitude larger than will fit on a monitor screen. Disaggregation should therefore be developed selectively, for such sectors of resource as prove in use to be particularly sensitive - for example, as potential future bottlenecks.

AI.4.3 Costings

Data provided by the Parkside Finance Department was invaluable in attributing costs to units of resource falling under the Authority's control. However, cost figures were obtained from a range of sources, and further processing was necessary to make them consistent and directly relevant to the model format.

In general, costing was based on the average number of contact hours members of staff have with their clients. This was necessary because AIDSPLAN is built on resource consumption per client. Thus, for example, for occupational therapists who are contracted to work 37 hours per week, it would have been quite misleading to cost one hour spent with a client at one thirty-seventh of the total weekly cost of the therapist. We were advised that occupational therapists are in contact with clients for 25 hours per week, and this figure was used to calculate the hourly cost. (Clearly, exceptions to this rule occur in cases where staff are available to provide care for the duration of their contracted hours.) Similar arguments were used for other resources - for example bed-days numbers needed to be adjusted for bed occupancy rates in order to convert into required beds.

For staffing, costs were based on gross annual cost; average costs were employed where different staff grades or varying pay scales are involved in the delivery of care. Costs for investigations, tests, drugs etc. were based on information provided by the relevant departments within the hospital. In cases where current or historical costs could not easily be obtained, it was sometimes possible to produce estimates from the cost of an equivalent service elsewhere, or from literature sources with adjustments for inflation as appropriate. In the case of the voluntary sector, the costs have been based on the grant allowance for the provision of a service, for example hospice beds, or on the cost of providing the equivalent service within the statutory sector.

Since administrative costs, grants provided to the voluntary sector by Parkside, research expenditure, overheads, etc. are not directly related to patient numbers, they were not accounted for in the care options, but were aggregated elsewhere in the model.

AI.4.4 Care options

Constructing care options for the different categories of HIV/AIDS patients proved to be the most complex and taxing of the tasks involved in operationalising AIDSPLAN. This necessitated the estimation of the average number of units of each resource consumed annually in the delivery of service to a patient in the given category.

Hard information based on hospital activity levels was not always available; even where it had been collected it was frequently not in easily accessible form. Often it proved necessary to supplement such objective information with the judgmental estimates of those with the most relevant experience. Thus, outpatient records revealed that AIDS patients were seen by the respiratory nurse on average four times per year; to convert this into usable form we obtained from the nurse an estimate that the average duration of a visit was approximately half an hour. Similarly, we were able to adjust the inpatient stay component of the care option for AIDS patients without a home (relative to those with a home); this was achieved by obtaining a consultant's estimate of the delay in discharge procedures which lack of a home typically produces. In other cases, was made of results produced by other researchers in the field [Bebbington and Warren 1988; Rees et al. 1988].

When specifying care options for use in Parkside it proved necessary to reduce the original number of categories. The omitted categories were those for children, and those which distinguish patients with and without informal support. The omission of child categories was due to lack both of information and of extensive experience on which to form quantitative judgments. There were no documented statistics available on the number of children with HIV/AIDS being treated in Parkside, due to confidentiality restrictions imposed by the Child Protection Act. However, the number was certainly small, so that the exclusion of these categories from the current set of care options will not have had significant cost and resource repercussions. Nevertheless, given the growth of the epidemic among the heterosexual population it is to be expected that the numbers in the child categories will increase. Therefore, it is anticipated that the model may be extended by establishing care options for these categories in due course.

Similarly, lack of reliable data or other information sources made it infeasible to establish care options which distinguish between the resource demands of people with or without informal support.

AI.5 The uses of the model

The model is designed as a decision support tool capable of being used by Parkside (or elsewhere) to explore the future of its services for people with HIV/AIDS. It can be used to estimate the consequences of alternative future trajectories of the epidemic, both in aggregate, and in terms of the balance between different risk groups. And it can be employed to examine the resource implications of possible modifications to models of care, innovations in drug treatment, or changes in policy or service provision.

The model was developed at a level of detail appropriate for use to support planning at a strategic level. It provides comprehensive coverage of the services provided by Parkside, and related services provided by other agencies. The model in the form in which it was employed in the research related to this thesis can be used to indicate broadly advantageous directions for policy on HIV/AIDS-related services. It can also be adapted, by selective enhancement of detail in the relevant resource sector, to provide a useful tool at resource level also. In the short run, however, the most likely clients for the model are those within a health authority, or comparable body, who have particular responsibilities for, or direct interest in, the direction of strategy for HIV/AIDS services.

Many of the future uses and developments of the model will emerge from the ongoing concerns of those who use the model. However, some particular ways of using the model are suggested.

(a) Sensitivity analysis. AIDSPLAN necessarily incorporates a range of judgments and assumptions. Where these are regarded as open to question, the model can be run with contrasting formulations. This "sensitivity analysis" permits the identification of which assumptions are critical to decisions and which are relatively insensitive. This focuses attention selectively on what are the key uncertainties which require urgent investigation, possibly involving further use of AIDSPLAN, and which issues can be at least temporarily deferred.

(b) Policy analysis. AIDSPLAN can be used to explore the resource implications of a wide variety of impending decisions or possible policy changes. For example issues confronting Parkside at the time when AIDSPLAN was under development which suggested themselves included: strategies for the diversion of people with HIV/AIDS to other centres of expertise, the transfer of the responsibility for the Home Support Team (a team of nurses who facilitated the transition of hospital patients to the community), and the adoption of a community care strategy. The implications of possible changes in care options for particular patient categories could also be explored - such as the consequences of more General Practitioner involvement in the care of HIV/AIDS patients. Other alternative "models of care" could also be developed, for example based on care delivery in other specialist Districts. AIDSPLAN could be further used to justify bids for funds for HIV/AIDS-related services, or to support joint planning with other agencies.

An example of policy analysis using is given by Rizakou et al [1991] demonstrated that despite the expected rise in patient numbers, an increase in AIDS beds could be avoided, provided the need for hospitalisation could be reduced through better support in the community and greater expertise in the treatment of AIDS patients.

(c) Scenario analysis. The resource implications of many of the possible decisions and practices in (b) above necessarily depended in part on uncertain factors outside the control of any health service agency. Such uncertainties include - the future numbers in different patient groups, the availability of prophylactic or alternative drug treatments (and their timing), the continuation of priority funding etc. Uncertainties current at the time AIDSPLAN was developed include the potential extension of AZT to classes of asymptomatic patients, the possibility of reduced dosage, and of use in conjunction with other drugs still at an experimental stage, but likely to become widely available within the next few years. The resource implications of different scenarios involving prescription of AZT to asymptomatic patients are explored in Rizakou et al.[1991], where it was shown that the total cost for drugs could increase by almost 50% if half of the asymptomatic patients were to receive AZT.

AIDSPLAN can be used to devise interim "commitment packages" of decisions which avoid overcommitment to policies based on just one reading of the future; to identify potential resource bottlenecks where relaxation would most enhance future flexibility; and to construct action trigger points to ensure that resource commitments are not made sooner (or later) than they should be.

The manager responsible for HIV/AIDS planning in Parkside in 1991 [quoted in Rizakou et al. 1991] summarised the advantages of AIDSPLAN as follows:

> "AIDSPLAN is proving to be a useful tool for testing out different approaches to how we provide treatment and care to this growing care group. Of particular note is the ability of the model to provide tailored local projections for newly diagnosed people with AIDS and the ease with which this information can be processed with regard to the care groups constructed.
>
> In an area of such uncertainty it is imperative that health care planners are able to respond to the urgent pressures to provide new services in a way which is both appropriate and effective. The quick and easy "what if" function afforded by AIDSPLAN allows the ideas and views of clinicians, managers and users of the service to be considered. This is particularly valuable at a time when there is greater emphasis than ever in the National Health Service to improve the quality of services to consumers."

APPENDIX II

CALCULATION OF THE SIMILARITY COEFFICIENTS

APPENDIX II

CALCULATION OF THE SIMILARITY COEFFICIENTS

This Appendix gives details of the calculations of the cluster analysis similarity coefficients for the ten hypothetical cases described in Section 5.2. The calculations for cases 1 and 2 will be presented in detail. The values of the coefficients for the other eight cases are calculated in a similar way.

The formulae for the six coefficients are:

Coefficient (i): (a + d)/(a+b+c+d)

Coefficient (ii): a/(a+b+c)

Coefficient (iii): 2a/(2a+b+c)

Coefficient (iv): 2(a+d)/[2(a+d)+b+c]

Coefficient (v): a/[a+2(b+c)]

Coefficient (vi): a/(a+b+c+d)

The scale of qualitative measurements of the performance of each future (V, G, F, P, C) can be seen as the five binary variables on which the variates (decisions) are measured as shown in Figure AII.1.

V	1	0	0	0	0
G	0	1	0	0	0
F	0	0	1	0	0
P	0	0	0	1	0
C	0	0	0	0	1

Figure AII.1: Binary coding of performance scale

Each of the cases of Figure 5.4 can be expressed in terms of these five binary variables, in a way similar to that shown in Figure 5.2. For example, cases 1 and 2 of Figure 5.4 which are:

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	V	G	F	P

Case 1

	d_1	d_2	d_3	d_4
C_1	V	G	F	P
C_2	G	F	P	C

Case 2

can be transformed to:

	d_1					d_2					d_3					d_4				
	V	G	F	P	C	V	G	F	P	C	V	G	F	P	C	V	G	F	P	C
C_1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0
C_2	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0

Case 1

	d_1					d_2					d_3					d_4				
	V	G	F	P	C	V	G	F	P	C	V	G	F	P	C	V	G	F	P	C
C_1	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0
C_2	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1

Case 2

The six alternative coefficients can now be calculated. In the formulae for the coefficients, "a" represents the number of positive matches (two 1's in the columns of the tables above), "b" and "c" the number of the mismatches (0/1, and 1/0, respectively), and "d" the number of negative matches (two zeros).

Thus, for case 1: $a = 4, b = 0, c = 0, d = 16$

and for case 2: $a = 0, b = 4, c = 4, d = 12$

Therefore, the values of the six coefficients for case 1 are:

Coefficient (i): $(a + d)/(a+b+c+d) = (4+16)/(4+0+0+16) = 1$

Coefficient (ii): $a/(a+b+c) = 4/(4+0+0) = 1$

Coefficient (iii): $2a/(2a+b+c) = 2*4/(2*4+0+0) = 1$

Coefficient (iv): $2(a+d)/[2(a+d)+b+c] = 2(4+16)/[2(4+16)+0+0] = 1$

Coefficient (v): $a/[a+2(b+c)] = 4/[4+2(0+0)] = 1$

Coefficient (vi): $a/(a+b+c+d) = 4/(4+0+0+16) = 0.2$

Similarly, the values of the six coefficients for case 2 are:

Coefficient (i): $(a + d)/(a+b+c+d) = (0+12)/(0+4+4+12) = 0.6$

Coefficient (ii): $a/(a+b+c) = 0/(0+4+4) = 0$

Coefficient (iii): $2a/(2a+b+c) = 2*0/(2*0+4+4) = 0$

Coefficient (iv): $2(a+d)/[2(a+d)+b+c] = 2(0+12)/[(2(0+12)+4+4] = 0.75$

Coefficient (v): $a/[a+2(b+c)] = 0/[0+2(4+4)] = 0$

Coefficient (vi): $a/(a+b+c+d) = 0/(0+4+4+12) = 0$

The values of the coefficients for the other eight cases are computed in a similar way. The results are recorded in Table 5.2 in Chapter 5.

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