Valuing The Future: Issues In Modelling Intertemporal Decisions

A thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Science.

1999

Elizabeth Claire Atherton

School of Computer Science

Contents

List of Figures

List of Graphs

List of Tables

Abstract

This thesis is a contribution to the support of decision making. It considers how Ralph Keeney's (1992), 'Value Focused Thinking' approach can help decision makers form and resolve the issues they face. Specifically, it attempts to bring together the normative and descriptive research on structuring attribute trees.

The thesis focuses on long term intertemporal decisions, i.e. those that span hundreds or thousands of years. It goes on to look at both the normative and descriptive theories of intertemporal choice and describes a number of experiments that have made a contribution to the field. The difficulties introduced when a decision has outcomes spanning several time periods are discussed. Some of the anomalies between the normative models and the way people make decisions are presented, and suggestions are made as to how the decision analysis process can be modified to minimise these effects.

A new generic attribute structure for use in intertemporal decisions is developed. This moves away from a constant discounting model and groups time into distinct eras, while including it explicitly in the attribute tree. The advantages of modelling decisions in this way are presented and the structuring is tested in a series of experiments, both face to face and via interactive World Wide Web pages on the Internet.

This research shows that people sometimes wish to value the future differently to constant discounting models, especially in long term decisions. The World Wide Web experiments imply that the factors people consider when thinking about valuing the future are not always the economic ones used to justify discounting. The results also demonstrate that the idea of time era weights and including time explicitly in attribute trees appealed to decision makers. It proved to be a good way of communicating both to experts in the National Radiation Protection Board (NRPB)[†] and the subjects visiting the World Wide Web pages.

[†] NRPB advises the UK government on radiation protection issues.

Declarations

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

The Author

Elizabeth Atherton has obtained the following degrees:

University of Leeds 1991-1994: Bachelor of Science, First Class Honours degree in Mathematics and Operation Research.

University of Lancaster 1994-1995: Master of Science, with distinction in Operational Research.

Papers and Publications

E. Atherton (1998), 'Just the Job: MCDA for a Personal Decision', *OR Insight*, 11(2), 6-13.

E. Atherton (1999), 'Review of "Rethinking Value Elicitation for Personal Consequential Decisions", by G. Wright and P. Goodwin', Forthcoming in the *Journal of Multi-Criteria Decision Analysis*.

E. Atherton (1999), 'Moving Away From Discounting to Incorporate the Long Term Impacts of Decisions', Forthcoming in *RISK: Health, Safety and Environment*.

E. Atherton, T. Bedford and S. French (1999), 'A Decision Analytic Perspective on ALARP', *Confidential Report to IMC.*, School of Informatics, University of Manchester, Manchester.

E. Atherton, T. Bedford and S. French (1999), 'An Example of an ALARP Analysis Using Decision Analytic Methods', *Confidential Report to IMC.*, School of Informatics, University of Manchester, Manchester.

E. Atherton and S. French (1997), 'Issues in Supporting Intertemporal Choice', in *Essays in Decision Making*, 135-156, Edited by M. Karwan, J. Spronk and J. Wallenius, Springer-Verlag.

E. Atherton and S. French (1998), 'Valuing the Future: A MADA Example Involving Nuclear Waste Storage', *Journal of Multi-Criteria Decision Analysis*, 7(6), 304-321.

E. Atherton and S. French (1999), 'Valuing the Future: An Application of Hyperbolic Discounting with Time Era Weights', *Risk Decision and Policy* 4(1), 1-13.

E. Atherton and S. French (1999), 'Structuring Long Term Decisions', *Journal of Environmental Assessment, Policy and Management*, 1(2).

E. Atherton, S. French and A. Goloubenkov (1999), 'Comparison of Ranking Modules in RODOS', *RODOS Working Paper WG5-TN(99)1*, School of Informatics, University of Manchester, Manchester.

E. Atherton and J. Valverde (1999), 'Valuing the Future in Environmental Decision-Making: Implications for the Greenhouse Debate', *LSE Working Paper*, London School of Economics, London.

S. French, L. Simpson, E. Atherton, V. Belton, R. Dawes, W. Edwards, R Hämäläinen, O. Larichev, F. Lootsma, A. Pearman and C. Vlek (1998), 'Problem Formulation for Multi-Criteria Decision Analysis: Report of a Workshop', *Journal of Multi-Criteria Decision Analysis*, 7(5), 242-262.

Dedication

This thesis is dedicated to my family, friends and God who have been with me and supported me in everything that has happened in the last three and a half years.

Acknowledgements

Firstly to my family a great big thank you for their continued support, both emotional and financial and their unfailing love and care.

Thank you to Stuart for all the proof reading, for improving my English skills and for being there to turn to. What can I say, except, the usual.

To Dave, for the wonderful web pages and the technical support that went into them, his advice on technical computer issues and the vital email connections, a BIG thank you. Thank you for caring, for being there and for a friendship that will last, always.

To Becca for the kind use of her computer in the early days, and the constant use of her printer, for her words of wisdom, her love, time, prayers and support, thank you.

To my beloved cell group, especially my prayer triplet, thank you for your prayers and support and for providing weekly havens where I could share in fellowship with God.

To Simon, for advice, contacts, support, proof reading and for being the best supervisor anyone could ever hope for, a great big thank you.

Thank you to Chris for being the best secretary ever, for being so organised and keeping an eye on all the administrative matters.

Thank you to James for giving me the honour of writing a paper with him.

Thank you to Kath for organising all the business meetings, looking after all the administration and for being a good friend.

A special thanks to all the subjects who took part in the World Wide Web experiments and kindly gave their time and opinions.

Thank you to the Frank Gott Scholarship, the RODOS project funded by the EU, the Department of Computer Science at Manchester and Roderick Manhattan Group for funding me during my PhD.

And finally to God, for bringing me into being in the first place, for carrying me when I have been weak, for giving me uncountable blessings and always being there. I give you all that I am.

Overview of Thesis

This thesis is a contribution to the prescriptive support of decision making. In particular it describes how using Keeney's (1992), 'Value Focused Thinking' led the author to structure issues relating to the impacts of decisions with very long term consequences.

Long term decisions can be difficult and there has been much debate on discounting and its applicability. Despite this people often feel uncomfortable with the way long term decisions are made. Specifically, discounting has been discussed in the economic literature for a long time, though the debate has focused on the axioms underpinning the theory and their validity and has not covered people's perceptions of the method and the assumptions it makes about the World. On the other hand the psychological literature has looked at where people break the axioms and not how to devise new models to help decision makers maker better decisions.

Keeney (1992) says,

> *'Values are what we care about. As such, values should be the driving force of our decision making'*

Using this idea I model perception and value in long term decisions starting from a position that seems to accord with many human perceptions rather than from economic theory. The approach is prescriptive in nature, in that it aims to start with the decision makers' perspectives of the issues and guide them towards rational decision models of their situation and opinions.

The thesis reviews the literature on how people make decisions and how their opinions can be biased. This is used to develop ways of improving the decision analysis process and reduce the anomalies people exhibit. The lessons learned from previous experiments are used in the design of the World Wide Web experiments and the development of the new generic structuring.

The debates surrounding discounting are reviewed, focusing specifically on the philosophical and psychological debates. Situations when the assumptions underpinning constant discounting models do not hold are investigated and used to back up the new generic structuring.

The structuring is applied to two decision situations, nuclear waste disposal and climate change decisions. These contexts are used because of their long term nature and the fact that their outcomes span thousands and hundreds of years respectively. The structure is designed to be used in any long term decision situations, as a way to improve the decision analytic process.

Objectives

The objectives of the thesis are to:

Review normative and descriptive perspectives on attribute modelling:

- Highlight their strengths and weaknesses;
- Show how they can help or hinder real decision makers;
- Suggest how prescriptive decision analysis can build on them.
- Observe and facilitate a number of decision processes:
- Build an understanding of the skills needed in attribute modelling;
- Discover some of the problems real decision makers encounter.

Consider intertemporal decision making and some of the complexities it involves:

- Highlight areas where decision theory does not match real decision situations;
- Investigate how prescriptive decision analysis can help decision makers overcome some of the difficulties;
- Find where improvements can be made.

Suggest a new generic attribute structure to use in intertemporal decisions:

- To help decision makers model attributes spanning long time frames;
- Propose a new way of valuing the future;
- Redress some of the short-term biases many decision makers have.

Apply the structure to a number of examples:

- Compare it with other more standard approaches using:
  - Face to face experiments,
  - Interactive World Wide Web experiments,
  - Decision models built by others;
- Determine its acceptability to decision makers and how cognitively intuitive it is;
- Demonstrate its applicability to decision models.

Structure of the Thesis

In many ways the first two chapters have been written for the author's benefit, rather than as a claim to an original contribution to the literature of decision analysis. They describe the process of decision analysis and my experience of that process, showing how I learned about it by working with it. None the less, although they do not describe my contribution, they describe my starting position and my view of the process of decision analysis. This has an influence on the rest of the thesis and sets the style in which the later analysis was conducted.

Chapter 1 gives an overview of decision analysis, identifying ways in which the public can be involved in social decisions that affect them. It emphasises the important aspects of decision analysis and the importance of viewing the analysis as a development process. Tricks of the trade gleaned from observing experienced analysts are reported. Brief descriptions of the normative, descriptive and prescriptive theories of decision making are given, as well as an overview of Keeney's 'Value Focused Thinking' and the benefits of approaching decisions in this way. The research reported in this thesis relates to the structuring phase of the decision process, which is often the most difficult. All the analysis performed in the thesis was conducted in line with Keeney's 'Value Focused Thinking' and followed the principles outlined in this chapter.

Chapter 2 describes the decision processes that the author has observed or facilitated. These observations are included to show how the author's view of decision analysis developed and the important lessons learned prior to conducting the experimental research reported in Chapter 6.

Chapter 3 focuses on the nature of intertemporal decisions. It highlights some of the problems previous empirical studies have found decision makers face, and some of the biases that they can have. Suggestions are made about how the decision processes (and in particular the elicitation of preferences) can be modified to decrease the anomalies people exhibit. The importance of understanding the decision maker's view of the situation is outlined and the implications of mismatches between analyst and decision maker are shown. The issues outlined in this chapter need to be taken into account in all decision analysis, especially long term decisions. The issues highlighted in this chapter were taken into account when structuring the decision models for the experiments and when working with the decision makers. They also influenced the way in which the generic attribute structure was developed.

Chapter 4 focuses on the issues involved in modelling attributes. It reports on some of the results found in previous research and suggests how these findings can be used to improve the process of decision analysis. The importance of structuring the attribute tree carefully and iteratively is emphasised and the advantages of including time explicitly in the attribute tree are outlined. Simple examples are used to demonstrate these ideas. This chapter begins to develop the generic attribute structure created by the author and explains why this way of structuring long term decisions is beneficial.

Chapter 5 reviews the literature on valuing the future. It looks at philosophical, psychological and to some extent the economic arguments for valuing, or devaluing the future, discussing the validity and applicability of these in long term decisions. As this thesis is prescriptive in nature the chapter does not focus on the economic axioms underpinning discounting, but looks at the assumptions made by the theory that people disagree with and situations when these assumptions may not be valid. It goes on to compare several 'discounting' models, highlighting the importance that they give to the long term future. The idea of time era weights and the new generic attribute structure are developed in this chapter. Highlighting the advantages of using the structuring.

Chapter 6 describes the application of the generic structuring. The first application was a hypothetical nuclear waste disposal decision created from reports of real decisions and talking to people with experience in the field. This was used in face to face experiments to elicit hypothetical decision makers' opinions. The analysis was carried out following the guidelines explained in Chapter 1. A simplified version of this decision was placed on the World Wide Web as an interactive decision scenario and used to gather people's opinions about disposing of nuclear waste and the issues involved. A further World Wide Web experiment was also constructed to analyse how people would like to value the future and how they would divide up time. The generic attribute structuring was also applied to a climate change decision, which is also reported in this chapter.

It is noted that the chronological order of the World Wide Web experiments should have been the other way round; however, it was the results obtained from the first experiment that motivated the second experiment. The aim of the second experiment was to try to gain more insight into some people's opinions of the future and the acceptability of the generic structuring suggested.

Chapter 7 draws together the findings of the experiments and the literature searches conducted in the area. It suggests some implications of the research for decision analysis, and highlights where more research is needed to develop understanding in this field.

In summary I believe that this thesis develops a new way of structuring long term decisions by including time explicitly in the attribute tree. This enables the attributes assessed, their values and the uncertainty surrounding them to change over time. It lets decision makers model their situation more accurately as the attribute tree is dynamic, like the World.

A new way of analysing and modelling the time trade-offs in long term decisions is developed. Time is grouped into distinct eras, which are then given a value to reflect their importance. Combining this idea with the new attribute structuring helps decision makers to see what is important in each era and therefore makes the trade-offs over time more explicit.

The thesis describes how the structuring and time era weights can be used on their own or combined with standard discounting models to value the future. It is hoped that the methodology will encourage people to focus on what is important to them and help them to understand their values and make decisions based on them, in line with Keeney's (1992) 'Value Focused Thinking'. This in turn should encourage debate and lead to greater understanding, within and between different stakeholder groups in decisions.

Chapter 1 Overview of Decision Analysis

This chapter outlines the stages involved in performing a multi-criteria decision analysis (MCDA). It highlights the fact that decision analysis is a development process and involves decision makers discovering and structuring their understanding and opinions about the situation they face.

The chapter is divided into sections that group the processes involved in a decision analysis. We do not claim to present the only way of performing an analysis; we only highlight what has come to be seen as good practice. Any analysis will depend on the nature of the decision and the stakeholders involved, and will therefore be unique.

Some useful techniques employed by experienced decision analysts are presented and the ideas of normative, descriptive and prescriptive decision analysis are introduced. Keeney's (1992) theory of 'Value Focused Thinking' is explained and the relevance of this to decision analysis and in particular, to this thesis, are outlined.

Decision analysis can be thought of as a series of evaluation processes that often overlap. Figure 1.1 shows how decision analysis can be divided into several stages and some of the iterative processes that may occur.

Any decision analysis involves information gathering and processing. In Figure 1.1 it is assumed that the decision maker has already identified a decision situation and its context, otherwise this would be part of the process. Throughout an analysis the decision maker should be increasing the amount of information she has about herself and the situation she faces.

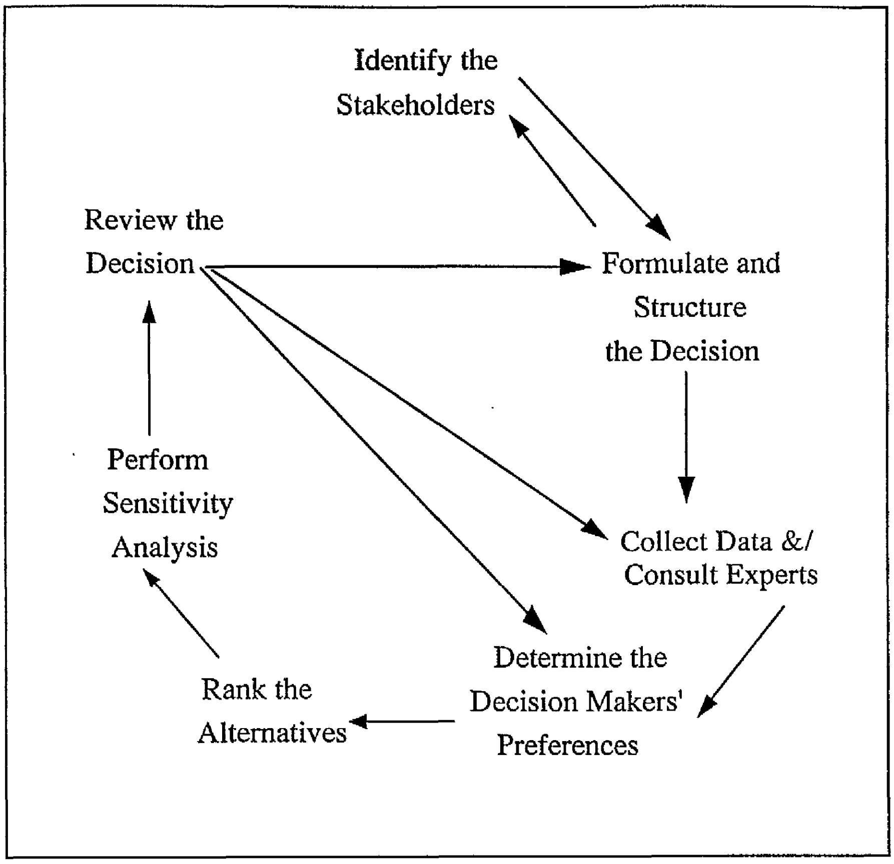


Figure 1.1: Overview of the Decision Process

Once the initial decision situation is outlined it is necessary to formulate it, to clarify what is important to the situation and how to achieve the desired outcomes. Formulating and structuring the decision is one of the most crucial phases and can be the most time consuming, as Chapter 2 shows. Next comes the process of evaluating the alternatives to determine how well each one performs on the attributes defined, then the relative importance of the attributes can be determined. Evaluating the decision alternatives can involve consulting experts and requires decision makers to think about how they feel about their decision; it is essential that during this phase their opinions are not biased by the analyst. Chapter 3 discusses how decision makers' opinions can be biased and the implications of this.

The ranking of the alternatives will depend on the preferences given by the decision makers and the performance of the alternatives. Once the alternatives are ranked it is important to review the decision to ensure that nothing of importance has been omitted. Sensitivity analysis can be used to determine how robust the ranking is, what has the greatest influence on the decision and to investigate uncertain values. The decision makers can then decide whether to repeat the whole, or part, of the analysis and increase the detail used in the model.

Each of the stages can be divided into separate inter-related steps. Outlines of the steps involved in each of the processes are presented in Sections 1.1 to 1.6. The decision and its structure determine the order in which each of the processes is conducted. There is no definite sequence that can be applied to all decisions, and even if decisions are classified as a certain 'type', the analysis will still depend on the specific nature of the decision and those involved in the process.

The information in the following sections provides guidelines for analysis, but should not be taken as the only way to carry it out. We simply emphasise the important steps involved and describe research that has suggested the benefits of structuring the analysis in certain ways. More detailed descriptions of the controversial issues involved are included in Chapter 3.

1.1 Identifying the Stakeholders

The decision may involve only one person. However in reality, with intertemporal decisions, especially those in the public domain, there are many stakeholders. Identifying who should be involved in a decision is often a difficult task.

There are two groups of stakeholders who have a vested interest in the decision being made:

- People with resources to influence the way the decision is made;
- People affected by the decision.

Stakeholders can be involved in the decision process to varying degrees; they can be observed, consulted or included as decision makers. In practice it may not be possible, or desirable, to involve some or even all of the stakeholders in the decision process. This may be due to the nature of the situation, time constraints, or even physical proximity. With intertemporal decisions it is not possible to involve future generations of people who are affected by the decision, as many of them may be too young to make decisions, or perhaps are not even born yet.

The involvement of stakeholders will depend on the nature of the decision. Some of the stakeholders may be unable to give their time or may be so geographically dispersed that their inclusion as a decision maker is not possible. Very complex decisions, with important issues of uncertainty and technical judgement, require the inclusion of technical experts. Such situations may make it difficult to include non-technical stakeholders in the decision process.

When deciding which stakeholders to involve as decision makers, two important issues are:

- 'Group buy-in';
- Audit trails.

'Group buy-in' refers to stakeholder commitment to the decision made. This is especially important in company decisions. For example, changes in working conditions would need 'group buy-in' to avoid strikes and maintain company morale. It may be possible to achieve this by consulting the stakeholders to obtain their opinions, without necessarily involving them in the process as decision makers. With social decisions it is even more important to achieve 'group buy in' as the public need to agree with the decision made on their behalf, in order to avoid long legal battles. This may only be possible by including the public as decision makers.

Audit trails are detailed descriptions of how a decision was made. They include the experts' judgements on technical issues and any conflict resolution undertaken. They are especially important in public decisions when the reason for the decision has to be justified. In order to achieve this, a detailed and well-recorded decision process must be undertaken.

Banville *et al* (1997) describe ways in which stakeholders can be classified, and elaborate on the issues involved in identifying and including stakeholders in a decision process. They suggest that using one of their proposed classification methods will help to identify the stakeholders of the decision. Once the stakeholders have been identified they suggest thinking about how each of them affects or is affected by the decision. Thus, it is possible to consider the stakeholders' points of view and therefore the issues they may think are important. This may make it clear that some stakeholders do not need to be involved in the decision process or highlight other stakeholders who have not yet been considered.

At some point, it is necessary to decide which stakeholders should take part in the decision process and to what degree they should be involved. This depends on the nature of the decision, but research (Armour, 1996) has shown that including those affected by a decision can greatly reduce the time it takes to find an implementable solution. At this point the stakeholders involved become the decision makers in the decision process. It is important to identify all the stakeholders of a decision even if they will not be consulted in the decision process. Thinking about them can sometimes help the decision makers to identify attributes to reflect the stakeholders' impact on the decision or the effects the decision has on them. Thinking about the stakeholders can help in the decision formulation.

1.1.1 Involving the Public in Social Decisions

In social decisions the success of the decision process cannot be measured solely by the ability to find a solution, as Creighton (1986) says:

> *'the measure of a decision is not just whether it is made efficiently and economically but whether the decision making process has sufficient legitimacy, and the decision sufficient acceptability, to permit implementation.'*

In the past, millions of pounds have been spent on decision processes whose solutions have been rejected because the people affected were not involved in the decision process. Governments tried to achieve public acceptance by changing people's beliefs through education and communication. The public were told about a decision, but not involved in it. In such situations the people affected by the decision often saw themselves as victims and were therefore antagonistic towards the decision. With issues such as nuclear waste or nuclear power plants the benefits are widespread, however, the risks are localised, giving high inequity. With this kind of decision, those adversely affected by the outcomes need to take part in the decision process if they are to accept its recommendations.

Armour (1996) and Harms (1996) present ways of including the public affected by a social decision as decision makers. They suggest handing the whole decision process over to the stakeholders, so that they have the money and resources to hire experts to carry out investigations. The stakeholders make the decision, not the government. Armour (1996) also shows evidence of the benefits of more democratic decision making in nuclear and chemical waste siting decisions in Canada. Such processes, cost less money and took less time to complete than decision processes not involving the affected public. Involving more stakeholders makes the decision process longer but decreases the total decision making time (including implementation), partly because there is a decreased chance of litigation.

In Sweden inclusive decision approaches have been used successfully to site nuclear waste. They consulted all the stakeholders and asked communities to volunteer to host the nuclear waste. The success may be partly due to the high level of trust the Swedish people have in the government's nuclear management team. This has been earned through open decision making processes and communication.

In contrast, Britain has faced difficulties in siting its nuclear waste. Nirex[1.1] had its proposed site rejected by the courts. It used a panel of 'experts' and asked them to 'imagine standing in other people's shoes' in order to take into account diverse opinions. The MCDA they conducted did not involve the general public. Reviews of the analysis (Stirling, 1996) have criticised it for not taking into account public opinion.

The Parliamentary Office of Science and Technology (1997) suggest that, *'Engendering public trust and involvement would clearly be an important component of any future process'*.

There should be *'much greater emphasis on public acceptability and participation in decision making'*.

That *'the process of decision making should be fair and trustworthy and that this should involve some form of public participation in a negotiated settlement'*.

It is important for the *'decision making process to be made more transparent and widened to include a broad range of contributions from interested and affected parties, and to develop a more consensual approach'*.

Recognising the need to include the public in decisions which affect them is only the first step. It remains to be seen how successful Britain will be in actually involving a sceptical public who already distrust the nuclear industry.

Getches (1996) states that a decision process involving the public requires:

- Clear focus;
- Committed participants;
- Leadership capacity;
- Sound structure and process.

[1.1] Nirex was set up by the UK government to dispose of intermediate and low level radioactive wastes.

The public must believe that they have responsibilities in the decision making process and that they have power. The government or regulatory body must only be one of the decision makers and not the owner of the decision. Unless all the decision makers have equal status the process is biased and not all the stakeholders will view it as fair.

1.1.2 Modifying the Decision Process

The involvement of different stakeholders as decision makers in the decision process changes the nature of the analysis, as it involves multiple decision makers. It is necessary to carry out more work as each stakeholder (now a decision maker) taking part must be consulted about their opinions and preferences. Boiney and Maguire (1994) suggest working first with decision makers on an individual basis to elicit their opinions. They may feel more free to express extreme views, and there is less chance of important issues being ignored due to peer pressure or fear of other decision makers. This approach is also advocated by Keeney (1988) who suggests first talking to all the decision makers together to outline the decision situation and their role in the analysis. He then advises working with the decision makers individually to determine what is important to them. They can then be brought back together to increase their shared understanding. Focusing first on the issues the decision makers feel are important is essential, as these will influence their opinions (Keeney, 1992).

The type of decision being made will again affect the analysis. In a company situation decisions are made and then implemented almost immediately. The amount of risk involved may be relatively small because of the short time frame of the decision, and there may be only a small number of extreme views. In public decisions the consequences are often very long term. As such, there is more risk involved, and the decision makers may also have very extreme views. In the latter case it may be particularly important to first consult the decision makers individually, in order to obtain opinions on the risks involved and gauge any extreme views that may exist.

Boiney and Maguire (1994) suggest that all the stages in Figure 1.1 should first be carried out separately with each decision maker. Sensitivity analysis can then be used to identify the issues which are most important to each decision maker and the changes necessary in decision makers' views so that they agree. Only after all this analysis has been carried out do they suggest bringing the decision makers together to share information and the reasons for their views. The aim of the joint meetings is then to find a compromise between the decision makers by creating new alternatives or providing a better understanding of opposing views which may result in their modification.

It may be useful to bring the decision makers together after the decision has been formulated to encourage shared understanding of the issues. This may result in agreement on the issues of importance, without looking at the relative importance of the issues. Hence, the decision process would involve individual and group sessions to develop decision makers' understanding of the decision. The nature of the decision would determine the amount of group and individual work needed. The amount of group work will determine how the process progresses.

If all the work is done in groups then the structure will be as outlined in Figure 1.1 and stages (7) to (14) (on the next page) may not be necessary. If necessary step (2) could be performed with individual decision makers first, then brought together in a group to create a shared understanding of the decision being discussed. Steps (3) to (6) could be carried out with individual decision makers to model their opinions without the influence of other decision makers before bringing them together to discuss their opinions. The advantages of obtaining individual opinions first were outlined earlier, and though this may make the decision process longer the information obtained may be more comprehensive in the long term.

If the decision makers are consulted individually first, then the decision process could go through the following steps:

1. Identify the stakeholders who are to be involved in the decision process.
2. Formulate and structure the decision with the decision makers.
3. Determine the decision makers' preferences.
4. Optimise the alternatives given the decision makers' preferences.
5. Perform sensitivity analysis to ensure decision makers are content with their views.
6. Review the decision.
7. Perform sensitivity analysis to determine the changes necessary to reach agreement.
8. Encourage decision makers to share information and views.
9. Update beliefs and values.
10. Optimise the alternatives given the decision makers' preferences.
11. Review the decision.
12. Try to find a compromise.
13. Review the decision structure.
14. Repeat 9 to 13 until a solution is found.

1.2 Formulating and Structuring the Decision

This is one of the most complex processes of decision analysis and, if completed skilfully, can be of great benefit to the other processes. It is essential that the decision makers are not influenced by the analyst. If this process is completed poorly it may result in the wrong decision being analysed. It needs to be carried out carefully with the decision makers as this should help them develop their understanding of the situation and the issues involved. In light of this, the decision makers' views may change and it is important they realise that the aim of the analysis is to help them understand their situation more clearly.

Each of the stages involved in formulating the decision will probably be performed several times as the decision makers gain new insight. The process can be divided into several iterative stages:

- Specify Objectives;
- Generate Alternatives;
- Specify Attributes;
- Identify Scenarios.

The order in which the first three stages are conducted can vary depending on the decision situation.

1.2.1 Objectives or Alternatives First?

Research has been carried out to determine the advantages of specifying the objectives before generating the alternatives. Ho and Keller (1988) reviewed research on how decision structuring affects the number of alternatives created by decision makers and related this to psychological theories of cognition. Two important issues to consider are:

- Whether to focus on alternatives or objectives first?
- How to focus attention on the alternatives and objectives?

The answers to these questions will depend on the nature of the decision and the alternatives currently available. If there are a fixed number of alternatives available then creating other alternatives may aid the decision makers' understanding of how they feel about the available alternatives. If, however, it is up to the decision makers to create the alternatives then careful attention needs to be paid to how the presentation of information may affect the alternatives they create. Heerboth *et al* (1980) found that giving decision makers alternatives did not increase the number of alternatives they created and that the alternatives they came up with were related to the original ones. Casey *et al* (1987) discovered that giving example alternatives to decision makers may have limited the number of alternatives they created. In Isenberg's (1986) research decision makers who were asked to create an initial alternative of their own went on to give effective alternatives. The research seems to suggest that if decision makers are presented with alternatives first they may 'anchor' on these initial alternatives and find it difficult to create new and novel alternatives, while decision makers asked to create an initial alternative for themselves may be more able to think creatively.

Another way to formulate the decision is to focus the decision makers' attention on their objectives first, and then ask them to create alternatives which meet those objectives. Research has shown that the way that decision makers are asked to create alternatives after specifying the objectives affects the alternatives they create. Brown *et al* (1980) found that decision makers create more alternatives when they are presented with the objectives one at a time. Keeney (1986, 1992) also advocates this method, and states that values are what people care about and as such should be what drive a decision analysis. Focusing decision makers on one objective at a time may anchor them on the first objective stated, but it may help them to create good alternatives which score well on at least one objective.

Hausmann *et al* (1983) discovered that more alternatives were generated when the objectives were specified in detail. However, too much detail may eliminate some alternatives from the decision process unnecessarily. They also found that decision makers who rated the objectives' importance before creating alternatives, created less alternatives than those who did not rate the objectives. However, the alternatives created by those who rated the objectives scored higher in the final analysis. The research suggests that adding decision makers' opinions into the process early on may encourage them to create fewer, better alternatives than those who do not think about how important the objectives are to them.

Brown *et al* (1980) investigated the idea of combining the identification of objectives and alternatives, encouraging decision makers to think about an objective and then to create an alternative to satisfy that objective. They were then asked to think about new objectives that the new alternative met and then create further alternatives that would also meet these new objectives, and so on. This technique encouraged decision makers to create more alternatives. The research suggests that an iterative process may be the most successful in helping decision makers create alternatives.

Kahneman and Tversky (1981) showed how changing the framing of a decision affected the choice made. Similarly, changing the description of the objective or the way it is measured (for example, going from percentage change to actual monetary values) may encourage the decision makers to think differently and therefore create more alternatives. Similarly, getting decision makers to think about the scenarios which may occur after the decision is made, may help them to create alternatives. Analysts should be careful however, to focus attention on the positive scenarios first. Starting with pessimistic scenarios may fixate decision makers on the negative aspects of the decision and therefore encourage them to create cautious alternatives.

1.2.2 Top Down and Bottom Up Approaches

Two approaches to the order of evaluation are *Top Down* and *Bottom Up*.

The *Top Down* (or *Objective Driven*) approach involves determining the aims of the decision first and then developing these aims into objectives, which are subdivided into attributes. This is what happens in 'Value Focused Thinking', Keeney (1992).

The *Bottom Up* (or *Alternative Driven*) approach involves first determining a set of alternatives, and then identifying what differentiates the alternatives. The differences are developed into attributes, which are grouped to give objectives.

Buede (1986) identifies situations when each approach may be more applicable. He states that the *Top Down* approach may work better when the decision is strategic, that is, the decision maker knows the problem to solve, but not the alternatives available. *Bottom Up* may work well when the decision is tactical, that is, the alternatives are well defined and the issue is identifying differences between the alternatives. The *Top Down* approach is similar to that advocated by Keeney and Raiffa (1976).

In practice, decisions rarely fall neatly into one of the definitions, and it is necessary to iterate between the different steps and develop the decision makers' understanding of the decision and the processes involved. It may be true that identification of the objectives and attributes will occur simultaneously rather than separately, or in a definite order. In the following sections the *Top Down* approach will be used, as this is more likely to produce more innovative alternatives and is in line with 'Value Focused Thinking', Keeney (1992).

1.2.3 Specify Objectives

This stage involves determining the decision makers' objectives, that is, what they want to achieve or avoid. Objectives may be defined by:

- Legislation;
- Company policy;
- The decision makers.

A decision could involve each kind of objective. If the decision makers are unsure about what they want to achieve or avoid, then the initial objectives may be vague and will need to be modified and clarified as the analysis progresses and their understanding of the decision develops. When the alternatives are created it may become clear that new objectives are important, so it is necessary to see the list of objectives as flexible and able to evolve throughout the analysis.

1.2.4 Generate Alternatives

This involves the decision makers identifying the alternatives available to them or creating new alternatives to meet the objectives they have defined. It may be that the decision situation is such that there are a limited number of alternatives available. In more complicated situations it is up to the decision makers to create the alternatives, which will require imagination and insight.

1.2.5 Specify Attributes

Attributes are the way in which decision makers can evaluate how well an alternative achieves an objective. Keeney (1992) notes that there are different kinds of attributes:

Natural — A natural attribute gives a direct measure of the objective involved and the attribute is universally understood. For example, cost can be measured in monetary terms.

Constructed — These attributes are created for a specific decision context and therefore are not universally understood. In general, constructed attributes involve descriptions of several distinct levels of impact that indicate the degree to which the objective is achieved. In these cases the attribute must define the objective as well as indicate an alternative's achievement. For example, 'minimise environmental degradation'.

Proxy — The attribute is used because of its perceived relationship to the objective. For example, rain acidification could be measured via the amount of sulphur dioxide in the air.

It may be that, when thinking about attributes, the decision makers realise an important objective has been omitted or an attribute which could or should be measured has not been. Therefore, the process will be iterative. Once the attributes have been identified it is necessary to measure each alternative on each attribute to indicate how well the alternative achieves each objective. The type of attributes used determines the type of analysis involved. There may be some direct measurements of attribute values or subjective judgements (See Keeney 1992). The process may also require the help of experts. An alternative's score may depend on future events. In this case, scenarios will need to be defined that describe what might happen in the future before an alternative's score on an attribute can be determined or ratified.

It may be possible at this stage to determine levels that alternatives must achieve on an attribute in order to meet legislation or be acceptable. If this is the case, cut-off values can be identified to eliminate undesirable alternatives from further analysis.

1.2.6 Identify Scenarios

It is important to identify what may happen once the decision has been made and how this will affect the outcome of the decision. Scenarios should be created which cover the possible changes in the world that could affect the decision outcomes. It may be that a decision has to be taken before an external situation is resolved, and therefore there is uncertainty about the outcome of the decision. For example, new legislation may be passed which would make one of the alternatives infeasible or less acceptable. In such cases the decision makers have to attach some sort of probability to the occurrence of a scenario. Some of the scenarios may be related to the decision choice, for example the probability of a nuclear accident will depend on the structure built to hold the nuclear waste. In this case the probability of a scenario occurring may be different for each alternative.

Identifying scenarios and their probabilities can be very complicated and may require help from specialists in the fields involved. It may not be possible to give exact probabilities to the likelihood of the events, so uncertainty will be introduced into the model. Any estimates can be subjected to extensive sensitivity analysis to determine the effect of the uncertainty, and further modelling can be undertaken if the uncertainty affects the decision taken. It is important to determine how the different scenarios affect the attributes and the values for each alternative. This is a complex issue and will require careful thought from the decision makers.

1.3 Collect Data and/or Consult Experts

Once the attributes have been decided it is necessary to determine how well each alternative performs on the attributes. In order to do this data may need to be collected. This can involve scientists, engineers and experts from many disciplines. Some data may be collected by field visits and observations, however, for new or unfamiliar attributes it may be necessary to consult experts and ask for their opinions. Roger Cooke has conducted research into how to calibrate the opinions of experts and has created software to help to determine the reliability of the results experts give, see Cooke (1991, 1995) and Cooke & Waij (1986).

1.4 Determining the Decision Makers' Preferences

In order to rank the alternatives the decision makers need to decide which objectives, and therefore attributes, are the most important. As mentioned earlier, it may be that some objectives are essential due to legislation. In this case the legislation can be used to eliminate undesirable alternatives and set standards. Some of the difficulties of working with decision makers to elicit their preferences are discussed in Chapter 3. The important issue is to try not to bias the decision makers' preferences due to the questions posed.

The decision makers' attitudes towards uncertainty and the possibility of negative outcomes needs to be determined, so that utility functions can be created for each of the attributes. Some of the utility functions may be linear, in which case, detailed analysis will not be necessary. However, some may be non-linear and therefore require the decision makers to consider their preferences carefully.

Specifying preferences and opinions can be very difficult, especially if the alternatives have not been experienced by the decision maker. They may have to try to imagine what it will be like to be in an alien situation, or think about how certain outcomes would make them feel. It is important to encourage decision makers to think widely and to use their imagination. Whilst this can be a key issue, another alternative is to talk to people who have been through similar situations and ask them for their opinion. Decision makers' preferences are often not well formed when they begin a decision analysis and part of the process is the creation and clarification of their preferences. How to develop their opinions without biasing them is difficult.

1.5 Optimise the Alternatives

Once the decision makers are happy with the alternatives being analysed and the attributes used to evaluate them, (i.e. the attributes sufficiently distinguish between the different alternatives and cover all the important aspects of the decision) their preferences can be used to determine the 'best' alternative. This can be achieved using decision support software, or if the decision model is small, the calculations could be carried out by hand. It is necessary to determine what type of objective function to use, that is, linear additive or a multiplicative function, see Keeney and Raiffa (1976).

1.6 Sensitivity Analysis

Once the 'best' alternative has been identified, it is necessary to evaluate how 'robust' the decision is. Any parameters that were vague can be varied to show their effect on the decision. The decision makers' preferences for attributes can also be varied to discover their effects. This allows the decision makers to see how changes in the values in the model affect their decision. It may also be useful to vary several values at once, to see their combined effect, as this may give more insight into the decision.

Sensitivity analysis may identify attributes or scenarios whose values need to be determined more accurately, as changes in their values affect the decision. This may highlight the need for more analysis, or further modelling of certain aspects of the decision. The purpose of sensitivity analysis is to show the decision makers how their decision may alter given changes in their values, and therefore the important aspects of their decision.

1.7 Tricks of the Trade

A workshop was held at the 16^{th} conference on Subjective Probability Utility and Decision Making in 1997. Three decision analysts from different schools of research worked with three decision makers to analyse their common decision situation. See French *et al* (1998) and Chapter 2 for a more detailed explanation of the problem. Part of the workshop involved reflections on the analysis, and insights into some of the 'tricks of the trade'. Some of the ideas are summarised below.

The workshop participants suggested that it was important to do the following in an analysis:

- Set out clearly the aims of the session;
- Encourage the decision maker to relax;
- Ask the decision maker to describe the situation as she sees it;
- Look at the broad issues first;
- Probe the surface and then investigate in depth;
- Listen carefully, recap and clarify the understanding you have;
- Iterate between suggestions and around different parts of the decision;
- Explore the *zero option* - what happens if we do nothing;
- Explore the *ideal option* - what if there were no constraints;
- Get the decision maker to look at the situation from different stakeholders' viewpoints.

The workshop also discussed useful questions that could be asked during an analysis:

Why is this your decision?

This establishes the decision makers' commitment to the situation and their role in it.

Do you have any anecdotes about the system, or something similar that you have experienced?

To give insights into the situation.

Who is the final decision maker?

To establish if there are other more important stakeholders who may influence the decision.

Which alternative do you think would receive most support?

This may help to gauge the opinions of the other stakeholders.

Do you think people would be willing to pay to solve the problem?

To give an idea of the importance of the problem.

Although what is appropriate will depend on the decision situation, the workshop provided an opportunity to learn from 'experienced' decision analysts the techniques that they find useful.

1.8 Normative, Descriptive and Prescriptive Analysis

There are three general interpretations (or uses) of decision modelling: normative, descriptive and prescriptive decision analysis. Traditionally, normative and descriptive research have been seen to be at odds with one another, while prescriptive research has been seen as a bridge between them, see Figure 1.2.

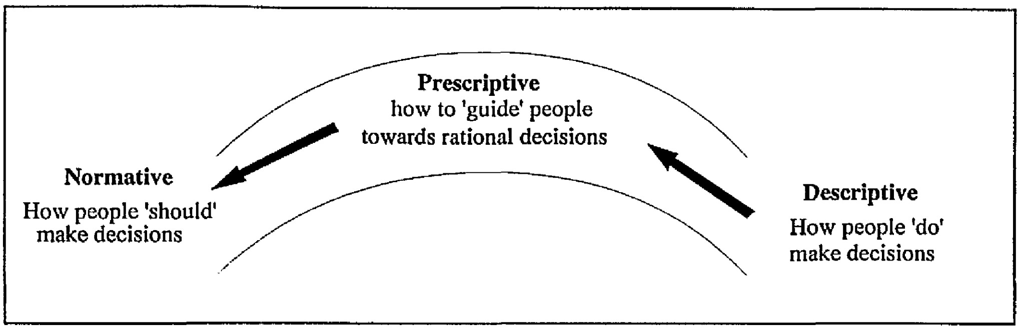


Figure 1.2: The Relationship Between the Three Schools of Decision Analysis

Mathematical decision models often come in two forms:

Descriptive Models those that claim to describe or predict real human behaviour;

Normative Models those that try to define how ideal people 'should' behave.

The following sections outline the ideas and motivations behind the different schools of thought and how they relate to one another.

1.8.1 Normative Decision Theories

These suggest how people 'should' make decisions, if they are to act rationally and logically. They are usually mathematically based and have their origins in philosophy, economics and statistics. An example is Bayesian decision theory, which suggests one should make decisions as follows:

- Encode beliefs as subjective probabilities;
- Encode preferences as utilities;
- Update beliefs in the light of data, via Bayes' Theorem;
- Maximise expected utilities to take decisions;
- Iterate as more data becomes available.

In reality there are anomalies between the behaviour which the normative theories encode and how people actually 'do' make decisions. These anomalies mean that people often do not act in the way the theories predict, and so it is argued that normative theories may be of little use in guiding real decisions. Normative theories do not take into account the internal inconsistencies that people have or how their values can be influenced and changed. Regret, anticipation, fear, cognitive limitations in calculations and attention span are not included in the models. Yet, empirical studies have shown that all these things affect the choices of decision makers (See Chapter 3).

Normative theories are usually based on mathematical axioms, which define 'rational behaviour'. They are often of the form, *if the decision maker believes* (*a*) *and* (*b*), *she should do* (*x*) *and* (*y*). The motivation for the axioms is what some researchers think is rational, logical behaviour. Once a 'basic' theory has been established, further research is often carried out to determine what happens if some of the axioms are removed or modified. This can lead to a more accurate model of the behaviour of real people, or how researchers believe real people behave.

1.8.2 Normative Intertemporal Decision Theories

In intertemporal decision making, one of the most well known normative models is *discounted utility theory* (DUT). The axiomatic basis of DUT is surveyed in French (1986). The theory assumes that people discount future outcomes at a constant rate. Each future outcome is *devalued* by multiplying it by a discount factor, which decreases as a geometric function. It should be noted that DUT is entirely compatible with the Bayesian School, in that it provides a particular form of utility function for intertemporal contexts. However, empirical studies have shown many anomalies that people exhibit, which tend to refute this theory and the assumptions it makes (Loewenstein and Prelec, 1992).

More complex utility functions for preferences over time-streams can be built upon multi-linear and other multi-attribute functional forms, see Meyer (1976) and French (1986, 1996). Such forms allow the value assigned in one period to depend upon the consumption in other periods and, perhaps more importantly, they allow the risk attitude to consumption in one period to depend upon consumption in other periods.

1.8.3 Descriptive Decision Theories

This school of research encompasses empirical studies of human behaviour. Such studies come mainly from psychology and seek to describe how people *do* make decisions. Descriptive models do not seek to aid people in making 'rational' decisions. They do not indicate how people can change the way they view decisions in order to avoid 'inconsistencies' or 'biases' in their choices. Indeed, words such as 'inconsistency', 'bias', and 'anomaly' only take meaning when descriptive theories are compared with normative theories.

Many of the studies are carried out in laboratories, often using students as their subjects. Some researchers argue that this is unrealistic and makes the results of the experiments unsuitable for generalisation, see Beach *et al* (1987). When looking at descriptive research it is necessary to question how realistic the experimental situations are and how easy it is to generalise the results to the real world.

Beach *et al* (1987) found that there is a citation bias. Negative descriptive results, which show anomalies between normative theories of decision making and how people behave, are cited more often than results showing people acting 'rationally'. Therefore, a literature search may suggest that people are very bad at making judgements. In truth, the situation may be less serious than it is made out to be.

Beach *et al* (1987) go on to say that:

- Often, the tasks used to evaluate subjects' judgements are contrived and unrepresentative of the tasks they are generalised to;
- Subjects are sometimes asked to make judgements which they are not qualified to make;
- Subjects may frame the decisions differently to the researchers and therefore effectively work on different tasks;
- The frame to use is often unclear and therefore it is difficult to evaluate subjects' performance.

All of these criticisms undermine the validity of descriptive research. However, they back-up research which suggests that the way information is presented and the questions asked can have a large impact on the answers decision makers give. The fact that in experimental settings decision makers misunderstand their tasks should alert analysts to the possibility of this happening in real decision situations (See Chapter 3). Finding anomalies between normative theories and the way people act is useless unless this motivates decision analysts to try to help people overcome their inconsistencies.

1.8.4 Descriptive Intertemporal Decision Theories

Loewenstein and Prelec (1992) present a model of intertemporal choice that can accommodate anomalies between DUT and observed decision making. The model assumes that intertemporal choices are defined with respect to deviations from a reference point or status quo. A value function and a discount function are used to define a decision maker's opinions. However, although this model describes behaviour, and possibly explains anomalies, it does not itself suggest how people can be helped to make more rational choices.

1.8.5 Prescriptive Decision Theories

Prescriptive decision analyses seek to guide decision makers toward consistent, rational choices, while recognising their cognitive limits. They use descriptive theories of how people 'do' make decisions to understand people's cognitive processes, while using normative theories of decision making as the ideal way to make decisions. Prescriptive theories try to help people to analyse their decisions in the correct way and make rational choices. Bell *et al* (1988) say that prescriptive analysis tries to answer the question of,

> *'How can real people - as opposed to imaginary, idealized, super rational people without psyches - make better choices in a way that does not do violence to their deep cognitive concerns?'*

Prescriptive analyses focus on trying to aid decision makers. They recognise that care is needed to avoid decision makers' choices being biased through poor framing of the questions asked in the elicitation of their beliefs and preferences. Descriptive analysis about what influences decision makers' preferences are used to formulate ways of overcoming the problems and care is taken when designing the elicitation procedures. Information would be presented in a neutral frame, for example, stating the number of lives saved and the number of lives lost. In this way the decision makers can focus their attention on the information which they think is more important, rather than only being able to focus on that given in the decision description. This also helps the decision makers to consider all the aspects of a decision, even though they may not be equally important.

Unlike normative analysis, prescriptive analysis does not assume that the decision makers come to the analysis with clear, well defined opinions which just need to be uncovered. It is often the case that decision makers do not know how they feel about certain aspects of the decision and part of the purpose of the analysis is to help them to develop their opinions. Prescriptive decision analysis is invariably an interactive process that guides the evolution of the decision makers' judgements and builds their understanding of their situation. The modelling is cyclic. The decision makers' beliefs and preferences are analysed and modelled, which gives insight into their judgements, often leading to revisions of the model. The process continues until no new insights are found. The decision makers' preferences and beliefs evolve as they understand both the situation and themselves better, thus helping them towards more informed, rational and consistent choices.

Prescriptive analysis can be built on the Bayesian characterisation of decision making, but extends this to include: elicitation procedures, sensitivity analysis and remodelling cycles to enhance understanding until the modelling is *requisite*. Phillips (1984) describes a theory of requisite modelling:

> *'A requisite decision model is defined as a model whose form and content are sufficient to solve a particular problem. The model is constructed through an interactive and consultative process between problem owners and specialists.'*

Further discussion of how prescriptive analysis brings descriptive and normative theories together can be found in Bell *et al* (1988) and French (1996).

1.9 Value Focused Thinking

'Value Focused Thinking' (Keeney, 1992), as its name suggests, focuses on decision makers' values. Keeney says:

> *'Values are what we care about. As such, values should be the driving force of our decision making. They should be the basis for the time and effort we spend thinking about decisions.'*

In reality this is not usually the case; decision theories often focus on the alternatives that are available and not what the decision makers want to achieve.

Keeney criticises many decision theories for looking at:

- How to solve decision problems;
- How to analyse alternatives;
- How to evaluate alternatives given a quantified objective function.

He claims instead that theories should look at:

- How to identify potential decision opportunities;
- How to create alternatives;
- How to articulate qualitative objectives on which to appraise alternatives.

Another widely used decision theory is Alternative Focused Thinking. This identifies the alternatives available in a decision and then looks at the objectives, or criteria, to evaluate them. It then picks the 'best' alternative available on this basis. Value Focused Thinking identifies what the decision makers care about and then creates alternatives to meet these desires.

Focusing on the alternatives available in a decision situation constrains decision makers. It does not encourage them to think widely about what they want to achieve. Section 1.2 outlined some of the research that has indicated that focusing decision makers' attention first on their values or objectives helps them to create more inventive alternatives. It also helps them to identify what they want and then encourages them to create ways of achieving it.

With short term decisions it may sometimes be permissible to focus on the alternatives available, but with long term decisions it is important that decision makers think very clearly about what they want and all the possible ways of achieving it. Focusing attention on people's values has several advantages, especially in the realm of long term, social decisions.

Guiding Information Collection

Knowing how to evaluate alternatives and on what basis can be difficult. This is especially true when there are several stakeholders involved in the decision process. By focusing on values it is possible to identify what should determine the acceptability of the alternatives and what information is required to determine this. Effort can be concentrated on obtaining the information necessary to distinguish between the alternatives and not on collecting irrelevant information.

Improve Communication

In social decisions values are what are important to the public. If debate centres on the technical issues of a decision this can exclude the public from the discussions and make them feel ignored. Focusing on values involves the public in the decision making process and allows them to express their concerns. This can lead to a more inclusive decision making process, which is more likely to gain public acceptance (See Section 1.1.1; Armour, 1996 and Harms, 1996).

Multiple Stakeholders

Focusing on values identifies what people care about, making it easier for stakeholders to understand their differences and identify common ground. It is often easier to resolve disagreements over values rather than alternatives, as the discussion is more explicit and stakeholders are forced to justify their opinions. French *et al* (1992) found that focusing on values helped to diffuse tense discussions in a decision conference. It helped stakeholders to understand what other stakeholders were thinking and why, and showed that these differences did not change the decision.

Interconnecting Decisions

Some decisions are sequential and are built on what has happened in the past. Decisions made now can often have long term consequences and determine what options are available in the future. It is important to set out clearly what the aims are to make it possible to evaluate how well alternatives achieve these aims and maintain consistency between decisions. The overall aims should not change over time; if they do then either they were not fundamental aims or something external should also have changed. Setting out the aims clearly at the outset provides a way of monitoring what is happening. Any changes are then easy to see and will need to be properly justified.

Evaluating Alternatives

If the values are clear they provide an obvious way to evaluate the alternatives. Unless the values (and therefore objectives) are well defined the results of the evaluation will be limited.

Identifying Decision Opportunities

Many decision situations are reactive, not proactive, in that something happens and a decision has to be made about the best way to handle the situation. If people's values have been clearly identified, then it is easy to monitor how well these values are being achieved at different points in time. This enables people to identify opportunities that might help them achieve their aims better, so they are in a position of being able to create such opportunities and are therefore able to be proactive. This empowers people and gives them more control over their lives and their future.

1.10 Summary

This chapter set the context for the thesis. The following chapters will focus on the issues and difficulties involved in structuring and modelling attributes over time. The decisions under consideration involve issues that span hundreds, sometimes thousands of years, thus focusing attention on the complexity of long term decisions. Throughout, it will be assumed that any decision analysis conducted will follow the general structure outlined in this chapter and will be in line with Keeney's 'Value Focused Thinking'. The next chapter reports some of the author's experience of observing and facilitating decision analysis.

Chapter 2 Observations of Decision Processes

This chapter does not add any revelations to the decision analysis literature, but the processes reported served as an introduction for the author to the issues and skills involved in decision analysis. The chapter highlights the following observations:

- The structuring of a decision is often the crucial phase;
- Decision makers facing hypothetical decisions are less committed to finding a solution;
- Decisions involving long time frames are more complicated than short term decisions;
- Decision makers find it harder to give opinions when the decisions have long term implications;
- Judgements about lives and related issues are very difficult.

The decisions reported vary considerably. There is:

- A short term decision with one decision maker;
- A medium term decision with several decision makers;
- A personal decision with a three year time span;
- A hypothetical decision spanning ten thousand years.

The reports help to highlight some of the difficulties of structuring decisions and the problems that might be encountered. The chapter ends with some reflections on what the author learned.

2.1 Observation of an Immediate Decision

At the Subjective Probability and Utility Decision Making conference, which was held in Leeds in August 1997 I was invited to observe a decision structuring process conducted by Dr. Val Belton (the analyst). My role was to observe Dr. Belton working with a decision maker (DM) and comment on the process. The event was part of a workshop run by Professor Simon French and Lisa Simpson to compare different schools of thought on decision structuring. (Since then, a report of the workshop has been published, French *et al*, 1998.) The following paragraphs are exerts from that paper.

> The problem was set in the School of Computer Studies at the University of Leeds, where the three DMs lectured. In that way it was hoped that they would share a common context. Moreover, the problem was related to a real problem. Aspects of it had occurred a couple of years back. Nonetheless, the scenario set up involved many hypothetical aspects, particularly hypothetical actions of certain others in the School. The problem related to the provision of coffee and drinks for the members of the School of Computer Studies, including the undergraduates. At the moment there is a coffee room which can be used by postgraduate research students and staff only. The problem centred on the Common Room Committee who organise for the coffee, tea and sugar to be bought and wash the tea towels used in the room.

Last week two things occurred which have led to the problem. Firstly, the kettle in the Common Room blew up. One member of staff complained rather unpleasantly to a couple of members of the Common Room Committee. It was unfortunate that this came on top of a growing number of demands upon them and also at a time when perchance they were all frantically trying to complete a project report. Whatever the cause, the complaint escalated into a row and the Committee resigned *en bloc*, claiming no one appreciated the amount of effort they put in. Thus there is no kettle in the Common Room, no replenishment of supplies and no one willing to take on the task. Secondly, the University Refectory have notified the Head of School that the Mathematics Coffee Bar is too small to be viable and they will be closing it at the end of the calendar year. Three lecturers (the DM's) have been asked by the Head of School to prepare a report on ways forward. They have been told to think very widely and report in two to three weeks.

2.1.1 The Analysis

One of the most notable aspects of the analysis was the relaxed way in which it was conducted. Dr. Belton guided the focus of the DM while allowing him to speak freely and explore aspects of the decision. The DM was allowed to write when he felt motivated to and participated in the process in a friendly and open manner. This approach enabled the DM to consider the issues at his pace and in his way, rather than being ruled by the analyst. The process was controlled by the analyst, in that the DM's attention was focused on different aspects of the decision, but once focused the DM was encouraged to explore the aspects as he pleased.

To start the whole process off the DM was asked to describe the problem as he saw it, I believe this helped the DM to realise that the analyst was interested in his feelings and thoughts while giving Dr. Belton a background to the problem. During the analysis all the main points were placed on 'post-its', which were put on a white board and moved around as the analysis progressed. The 'post-its' were grouped into stakeholders, alternatives and attributes. This helped to structure the decision and identify how the different aspects related to one another.

During the analysis the DM's attention was focused on different aspects of the decision and their interaction, following a process similar to that outlined in Chapter 1. The analysis began by focusing on the stakeholders, their role in the system and the resources available to them. What the DM wanted to achieve was established and ways to accomplish this were discussed. This helped to create new alternatives, which were then related to the stakeholders. The DM was encouraged to think of ways of combining the alternatives and altering available resources to improve them, this also helped to create new alternatives. The order in which the analysis was conducted followed the ideas of 'Value Focused Thinking', Keeney (1992).

The analysis was, at first, quite general, then focused in on the important issues. As the analysis progressed it became clear that there were two important aspects to the decision: the immediate problem of restoring the coffee club and the long term problem of the coffee facilities available. As time was limited the DM was asked which part of the decision he wanted to concentrate on. He decided to deal with the immediate problem in the system. In this way the decision structuring centred on the issues which the DM thought were important, and gave him power in the decision process.

At several points in the analysis Dr. Belton reviewed the information uncovered. This served as both a check on the understanding of the DM's comments and a summary of what had been said, which helped to clarify the issues. The DM was asked to consider how other stakeholders might feel about aspects of the decision and the alternatives available. This encouraged the DM to look at the problem from different perspectives and to think about other people's opinions. To help create new alternatives the DM was encouraged to take a broader view and was asked about other coffee systems that he had experienced. The process ended with a summary of what had been discussed and possible ways forward. This helped to clarify what had been achieved and what could be done in the future.

In the review session, comments were made about the decision structuring. By defending the analysis the DM showed that he felt he played an active part and so any criticism of it was a criticism of him. The other observer, Professor Robyn Dawes, commented that he thought that the analysis did not get to the 'real' decision and that it only scratched the surface. When questioned the DM commented that he had not wanted to discuss certain aspects of the problem and so had steered the analysis away from those issues. This emphasised the point that DMs can manipulate the analysis so that it concentrates on the issues they think are important, and not necessarily what needs to be analysed. Reasons for this may have been that the situation was hypothetical, or that the process was being watched by several people, making the DM reluctant to talk about very sensitive issues. Ultimately, it is only possible to obtain the information that people want to give, and this may not be everything that is required.

2.2 Observation of a Short Term Decision

Word of Life (WOL) is a church with a congregation of about two hundred. It is based in Burley, an inner city area of Leeds which has a high proportion of students, though the church also aims to serve the local, 'native' Leeds people as well. WOL is entering a new era. It has just purchased an old church building which needs considerable refurbishment to make it ready for use. The aim is to turn the building into a multipurpose centre, with facilities for a crèche, coffee shop, second hand shop and meeting rooms. The church is also starting a new congregation, which will be aimed at families and Burley residents, while the other congregation will be targeted more at students. As a result of the church purchase and the formation of the new congregation the leadership of the church have decided to review where WOL has developed from and where they are going in the future. In particular, the process of communication is not always effective, and the congregation does not always understand what the leadership is trying to do, and so does not get involved. With this in mind, and given the importance of the events to come, the leadership decided to look at new ways of communicating with the congregation. The group wanted me to help them to establish how to communicate the church history, to understand where the congregation wanted WOL to aim for in the future, and to prioritise the church activities.

WOL is a cell church which means it is based on small groups of people who meet together regularly and become a close support group for one another. Each cell group consists of around four to ten people, who meet at least once a week. They have one or two cell leaders and an assistant cell leader who are responsible for organising the cell meetings and pastoral care of the members. The streets around the church are allocated to cells, who pray for and work in them, by helping members of the community, for example, by visiting the elderly or running errands. On this basis, cells are grouped into zones that are looked after by zone pastors, who tend to the needs of the cell leaders. A group of leaders make up what is called Prayer and Planning, which has the job of deciding church policy and the overall running of the church.

2.2.1 Analysing the Decision

Prior to the analysis several meetings had taken place to discuss the church history and what needed to be communicated to the congregation. All of the information was well known to those involved, but they had no idea how this information could be structured so that it was easily understandable. Part of the information to be communicated was the authority structure within the church and the importance of the roles of those involved. The first part of the analysis was identifying the stakeholders of the situation and how they relate to one another. I then helped the group to structure their ideas and represent them diagrammatically, to make it easier for others to understand. The hierarchy in Figure 2.1 was created to show the authority structure within the church. First of all, it was important to explain how to interpret a hierarchy and how it conveys information and relationships between the elements in it. The concepts seemed very logical to those involved and helped to structure the other information that had been considered.

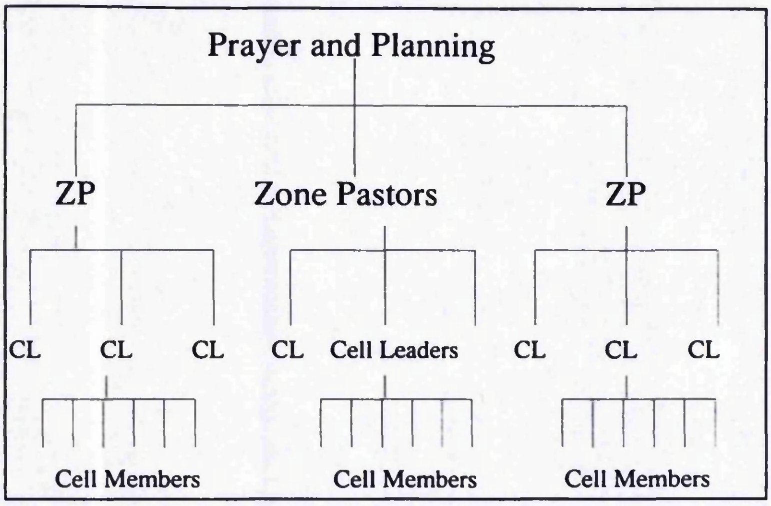


Figure 2.1: Church Leadership Hierarchy

Those involved with Prayer and Planning, and other people with jobs in the church had already worked on several important issues. The group had been studying the history of WOL and had looked at how the church had developed. From this they had worked out:

- A vision statement which describes the overall aims of the church;
- A doctrinal basis which set out the church's basic beliefs, taken mainly from the Bible;
- A set of values, which are headings for the church's activities, that is, worship, community and mission;
- A set of *distinctives* which make WOL different from other churches.

The group had come up with a list of issues, which they were unsure how to handle. The main issue was that of giving some structure to the thoughts and opinions of those involved, so that others could understand them. After introducing the idea of hierarchies, the group thought that this would be a good way of representing the information. They wanted to include the idea of time and how the history of the church had influenced where it is today. They also wanted to show how the vision statement impacted on all the other elements, and that the story (history), doctrinal basis and values combined to form the distinctive elements of the church. Figure 2.2 shows how they structured the information to represent the inter-relationships.

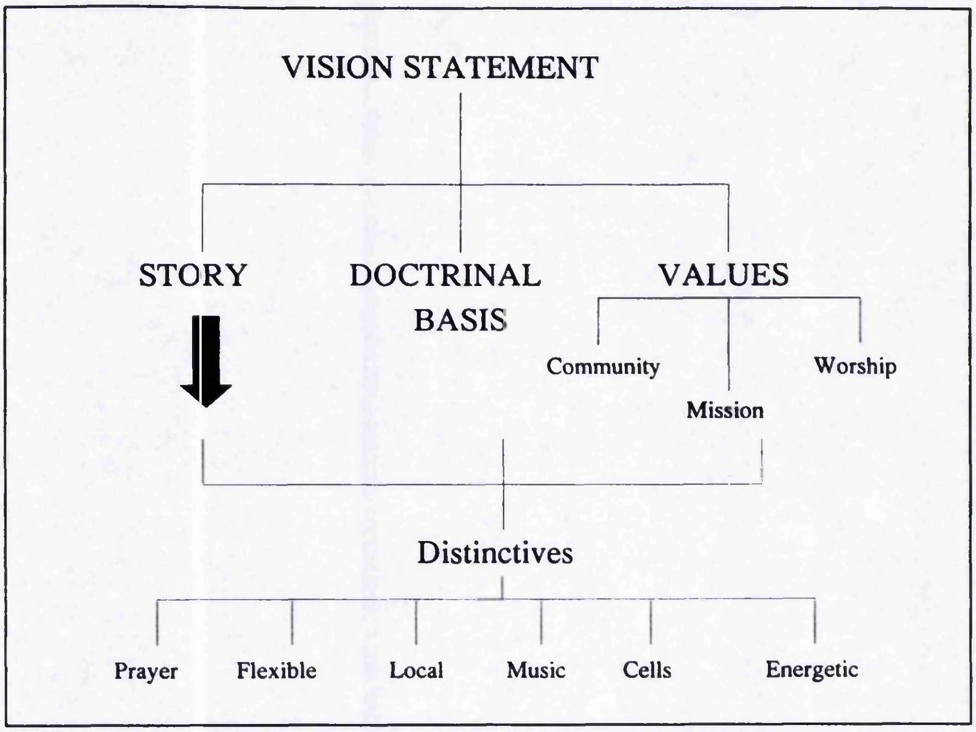


Figure 2.2: The Factors Influencing the Character of Word of Life

The aim now was to decide how to communicate this information to the congregation and to ask them for their contribution to the question of, 'Where Next?'. I decided to focus the group's attention on what it was they wanted to achieve and why, by posing five questions. These were aimed at trying to establish the aims and objectives of the process and the stakeholders' roles in it:

- What information do you want to convey to the church members?
- Why are you doing this?
- Why is it important that people in church know this?
- What will this lead on to?
- What are people's roles in this?

Answering these questions helped the group to understand clearly what they were aiming for. This then enabled them to think about how they might go about achieving it. Looking at people's roles helped them to see that people in the church would have various reactions to the information and would need to understand and accept it to a different extent. This led them to think that they should present the information to different groups in the church at separate times. The issue of helping people not only to understand the information, but actually feel that they owned it and were part of it, came out as an important aim. The group realised that it would be important to help the church members understand their roles in the process. This was in line with the ideas of Handy (1993). If people feel they have a role in a situation they are more likely to 'buy into' the concepts and become involved.

It was decided that the level of information people needed was proportional to the size of their role. Prayer and Planning, zone pastors, congregational leaders and church workers really need to understand and accept the 'history' of the church. This is because they have authority in the church and are in decision making positions. Cell leaders also have to have a very good understanding of the 'history' because they also have positions of responsibility, particularly the pastoring of church members. The congregation as a whole, although needing to understand the information clearly, does not have to accept and understand it as fully as those in positions of responsibility.

I did not think that imposing a formal structure would help the group to shape their thoughts and so grouped the information without applying technical labels to it. For example, stakeholders were referred to as 'those involved' or 'church members'. The answers to the questions can be summarised in 'traditional' decision analysis terms as follows.

2.2.2 Aims and Objectives

- Communicate the church history to the congregation;
- Help the church members understand where they fit in;
- Help church members to understand their role in church;
- Use this as a building block to help the church members decide what to do in the future;
- Increase unity and community;
- Involve the church members in the decision process for the future.

The group decided that there were two overall aims, which created two decisions that needed to be addressed:

- Communicating the church history;
- Involving the church members in making plans for the future.

As a result of this the group decided to create a two-phase strategy to meet these aims.

2.2.3 Stakeholders

- Those outlined in Figure 2.1;
- Their roles vary depending on the amount of responsibility they have in the church;
- The amount they need to understand the information depends on their roles.

The first thing to think about was alternative ways of communicating the information to the church members.

2.2.4 How to Communicate the Church History

The group decided that the ideas should be communicated to the stakeholders in stages, starting with those with responsibility in the church. By talking to zone pastors, congregation leaders and church workers first, they felt that this would give a market test of the information and provide an opportunity for some fine-tuning before talking to the congregation. It might also indicate how easy it would be to pass on the ideas to the rest of the church, because the 'buying in' process would be more difficult as the church hierarchy was descended and people's level of involvement decreased.

The next stage would be to communicate the ideas to the cell leaders and then finally to the congregation. It was decided to have separate meetings with the cell leaders because they would need to fully understand the issues in order to lead discussions in cells. The question now was what format these meetings should take. Those with positions in the church come together on a regular basis for planning sessions, so it seemed logical to use one of these meetings to convey the information to the zone pastors, congregation leaders and church workers. A meeting of the cell leaders would be used to convey the information to them. Pictures and diagrams, which summarised the information and emphasised interactions, were seen to be the most appropriate way of communicating the information.

The next question was how to convey the information to the congregation. Several options were suggested:

- Cell group meetings;
- Church services;
- Special church meetings.

The group deliberated on the advantages and disadvantages of each of these options. They decided that as the history is fundamental, it would seem practical to communicate this to the entire church together, that is by a church gathering rather than in cells. In this way any subjective interpretation by cell leaders would be avoided and it could be ensured that the whole church received the same message. This would also help to establish a feeling of joint ownership of the ideas - that this was something that belongs to WOL as a body and community, which was one of the original aims. Thoughts about the type of church meeting to have were discussed, as people were usually very busy, organising another church evening would be difficult, and so it was decided to use normal church services.

After this congregational communication it was considered important to allow time for the issues to be discussed in cells. This would help people to express their feelings and to take more ownership of the concepts. Although the values are non-negotiable, the way they are ranked will change depending on the context in which they are being considered. There are three levels to consider.

- Church;
- Cell;
- Individual.

It would be necessary to emphasise that the ideas apply to each of the three levels and that their importance may change at each level. This will depend on the cell group, the talents of the individuals and God's calling on their lives. It would also be important to put across the idea of this individual involvement. The group seemed happy with the strategy that they had come up with and decided that the people who had worked on the ideas would present them to the other members of the church. These people were left to think of ways to convey the information diagrammatically, so that it could be understood easily.

2.2.5 Obtaining the Church Vision

The next issue was how to involve the church members in defining the church's vision for the future. The aims were similar to those outlined previously: to encourage the congregation to own the vision and to get involved in church activities. Members of the group immediately began to think about things that had been done in the past and the successful and unsuccessful attempts to encourage church members to get involved in church activities. Analysing past events showed that when the leadership told the church of activities that were going on and asked them to get involved, the response tended to be very low. However, if the leadership asked the church to think about what activities they wanted to do, then the response was higher and people became involved more freely. However, the question remained as to how this could be achieved. Again, group members began to think about events that had happened in the past. They mentioned a questionnaire that had been created to identify the talents people in the church had, and decided that this would be a good way of obtaining information about what people wanted the church to do.

It was suggested that the communication process should be similar to that for the church history. Zone pastors, congregation leaders and church workers would be consulted first, then cell leaders, and then the congregation. The group decided that the questionnaire should be split into sections to reflect the *values*, and that there would be sections for church, cell and the individual. This would help people to own the vision and give space for people to express their own ideas and talents. The method of elicitation would differ slightly at each level and the role of the individuals involved would be different. The group decided that it would be good to have a church meeting to discuss the ideas with the congregation and then use cell meetings for completion of the questionnaire. The process of aggregation would also be difficult because it would again have to be done on two levels; cell group level and zone pastor level. It would then be up to Prayer and Planning to decide church activities based on the information elicited.

2.2.6 Reflections

My role in the analysis was to help the group to structure their thoughts and help them to focus on what it was they wanted to achieve and the best ways of doing this. The information required was already available, but it was not clearly structured, and the relationships between different pieces of information were unclear. The use of hierarchies to structure information helped the group to clarify their thoughts. By posing questions, I helped the group to concentrate on their aims and objectives and on the stakeholders involved. Focusing the group on what they cared about (their values) helped them to identify what they wanted to achieve and ways of doing that. Before the analysis they did not have a clear idea of what they wanted to do. The analysis focused on the group's values in line with 'Value Focused Thinking'.

As the process was quite informal I avoided using technical language and tried to keep to the format of the meetings that had taken place before I became involved. Thus, the group was not overwhelmed with the process itself and did not feel intimidated by my involvement. Knowing all the members of the group on a personal basis helped them to accept me as a member of the team and not a dictator or organiser, which I think also helped with the process. The experience helped me to see the importance of decision structuring and to understand how difficult it can be to shape thoughts and ideas. By introducing simple decision analysis techniques I managed to help the group to organise their thoughts and devise strategies for achieving their goals.

2.3 Observation of a Personal Decision

S is an actuary who had been offered two jobs. He already had a job and needed to decide which, if either, of the job offers he wanted to take. I offered to help S to think about the issues involved in his decision and how important each of them were to him. At first S did not seem to realise that staying with his current firm was, in itself, a choice. After I had explained to him that this was an active decision and that we needed to analyse his current job in the same way as his job offers, we had three alternatives to consider. The act of defining his current job as a choice may have also decreased the status quo bias, as S had to evaluate it as a new possibility.

As this was a personal decision, S and his family were the only stakeholders, and he thought that his opinions reflected his wife's and would take into consideration the needs of his one-year-old son. The analysis was carried out very informally at S's house, which helped him to feel relaxed.

The whole process consisted of two meetings, approximately one week apart. The first meeting was the longest. At this meeting I helped S to identify the attributes, evaluate the alternatives with respect to each of the attributes and identify the relative attribute weights. The second meeting was used to update the model in light of new information that S had obtained and to perform sensitivity analysis on some of the attribute weights and values about which he was unsure.

At the beginning of the first meeting I explained carefully what we hoped to achieve. I described the concept of multi-criteria decision analysis (MCDA) and how we would elicit S's values and opinions. S found it easy to understand the ideas behind MCDA as he had a mathematical background. We discussed how S could include uncertainty in the model, and he mentioned that this might be useful. I explained the ideas behind 'Value Focused Thinking' and how we would evaluate the alternatives with respect to what S cared about and what was important to him. The stages of MCDA that we would go through were outlined, as follows:

- Identifying attributes;
- Evaluating the alternatives with respect to the attributes;
- Evaluating scenarios of the future;
- Weighting the attributes;
- Optimising the decision;
- Iterating and performing sensitivity analysis.

The whole process was carried out at a pace that S was happy with. At several points during the analysis I reviewed what we had achieved, to ensure that I had understood S clearly and to help him to clarify things in his mind.

2.3.1 The Decision

The decision was such that the alternatives were already known and the main issue was helping S to think about the elements in the jobs that were important to him, and why. I started by getting S to think about all the attributes of the jobs. He already had lots of ideas about what each of the alternatives entailed and he came up with lots of attributes that he wanted to measure them on. Each attribute was written on a separate piece of paper and put on the floor. When S thought he had identified most of the attributes, we recapped, and he helped me to group the attributes into super-groups. This helped him to think about the broader picture and identify attributes that he had missed out. The new attributes were added to the original ones and put into their relevant groups. Figure 2.3 shows the attribute tree (*Challenge* was only added at the second meeting).

S's salary increases when he passes exams and so *Pay Rises* one and two are controlled by the probability that he does, in fact, pass. S thinks that he has a 50:50 chance at each exam that he sits. At his present company he has a company pension, which will be lost if he moved to a new company. He also has an interest free loan with his present company, which would have to be repaid.

S believed that the pressure he was under was very important. This would be affected by the number of hours he had to work (and whether they were flexi-hours), the number of holiday days he had and the stress he would be put under at work. Some of these were clearly objective while some were subjective and depended on how S viewed the companies and information he had gathered on them.

Some attributes under *Working Environment* were very important while others were more aesthetic. *Rank* in the company, *Management* and *Office Structure* were all related to S's position in the company and how he would be managed. The idea of having a clean slate appealed to S as he thought it might be good to start again, without any prejudices. *Variety of Work* was also important, he thought it would help his job prospects in the future and also give him more job satisfaction.

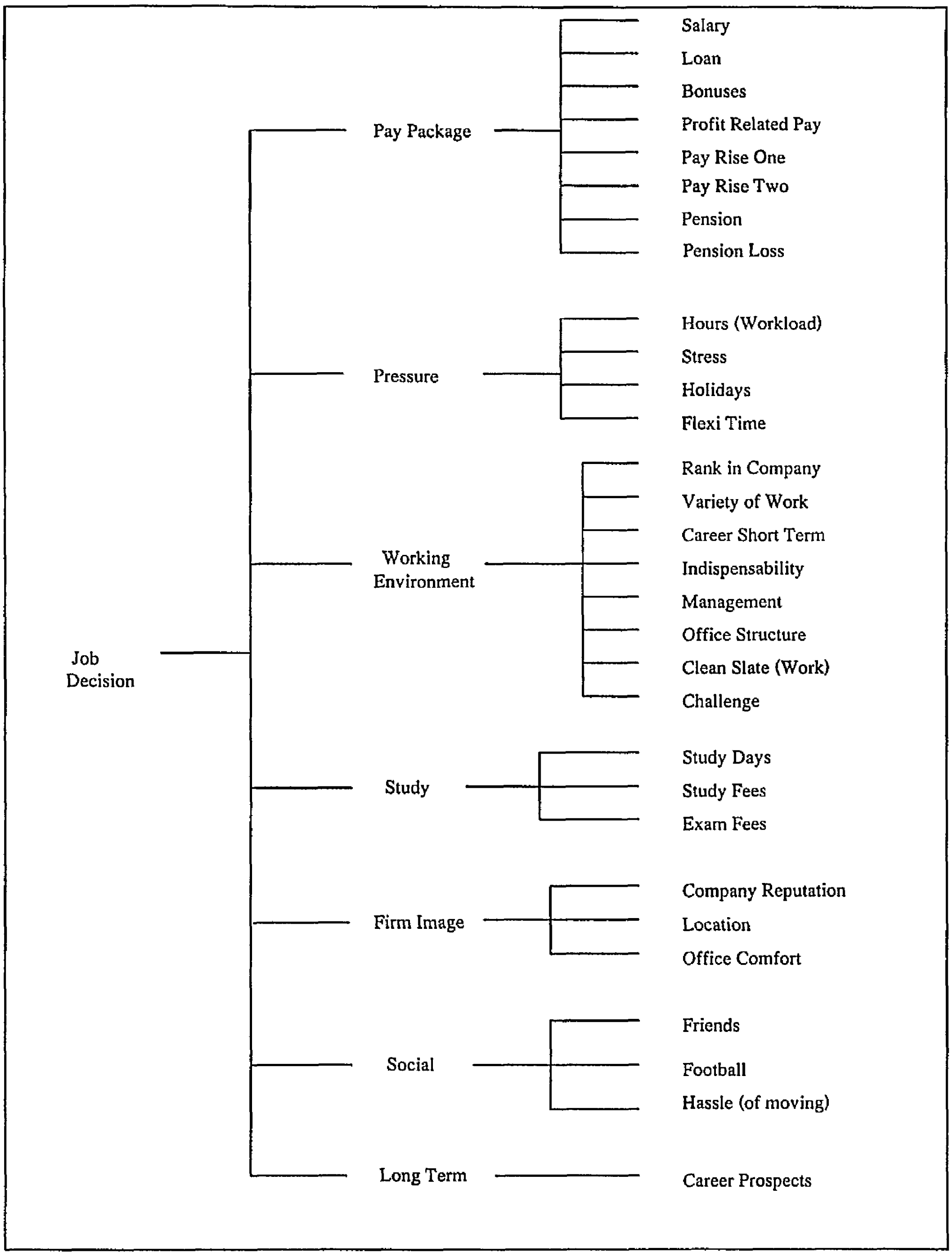


Figure 2.3: S's Attribute Tree

When the analysis was carried out S had just taken an exam. If he passed it he would have another two to take. The number of study days he is given depends on whether he has already taken and failed an exam. The company will only pay fees for exams he has not already taken while working for them. If S changed companies it would be as if he was starting again, as the new company would give him a fresh start exam-wise, pay his fees and give him all his study days. At his current company he would have to pay his own fees for one of his exams and not have as many study days.

Firm Image covered many aesthetic attributes such as the *Office Comfort* and *Location*, and though S did not think that these were very important he wanted to include them. *Company Reputation* however, was important as this determines which clients the firm has and the prestige of working for them.

S thought that the *Social* aspect of work was important, as he enjoys playing football and interacting with the people he works with. As with most people S does not like the idea of change and therefore included an attribute to reflect the stress of moving.

The *Long Term* attribute looked at S's career prospects three years down the line, as this is when S thought he would probably review his situation. He believed that the outcome would be uncertain and would depend on how well he did in the company he was working for. He assigned probabilities to the possibility of doing well or badly and to the possibility of leaving the company at the end of three years. He also gave a value to each of the good and bad outcomes, depending on which company he was at.

Twenty-nine attributes may seem like too many to use, but each of them were important to S and encompassed some aspect of his decision. As S was the only DM involved in the process, it was relatively easy to obtain values for each of the attributes from him and perform the analysis. The computer package (Analytica, 1998, an influence diagram based software) used to model the decision makes it straightforward to model lots of attributes clearly, by having a network of influence diagrams, which link together. The model had a top level influence diagram, which had all the super-groups on it, and then separate, linked diagrams containing all the attributes in the super-groups. This made the computer presentation of the decision very clear and allowed S to look at one group of attributes at once. By including all of the attributes S mentioned, the model included all of the aspects of the decision that he thought were important. This made him feel comfortable with the model and that it covered everything it needed to.

2.3.2 Evaluating the Alternatives

After all the attributes had been identified, I asked S to score each of the job alternatives against them. For some of the attributes, for example *Salary*, it was easy to score the alternatives. The scores were then converted into a scale from 0-100 to give the relative scores of the alternatives for each attribute. For more subjective attributes, for example *Company Reputation*, S gave the values that he thought were appropriate to each option. The alternative with the highest score was given a value of 100, the alternative with the lowest score was given a value of 0. The other alternative was given a value in between 0 and 100 either in proportion to the original range, or where S thought that it should be valued. The financial attributes were measured over a three-year period as S believed that he would review his job situation after that time.

Once each alternative had been scored on all the attributes, I asked S to rank the attributes. He arranged the pieces of paper so that the order reflected the relative importance of the attributes. When he had an order he was happy with we began to give weights to the attributes. We started by giving the salary attribute a weight of 1000. 1000 was used so that S could assign small differences between attribute weights. In the computer model the attribute weights were divided by 10, so that they were 100 or less. From this starting point we then looked at other attributes which were measured in monetary terms. In this way I began with the easy comparisons to help to give S a feel of the procedures involved and to make him familiar with the idea of comparing attributes. When assigning a weight to an attribute the range of the scores of the alternatives was visible to S and I kept reminding him that the weight should be related to the range of the attribute. S found this easy to understand and could assign the weights without any difficulties.

Once all the monetary attributes had been weighted, we began to look at other attributes that were easy to convert into money terms, for example *Holidays*. S thought that he would be willing to work two days to have one day of holiday. Thus, a day of holiday was worth two days' pay and so we converted it to its monetary equivalent and assigned the relevant attribute weight to it. We then looked at the more subjective attributes, for example *Company Reputation*. The analysis had therefore progressed from relatively straightforward comparisons to more complex ones.

The process of giving weights to the attributes resulted in some re-arranging of the rank of the attributes, as S realised that some of the attributes were worth less to him than he had originally thought. He found it relatively easy to assign weights to the non-monetary attributes, partly because the weights of the monetary attributes had already been worked out and the subjective attributes lay between these in the rank order. This gave S a 'ball park' figure for their weights, which made them easier to assign. Again I reminded S to concentrate on the ranges of the attributes as well as the 'importance'.

2.3.3 Modelling the Decision

Once all of the attributes had been weighted I modelled the decision in Analytica. This gave an initial solution which I explained to S. In the meantime S thought again about the attribute weights and even gave the weights to his wife to think about, to see if she thought he had been 'misguided'. S himself felt confident with the weights because he said that they were based on logic and that they made sense to him.

2.3.4 Incorporating Changes in the Situation

After a few days S and I met up again, this time with the computer model. Between the first and second meeting S had received some extra information. This meant that some of the jobs scored differently on the attributes. S also introduced a new attribute (*Challenge*) to reflect the challenge that he felt he would face at work by working with people who were better than him. S had also indicated some weights that he wanted to do some sensitivity analysis on. We adjusted the weights and looked at the results. The decision changed owing to the new information. Thus, S had performed a sort of Bayesian update without really realising what he had done. We found that the sensitivity analysis did not change the result of the model and he therefore felt comfortable that the model was stable and would not change even if his situation altered slightly.

2.3.5 S's Reflections

The new result agreed with the decision S had himself made. After the analysis we talked about the techniques I had used to help him analyse his choices and how he felt about them. He felt that structuring the decision had helped him to think clearly about the issues involved. It had made him realise that some of the issues were less important than he had at first thought. By identifying the issues he was able to then discuss them with friends and colleagues and analyse the jobs more logically. This helped him to gather more information and to make his decision.

S has a background in mathematics and was therefore very numerate. This helped him to understand the concepts of the decision modelling process and helped him to assign weights. He felt that the whole method was very logical and that the end decision model matched his opinions and thoughts, which made him confident in the choice made and content with the analysis.

Structuring the decision took the most time. The whole process took about four and a half hours. About half of this was spent structuring the decision and determining the attributes. The process showed that structuring was the vital stage in the decision making process. If this had not been done carefully then S would not have been satisfied with the results.

2.3.6 A Final Twist

After making his decision and beginning the process of accepting one of the new job offers his current employers took S to lunch. They had heard that he was thinking of leaving and wanted to try and persuade him to stay. Having performed a detailed decision analysis process S knew exactly where the current job fell short of his other offer. This put him in a strong position to negotiate the terms and conditions he would require if he were going to stay at the company. His employers agreed to meet his requirements and S has stayed with his original firm, but on much better terms.

2.4 Observation of a Hypothetical Intertemporal Decision

As part of my research I created a hypothetical decision scenario, with the help of scientists, engineers and papers on previous studies of siting nuclear waste. There is a detailed description of the model in Appendix A2. After structuring the decision, Professor Simon French and I worked with an organic chemist and a philosopher to obtain their opinions on the importance of its different aspects. From the outset, both people had been involved in the decision structuring, and the chemist had contributed data and many comments on the description of the decision.

2.4.1 Meeting with the Chemist

The meeting began by reviewing the final version of the decision. The chemist made comments about certain aspects and suggested that some of the data was unrealistic. We worked with him to change the data so that it was more applicable. The DM has worked in the area of nuclear waste for several years and has been involved in projects that analyse different ways of managing nuclear waste. We thought that he would be able to give us his opinions on how important each aspect of the decision was. Simon led the analysis as he had more experience, but the process was unsuccessful. The DM would not give us any indications of how important he thought each of the different elements of the decision were. He told us that he believed we had included all of the important issues in the description and that the data we had put in the decision was realistic. However, he would not say which parts were the most important to him, stating that he did not feel qualified to make those sorts of judgements. When pushed further he said that the decision was far too complicated for him to be able to comment on and that he did not have the experience necessary. We did not pursue the issue any further.

2.4.2 Meeting with the Philosopher

The philosopher looks at the ethical issues involved in scientific change, environmental issues and environmental policy. She said that she thought that the description of the decision covered all the important aspects, but would not give her opinions on their relative importance, feeling that it was unethical for a philosopher to give opinions on the importance of different aspects of a decision.

In order to obtain importance values for the model I worked with Simon French to obtain his preferences. As he was committed to the decision situation, and also has experience working in this field, he was more than willing to give his preferences.

2.4.3 Reasons for the Decision Makers' Reluctance

The decision scenario was completely hypothetical, although the information in it was realistic. The DMs we talked to had been involved in structuring and developing the decision, but did not own it because it was hypothetical. Therefore they could avoid giving their opinions to us because there was no penalty for not co-operating and they did not really have to make the decision. Both the DMs had been very co-operative in the earlier stages of the process and had given us lots of very useful information, but this had been objective information, backed up by their experience and was not subjective or personal opinion. The scientist did not feel qualified to make judgements because of the very long term nature of the decision and its importance (had it been real). The philosopher claimed it was unethical, while commenting that she did not think she was able to make that sort of decision. French *et al* (1992) also found that with important intertemporal decisions DMs were reluctant to own the decision and wanted to pass the responsibility on to someone else. When using hypothetical situations it is very difficult to obtain commitment from the DMs involved.

2.5 Important Observations

Observing decision processes has shown how people react differently to real and hypothetical decisions. When the DMs owned the decision, and it was real, they were very committed to finding a solution. The element of 'ownership' was less prevalent in the hypothetical decision situations. The difficulties encountered in the hypothetical examples emphasise the dangers of generalising from laboratory results to the real world. The way that DMs reacted in the different analyses was greatly affected by the situations they were in and whether the decision was real or not.

The workshop setting made the DM reluctant to reveal sensitive information as there was an audience and he felt vulnerable. This emphasises the importance of helping DMs to feel relaxed, safe and in a confidential environment. It is important that they do not feel their comments are going to be used against them or judged by anyone else. In the hypothetical intertemporal decision the DMs again felt very vulnerable and did not want to reveal their opinions.

The most important part of all the analyses, and the part that took the longest to complete, was the structuring of the decision. With the immediate decision it took the whole of the workshop, and even by the end of the two hour session the analysis had not reached a point were the analyst could ask the DM for his preferences. In the church decision, most of the meetings were spent structuring the thoughts of the DMs; the actual decision process took much less time. This was also the case for the personal decision. With the intertemporal decision many months were spent meeting with the DMs and obtaining the correct structure for the decision. The elicitation of preferences (which worked) with Simon French only took two hours. Research on how to help DMs structure decisions is still very limited. Chapter 1 outlined some of the work done to date.

The immediate and short term decisions did not differ significantly in their complexity, however, the time taken to structure the short term decision was much longer. Part of this may have been because there were multiple DMs in the church decision, or possibly that the decision involved multiple time periods. In the workshop the DM had opted to focus on the immediate decision and not the longer term one, perhaps because this was the most pressing issue, or he thought it would be easier to deal with.

The complexity of decisions increases when their outcomes span several time periods, especially when the time periods are very long. The implications of the decision also increase, and therefore so does the responsibility involved. When trying to obtain preferences for the intertemporal decision the DMs kept saying that they did not feel qualified to give answers to the questions and that it was too hard for them to handle. The next chapter discusses more of the complexities of intertemporal decisions, indicating how decision analysis can be conducted to help decision makers deal with these issues.

Chapter 3 The Complexity of Intertemporal Decisions

The fact that intertemporal decisions span time makes them very hard to handle. The decision process itself may take a long time and the decision makers involved might change which could introduce differing opinions. As with any decision process, there is a sizeable human element, with the associated problems of human irrationality and fallibility. In this chapter the difficulties introduced because of the time aspects are explored and some of the anomalies that have been discovered through psychological research are reviewed.

The initial sections discuss some of the difficulties surrounding intertemporal decisions, highlighting the fact that the decision process itself will be dynamic. Some of the issues involved in measuring equity over time are discussed in the following sections, as well as methods that have been used in the past.

Many anomalies have been discovered between the normative theories of intertemporal choice and the way people actually make decisions. Some of these anomalies are reviewed in this chapter along with ways of modifying decision analysis to help people avoid them. How people view the decisions they are making and the choices they are given to elicit their preferences are very important. The issues surrounding the framing of decisions are discussed and suggestions about how to convey information in an unbiased way are given. Implications of the research presented in this chapter are made and ways to improve decision analysis techniques are proposed.

3.1 Dynamic Situations

Most decision situations are not static. The world is constantly changing and these changes can, and do, affect the outcomes of decisions. To try to take these issues into account in intertemporal decision making, the decision makers often think about scenarios of the future and how these may affect the outcome of their decisions. Unfortunately, the future cannot be predicted accurately and it is impossible to anticipate everything. Assigning probabilities to possible outcomes is also very difficult, and as forecasting techniques are often poor, can be very unreliable.

People have a tendency to anchor their decisions on the way things are now, and their perception of the present status quo. Yet the way things are now may not be the way that they are in a few years or perhaps a few months. Changes in management or government policy can radically affect how companies view situations, see Phillips (1982). Although they know this, decision makers find it very difficult to anticipate change and think widely enough about the context of their decision.

3.1.1 Spanning Generations

Complexity is introduced when decisions are made on behalf of other people, especially if they are not yet living. An individual's tastes and needs change over time, and these in turn alter their preferences. It is, therefore, even more challenging for people to make decisions that affect others yet to be born, and whose future needs are extremely difficult to estimate. It is hard to define 'equity' between generations; even then, it is difficult to treat future generations equitably because their circumstances cannot be fully predicted. We are concerned with precisely such decisions having long reaching effects. These issues arise in many different contexts including the nuclear safety field, the environment and general social policies.

Even if the consequences of decisions do not span generations of people, they can span generations in companies. Many decisions have long life cycles, for example, investments in equipment or machinery. Therefore, there is a need to take into account the changes in the company that may occur after the decision is made. Forecasting techniques are often very poor. They can predict situations for the next few time periods, but are less useful after that. This adds another element of difficulty, as future circumstances cannot be predicted.

3.1.2 Policy and People Changes

National and international policy changes during the implementation of a decision may affect the choices made. Therefore, it is important to get the decision makers to be aware of the possibility of changes and how these may affect the strategies they have chosen. This may help to reduce the Anchoring Effect and help the strategies span governments and generations.

The people affected by the strategies may also change with time, and it is important to focus decision makers' attention on how these changes may affect the effectiveness of their strategies. The effect a decision has on people may depend on their age; for example, the effect of radiation exposure is age dependent. Therefore, it is important to indicate to decision makers how strategies should develop over time to accommodate these changes. As many situations are dynamic, it is important to create dynamic strategies that can be adapted to change and develop as the situation develops.

3.2 Measuring Equity

Equity is a significant issue in social decision making. If the population feels they are being treated unfairly, they may suffer from stress and resentment, which will compound the inequity. It is important for decision makers to understand equity issues, as they can have a large effect on population morale and trust in the decision makers. The ability to treat people equally may be constrained by resources, and it may be necessary to balance the equity achieved against a decrease in the efficiency of a strategy.

The way decision makers view equity can be very different. In the decision conferences carried out to aid the design of RODOS[3.1] (Ahlbrecht *et al*, 1995), the analysts discovered that different groups of decision makers considered the equal treatment of people differently. One group thought that equity was achieved by using strategies that would decrease the dose[3.2] received by individuals with the same exposure by the same amount. Any measure not giving the same dose decrease for all individuals was excluded. Another group viewed equal treatment as offering all individuals the same chance to decrease their doses, which may have resulted in different exposure to radiation for individuals. This small difference in wording caused large differences in the countermeasures implemented by the two groups.

How to evaluate or measure the utility to individuals in a single time period is a problem in itself (see, French *et al*, 1995). When consequences accrue to populations over time, equity issues become even more difficult. Three approaches, and examples of the difficulties that are encountered, are outlined below.

3.2.1 Complete Lives

This theory looks at the utility a person receives over the whole of their life and compares it with the total utility another person receives. Temkin (1992) gave the following example; if A and B are two people and their utility is:

$$A = 2,2,8,8 \quad \text{and} \quad B = 8,8,2,2$$

The theory would consider the two people equal, because their total utility is the same. However, there is inequity between A and B at every stage of their lives which is bad. Thus, looking at total life consumption ignores the equity of consumption of one group in a population relative to another.

[3.1] RODOS is a Real Online DecisiOn Support system for use before, during and after a nuclear accident. Several European institutes under a European Union contract are creating it.

[3.2] Dose is a generic term for the quantity of radiation that impacts or is absorbed by an individual. Its scale is such that under the linearity hypothesis (Research has shown that the effects of radiation are linearly related to the dose.) the value is directly related to the increased risk of cancer the individual faces from the exposure. See French *et al* (1997) and NRPB (1989).

3.2.2 Simultaneous Segments

This view divides history into segments of about 20 years, and compares the equity between people in the same segments. The age of the person is considered to be irrelevant and therefore an 80-year-old can be compared with an 18-year-old. This is dubious because utility is often dependent on age.

3.2.3 Corresponding Segments

This view divides people's lives into segments of about 20 years and compares the utility people receive when they are the same age. This seems more logical as it compares like with like. However the simultaneous and corresponding segments views have another problem. Temkin (1992) showed that these views would see the inequality between A and B, and the inequality between C and D as equally bad.

$$A = 8,8,2,2 \quad \text{and} \quad B = 2,2,8,8$$

$$C = 8,8,8,8 \quad \text{and} \quad D = 2,2,2,2$$

This would seem objectionable, because the inequality between C and D may be considered worse than that between A and B.

In the simultaneous segments view, inequality only matters between overlapping generations. Therefore, inequality will matter within, but not between, the past, present and future. On the other hand, the corresponding segments and whole lives views can deal with non-overlapping generations. None of the views is ideal for all situations, and the view chosen will have important implications for how projects and equity are judged. It may be necessary to modify or combine the theories in order to give a better analysis of equity.

Analysing equity in populations is also problematic. If, in two populations, the absolute differences in utility between the rich and the poor are the same, and one population is larger than the other, then it seems logical to say that the larger population has more inequality. However, some would claim that the inequality is the same because the pattern of inequality in the two populations is the same. For an illustration, see Figure 3.1. Some would judge A and B to be the same because the absolute differences in inequality are the same, though B has twice the population size.

This has significant implications for intergenerational equity, as it is relevant in assessing equity between and within generations. Therefore, thought needs to go into how equity is to be measured with respect to the size of populations.

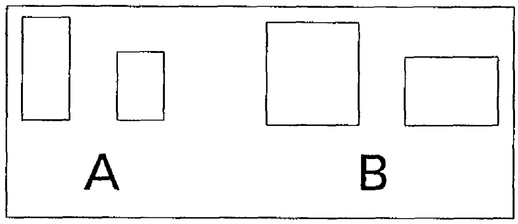


Figure 3.1: Population Utilities

There will not be one solution that will apply to all intertemporal decisions. The 'best' method of dealing with issues like equity will depend on the situation being faced.

3.2.4 Different Types of Equity

The issue of equity applies to many different decision areas: risk, injury, money payoffs, opportunities and threats. Some people assume that in all situations the more uniformly a risk is shared the more equitable and, therefore, the 'better' the option. In some situations, the good of the whole population can depend on a few people being treated in an unfair way. For example, in the case of very contagious diseases, some communities may be forced into isolation to save the largest number of lives in the whole population and to minimise the spread of the disease. Unfortunately, uninfected people in the isolated community are at much greater risk than people in the wider population.

Fishburn (1984), Keeney and Winkler (1985) and Sarin (1985) have looked at different kinds of equity in the decision process. They divided equity into categories:

Ex-Ante Equity - the equity of the decision process and the risks which give the outcomes.

Ex-Post Equity - the equity of the outcomes that actually occur after a decision is made.

Dispersive Equity - the equity of the distribution of risk over groups in the population.

In some decision situations all three aspects of equity are very important, but it may not always be possible, or desirable, to achieve all three. In the context of a nuclear accident, decisions often have to be made before there is a release of radiation. In this case, ex-ante and ex-post equity can be very different, depending on the occurrence and nature of the release. Fishburn (1984) and Keeney and Winkler (1985) discuss the axioms needed to achieve the different forms of equity and when they may not be compatible.

3.3 Anomalies Between Normative and Descriptive Theories

Normative theories of intertemporal choice try to describe how people should make decisions if they are to act in a rational manner. Discounted Utility Theory (DUT) is one of the most well known normative theories. It assumes decision makers choose between options by analysing the sum of discount factors, based on time delays. However, it is founded on axioms which people break when given certain choices. Many psychological studies have been carried out into 'how' people make decisions. Kahneman and Tversky (1981) analysed Expected Utility Theory (EUT) and showed that under many circumstances people did not conform to its axioms. Prelec and Loewenstein (1991) built on this work and discovered parallels between the anomalies in EUT and DUT. Similar anomalies occur between how people view time and probability.

The following sections outline some of the anomalies between the normative theories and 'how' people make decisions, and indicate how these issues need to be taken into account when working with decision makers. As intertemporal decisions often involve probabilities, they can suffer from both sets of anomalies.

3.3.1 Common Ratio and Common Difference Effects

EUT says that preferences between risky outcomes should not be affected by multiplying the probability of the outcomes by a positive constant, which is less than one. However, Kahneman and Tversky (1981) showed that this axiom was sometimes violated.

For example: (6,000; 0.45) ~ (3,000; 0.9)

(6,000; 0.001) > (3,000; 0.002)

The smaller the probability of winning the smaller the effect of changes in probability.

DUT says that preferences should depend on the absolute time interval between the delivery of outcomes. However, evidence has shown (Ainslie, 1975 and 1985; Chapman and Elstein, 1995) that the impact of a constant time difference is less significant if outcomes are remote. This effect violates a stationarity property, which is critical in DUT.

For example: £20 in one month > £25 in two months

£20 in 10 months < £25 in 11 months

The result of the Common Difference Effect is that preferences between two delayed outcomes may change if both delays are extended by a constant amount. It also implies that discount rates should decrease as a function of time delay, which has been shown to be true in empirical studies (Horowitz, 1988). Therefore, increasing the delivery dates in a pair of temporal outcomes by a constant amount decreases the ratio between the time delays. This, in turn, implies a decrease in the relative importance of time, because of the sensitivity to time ratios, which can lead to changes in preference.

Kahneman and Tversky (1981) showed that the further from certainty a probability is, the smaller the effect of changing the probability. Similarly, the more remote a delay is, the less effect a change in delay has.

3.3.2 Certainty and Immediacy Effects

Kahneman and Tversky (1981) discovered that a decrease in the probability of an event by a constant factor has more impact when the outcome was initially certain, than when it was merely probable. They called this the Certainty Effect. For small probabilities people tend to overestimate the occurrence of an outcome, but for large probabilities people tend to underestimate. This means that people give more weight than they should to small probabilities and less weight to large probabilities.

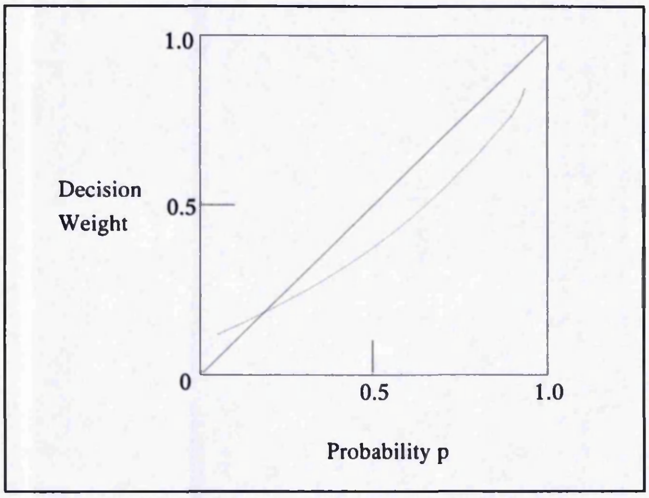


Figure 3.2: Decision Weight Function for Probabilities

Figure 3.2 shows the difference between the actual probability and the value it is given by decision makers. This effect is important in many decision situations that involve decreases in the probability of an outcome. If the outcome is bad, then a decrease in probability from 0.1 to 0 will be seen as far more important than a decrease from 0.2 to 0.1, even though the actual change in probability is the same.

Discontinuity has also been shown in preferences when outcomes occur immediately. This is because decision makers tend to be biased towards immediate outcomes. Studies have shown (Thaler, 1981) this by discovering very high discount rates for short time delays.

For example: £20 immediately >> £25 in one month

This effect also violates stationarity, which discredits DUT. There are cognitive similarities in judgement between moving from certain to uncertain outcomes and immediate to delayed outcomes, see Prelec and Loewenstein (1991)

It is important to stress the long term effects of strategies. Decision makers will be biased towards immediate short term actions. However, this may increase other harmful effects in the long run. This can be especially true of governments, who are often only concerned with strategies which will affect their chance of being re-elected and will therefore only have a four or five year time horizon. To counteract this it is necessary to emphasise the importance of all the attributes of the strategies to ensure that decision makers consider the long term implications.

3.3.3 Sign Effect

Kahneman and Tversky (1981) have shown that outcomes framed as losses induced risk seeking in subjects, while outcomes framed as gains induced risk aversion. They constructed the following pair of problems. The number in brackets indicates the number of subjects in the study and the percentages indicate the proportion of subjects choosing that program.

Problem 1:

(N=152) Imagine the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact science estimates of the consequences of the programs are as follows:

Program A: 200 people are saved. (72%)

Program B: There is a 1/3 probability that 600 people will be saved and a 2/3 probability that no people will be saved. (28%)

Which of the two programs would you favour?

Problem 2:

(N=155) The same starting scenario is given but the options are:

Program C: 400 people will die. (22%)

Program D: There is a 1/3 probability that nobody will die and a 2/3 probability that 600 people will die. (78%)

Which of the two programs would you favour?

In real terms, programs A and C are identical in their consequences, as are programs B and D. However, because the outcomes in Problem 1 are framed as gains (lives saved) people act in a risk averse manner, but with Problem 2, people act in a risk seeking manner because the programs are framed as losses (lives lost).

The difference in risk attitude for gains and losses also stresses the importance of consistent and carefully planned framing of outcomes. It is important to understand how subjects view the outcomes of decisions. If they view one outcome as a loss and another as a gain, their discount functions and risk aversion will be different. These may be perceived as contradictory preferences, when it is really a framing effect. One way to counteract this would be to state both the gains and losses incurred by a project.

For example, in the cases above the programs would be defined as:

Program E: 200 people are saved and 400 people die.

Program F: There is a 1/3 probability that 600 people are saved and a 2/3 probability that 600 people die.

Presenting the information is this way may induce a risk neutral attitude, though McNeil *et al* (1986) found that subjects gave more attention to mortality data than survival data. Therefore, the choices made would probably be closer to those in Problem 2. At least in this framing the subject is given all the information and not unduly biased by the analyst concentrating their attention on one aspect of the data.

Similarly, Thaler (1981) showed that the attractiveness of gains is discounted more steeply than the unattractiveness of losses this has been called the Sign Effect. In order for this to occur people must separate new choices from their existing assets and view the outcomes as gains or losses, which they treat differently. This contradicts the assumption of integration in DUT. The Sign Effect means people are more eager to speed up a gain than they are to delay a loss which means that choices framed as gains and losses will be treated differently.

3.3.4 Lives Lost or Decreased

Social intertemporal decisions can sometimes involve the issue of human lives. Some decisions involve trading off existing lives for those in the future, or changes in people's life expectancy. For example, in nuclear accidents there are usually a limited number of immediate deaths, but the life expectancies of the population can be dramatically changed and will depend on the decisions made.

The issue of trading lives is compounded by the possibility of future medical advances, and there is no way of estimating how these advances may affect the outcomes of decisions. This adds another element of uncertainty into the modelling process, which makes long term decisions even more difficult to address.

Fischhoff *et al* (1978a) found that people view the probability of loss as more important than the magnitude of loss. When looking at individual car trips they discovered that people did not wear seat belts because the probability of injury was very low. However, when the data was presented in a multi-trip dimension people said they would wear seat belts because the probability of an accident had increased from 0.01 to 0.33. This emphasises the need to guide decision makers towards analysing the long term health consequences of their strategies so that they avoid ineffective short term strategies.

McNeil *et al* (1986) discovered that presenting data on medical treatments as the life expectancy after treatment, encouraged decision makers to look at the long term consequences of their decisions. Whereas, presenting the data as the cumulative probability of survival biased the decision makers towards short term strategies. Since decision makers often exhibit an immediacy bias (Section 3.3.2) it may be better to express data about lives as changes in life expectancy.

3.3.5 Magnitude Effect

Studies (Thaler, 1981; Rachlin and Raineri, 1992; Chapman and Elstein, 1995) have shown an inversely proportional relationship between the absolute magnitude of an outcome and the rate at which it loses value when it is delayed. This contradicts the integration assumption made in DUT, and may occur because people are sensitive to relative and absolute differences in outcomes, which would change the desire to delay an outcome depending on its size.

Thaler (1981) found the following:

$15 immediately ~ $60 in a year discount rate = 0.25

$250 immediately ~ $350 in a year discount rate = 0.71

Which suggests that discount rates depend on the magnitude of the outcome.

3.4 Framing Issues

The way a question is framed affects a decision maker's preference. One example is given above in Section 3.3.3. This can lead to choices that may seem irrational, because the decision maker sees the situation differently to the analyst. Here we discuss some issues that should be considered when framing questions to elicit preferences, in order to avoid such biasing of the decision maker's responses. A major factor is the reference point to which the decision makers relate their preferences.

3.4.1 Reference Point

Several studies have been carried out to determine how people view outcomes, see Kahneman and Tversky (1981, 1984 and 1991) and Kahneman *et al* (1991). These results give an S-shaped value function which is very steep around the reference point for losses and has decreasing marginal utility for both gains and losses (see Figure 3.3). Kahneman and Tversky (1981) showed that the value function is concave for positive outcomes because people are risk averse in the domain of gains. People also tend to value a certain gain far more than an uncertain larger gain. They also discovered that with negative outcomes a certain loss is far more undesirable than a probable loss. This leads people to be risk seeking in the domain of losses and gives a convex value function.

Both losses and gains exhibit decreasing marginal utility. People's response to losses tends to be more extreme than their response to gains. This means that the pleasure people feel from gaining an amount of money is generally less than the displeasure that they feel from losing the same amount of money. The value curve is therefore steeper in the domain of losses than it is in the domain of gains.

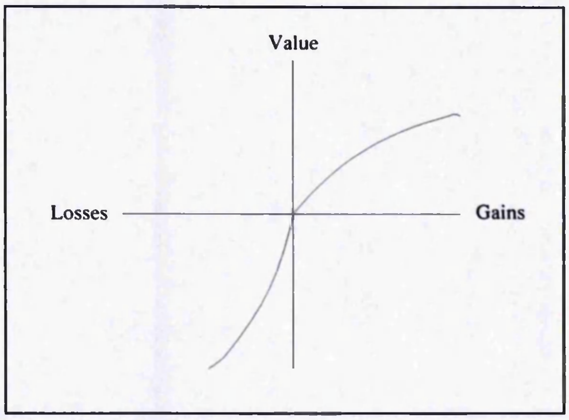


Figure 3.3: Value Function for Gains and Losses

It is important to determine what the decision makers' reference points are, as this will influence their preferences for the options they are presented with. Unless their reference points are understood clearly their preferences may seem to exhibit anomalies, which in reality will be due to the way they are framing the issues.

3.4.2 Status Quo Bias

Most people dislike change. It is often frightening and involves some element of uncertainty. Kahneman *et al* (1991) conducted experiments which showed that people suffer from loss aversion, especially with respect to the status quo. The research indicated that people require large incentives to move from the status quo. This makes people reluctant to make choices that have only small chances of improving their current situation. It also makes people less able to imagine changes in the status quo.

All decision processes involve hidden costs. There is the cost of thinking, and usually some cost involved in implementing the action. Kahneman and Tversky (1991) suggest that because of these extra costs, and commitment to earlier decisions, people may find it difficult to move from their status quo, and therefore they may reject new options that only offer small gains.

Continuing with the status quo must be seen as a choice and not the default. This will help decision makers to see that staying with the status quo is a decision requiring commitment, and this in turn may help them evaluate the other alternatives more fairly. This was the case in the personal decision described in Chapter 2.

3.4.3 Framing Contingencies

Kahneman and Tversky (1981) showed that when subjects were presented with a two-stage gamble they chose as if the first stage of the gamble had already occurred. This meant that they overestimated the certainty of some outcomes because they did not take into account the first gamble in the sequence. They presented subjects with the following gambles. (N = The number of subjects; % = The percentage of subjects choosing the option.)

Problem 3:

(N = 77) Which of the following options do you prefer?

A:	A sure win of $30	(78%)
B:	An 80% chance to win $45	(22%)

Problem 4:

(N=85) Consider the following two-stage game. In the first stage, there is a 75% chance to end the game without winning anything, and a 25% chance of moving into the second stage. If you reach the second stage you have the choice between:

C:	A sure win of $30	(74%)
D:	An 80% chance to win $45	(26%)

Your choice must be made before the start of the game, i.e. before the outcome of the first stage is known. Please indicate the option you prefer.

Problem 5:

(N=81) Which of the following options do you prefer?

E:	A 25% chance to win $30	(42%)
F:	A 20% chance to win $45	(58%)

The difference in choices between Problem 4 and Problem 5 could be attributed to the Pseudocertainty Effect, defined as an outcome which is seen as being more certain than it actually is because of the way the decision is framed. C and D in Problem 4 give exactly the same outcomes as E and F in Problem 5, however, the subjects did not view the outcomes in the same way. They assumed that they succeeded in getting through the first part of Problem 4, so the only uncertainty was with the second chance event.

Understanding how decision makers view a situation is difficult, but essential if the analyst is to be able to model their opinions. Analysts should present information in different ways and always in neutral frames, to try to limit the anomalies and biases the decision makers exhibit. The analyst should always bear in mind the ways in which decision makers' preferences and opinions can be biased or confused and conduct the analysis to minimise these effects.

3.4.4 Delay and Speed-up Asymmetry

In general, the amount decision makers will need to be paid to delay an outcome is larger than the amount they will pay to speed up its receipt by the same amount of time. Loewenstein (1988) has shown this effect. A temporal shift that is framed as a delay has more significance than when it is framed as a speed up of receipt. Unless this asymmetry is recognised, by noting the reference point when obtaining preferences, varying discount rates may be obtained for decision makers. The differences in opinions shown by the decision makers will be due to the reference point and not actual preferences.

3.4.5 Buying and Selling Price

Asking how much people would be willing to pay to obtain an object will elicit a different value than asking how much they would need to be paid to give up an object. The first value is often called the buying price and the second the selling price. The selling price is usually much higher than the buying price. The difference in values is due to what is called the Endowment Effect. This is when people value an object more highly when they possess it than when they do not. The Endowment Effect has been shown in empirical studies by Kahneman *et* al (1991), Knetsch (1989) and Loewenstein and Adler (1995). It implies that indifference curves shift when people obtain an item, which in turn implies a taste change. Therefore, it is important when obtaining preferences to avoid the Endowment Effect and to note the differences between buying and selling prices, so that values are not biased and reflect the decision makers' real preferences. Loewenstein and Adler (1995) conducted experiments that showed that people do not expect to experience an Endowment Effect and therefore underestimate its magnitude.

3.4.6 Matching and Choice Questions

Preference questions can be stated in different ways. Matching questions are those where subjects have to say which outcomes have the same value, or give a monetary value to an outcome. Choice questions are those where subjects have to choose which outcome they prefer. Matching questions involve the elicitation of discount rates and prices, while choice questions involve the elicitation of preferences. Ahlbrecht and Weber (1995a) discovered that the method of questioning determined the anomalies that occurred between subjects' answers and normative theories of choice. In matching tasks, outcomes that were certain were discounted more than risky ones and larger discount rates were used for initial waiting periods than for later ones. These anomalies were not exhibited in the answers to choice questions. Such results show that question frames can affect the discount rates elicited and that biases in decision makers' answers may occur when matching questions are used. Therefore, it is important to know what type of question has been posed and the biases this may have on the results obtained.

3.4.7 Compatibility Effect

The weight of an attribute is increased by its compatibility with the response. This means that if a subject is asked to state which outcome has the highest value they will concentrate on the monetary attributes of the outcomes and give less weight to the other attributes. Alternatively, if subjects are asked to rank the outcomes, they are more likely to evaluate the attributes fairly. This effect has been shown by Griffin *et al* (1990). This is also a framing effect that biases people's preferences, and must be taken into account when creating questions. To avoid biasing decision makers' opinions analysts should ask them to rank the outcomes.

3.4.8 Intervention Level Biases

In many decision situations there are intervention levels which determine courses of action, for example, legal constraints. In radiation protection, the intervention levels for evacuation may be:

Below *a*	- no action is taken
Between *a* & *b*	- protect the community (no evacuation)
Above *b*	- evacuate the community

Although these levels are useful guidelines, they can bias the decision makers' actions. They create a Compatibility Effect, which means that the decision makers may focus mainly on the radiation level in the situation and ignore the other attributes. This means they may act at the lower level of intervention, which may be overcautious, or cause more harm due to stress than that which would have been caused by the exposure to the radiation. To counteract this effect it is important to emphasise the importance of the other attributes when using intervention levels to evaluate strategies. Thus, it may be possible to avoid influencing decision makers into choosing strategies which are not health or cost effective, due to the bias caused. Similarly, it is important to encourage decision makers to consider all the attributes of a decision and not to focus on the most prominent ones.

3.4.9 Sequences and Individual Outcomes

People react differently to sequences of outcomes than to individual ones. Loewenstein and Prelec (1993) have shown that sequences tend to induce negative time preferences, while individual outcomes have positive time preferences. They found that two motives were important in time preference; impatience and desire for improvement. Impatience dominates single outcome evaluations while the desire for improvement dominates sequences of outcomes. Therefore, it is important to know whether a subject views an outcome as a single event or a sequence of events as this will affect their discount rates and preferences, which may lead to contradictory results.

The outcome of a strategy can be viewed as a single outcome or a series of outcomes. The way that strategies are presented can affect the choices people make. People generally want sequences to give improving outcomes, but prefer a smaller single outcome immediately to a larger delayed single outcome. It is important to inform decision makers if there are inconsistencies in their preferences. Since decision makers are usually biased towards immediate outcomes it may be better to present the outcomes of strategies as sequences, to focus decision makers' attention on the long term consequences.

3.5 Summary

Some of the issues discussed in this chapter need to be taken into consideration when performing any decision analysis; other issues are specific to intertemporal decision analysis. It is very easy for an analyst to bias the decision makers' preferences and opinions. As noted in Chapter 1, decision makers do not usually come to an analysis with a clear view of their opinions or preferences and are therefore open to suggestion. It is of vital importance that the analyst does not influence decision makers' opinions.

The chapter has tried to show where prescriptive decision analysis can bridge the gap between normative and descriptive research by modifying the decision process and presenting information carefully. The following chapters focus more specifically on the issues involved in modelling attributes over time and the trade-offs that have to be made between the present and the future.

Chapter 4 Structuring Attributes Over Time

In multicriteria decision analysis (MCDA) it is essential to elicit the importance that decision makers believe should be given to the different attributes. The previous chapter discussed some of the ways in which decision makers' opinions could be biased and how the elicitation method could obtain the wrong information. This chapter is concerned with the way an attribute tree is created for a decision and how this can greatly affect the relative weights attributes receive and therefore the decision made.

Borcherding and Weber (1993) state that attribute importance should be independent of:

- The description of the attribute;
- The structure of the value tree;
- The elicitation process.

Research, however, has shown that this is not the case. The first sections of this chapter describe some of the issues that affect attribute weights and their implications. (See Borcherding and Weber, 1993 and Keeney, 1992 for a discussion of elicitation methods and their effects.)

Particular issues involved with structuring decisions are illustrated using a hypothetical attribute tree concerning a car purchase choice. This example is used to show how including time explicitly in the attribute tree can help decision makers with their understanding of the situation and the trade-offs they have to make between the present and the future. Other advantages of including and making attributes time dependent are explored.

4.1 Changes in Attribute Weight

Studies have explored how people change their attribute weights over time. Kornbluth (1992) investigated this and how the volatility of a situation affected decision makers' weights. He found that as time progresses people expect to and do change their attribute weights. In very volatile situations people change their weights more often and they tend to focus on what they think are the most important attributes. French *et al* (1999) discovered that the attributes taken into account when evaluating strategies after a nuclear accident depend on the time of the evaluation. Atherton and French (1997) discuss how this can affect the decisions made after such events.

With intertemporal decisions, decision makers are faced with a project which has outcomes in several different time periods. The issues of importance in the different time periods may change, and this needs to be reflected in the attributes used. For example, when constructing a building the initial cost will be related to the construction, but once the building is completed, operating costs will be incurred. To model this, the attribute tree needs to include time explicitly.

If the decision process itself spans a relatively long time period then the decision makers involved may change and even if they do not, the opinions they hold may evolve or legislation may alter. This will affect the weights given to the attributes and must be accounted for.

The world is dynamic. We have no idea what will happen in the next minute, never mind the next century or millennium. In order to model decisions with long term impacts it is necessary to create scenarios of the future. However, our confidence in the validity of such scenarios will change over time. For example, engineers may be able to guarantee that a structure will function perfectly for fifty years, but be unsure of its stability after that. The uncertainty surrounding attribute values and future scenarios will increase over time. This needs to be incorporated into the decision model, which involves making attributes time dependent.

Loewenstein (1987) found that people are more concerned about the present than any other time in history. This would suggest that attributes that impact early in the decision process might be given more weight because of human biases and not necessarily logical arguments. It is therefore important for an analyst to make sure decision makers consider all the attributes, especially those that occur later on. This will be easier to do if the attribute tree makes it clear which attributes occur when.

Bellinger (1991) states that:

> *'each element of any decision sequence should be analyzed in its own time frame, and only over its effective length.'*

In order to achieve this, time must be included in the decision model and attributes must be assigned to the time era in which they occur. Decision makers will have to be aware of the lifetime of the project they are working on and this will help them to think more clearly about the long term impacts of their decision.

4.2 Omitting Attributes

Research has been carried out to determine the effects of omitting information in fault trees and attribute trees. The weight given to the information remaining, and the weight given to a category called *other*, meant to capture all the missing information has been investigated. Fischhoff *et al* (1978b) discovered that people were insensitive to the information left out. In their experiments *other* received far less weight than it should have done, as subjects underestimated the amount of missing information. Even experts in the field performed badly. The research shows that the subjects did not think clearly about all the issues involved in the decision and omitted important attributes. This may have been because they trusted the analysts, or misunderstood the task, or were under pressure, but it demonstrates how easily attribute weights can be influenced. It also shows that the amount of detail included has only a small effect on the perception of the issues.

Decision makers should be encouraged to think about the issues involved in a decision very carefully. The information and the way it is presented can bias decision makers' opinions, see Section 3.4. If they are given a list of attributes they may anchor on these and therefore miss out important aspects, in a similar way to creating fewer alternatives if presented with one initially (Section 1.21). Multiple decision makers may be more likely to think about all of the issues because they will have different perspectives of the decision. When thinking about the attributes it is important to use an iterative process to develop the decision makers' understanding of the situation.

4.3 Splitting Attributes

Several studies have been carried out to determine how splitting an attribute affects the weight it is given. Eisenführ *et al* (1988) and Fischhoff *et al* (1978b) found that an attribute that is subdivided receives more weight. This may be because the elements that make up the attribute become more comprehensible when it is split. If an attribute is not split, decision makers may not realise all the issues it involves and therefore give it less weight.

This emphasises the need to consider all the important attributes and ensure that the decision makers understand them. By structuring the attributes iteratively with the decision makers, it should be possible to ensure that they fully understand what each attribute entails and therefore give them the appropriate weight. This may not be the case if the analyst alone defines the attributes.

Pöyhönen and Hämäläinen (1996) investigated why people exhibit changes in attribute weights when attributes are split. They found that when attribute weights are normalised the average of each weight decreases as the number of attributes increases. If n attributes are normalised, the average weight given to each attribute over a large number of subjects tends to $1/n$. This is because the expected value of each normalised weight is $1/n$, if the weights are independent and identically distributed.

Pöyhönen and Hämäläinen analysed the experiments conducted by Eisenführ *et al* (1988). In the experiments there were two levels in the attribute trees. The attributes in each tree were split differently for the different subjects. Suppose the number of attributes on level one is n_1 and the number of attributes on level two is n_2. (In the experiments n_1 is always three and n_2 is four, five or six.) Assuming that the weights tend to $1/n$ then the level two attribute values will change depending on how many of them there are. See Figure 4.1.

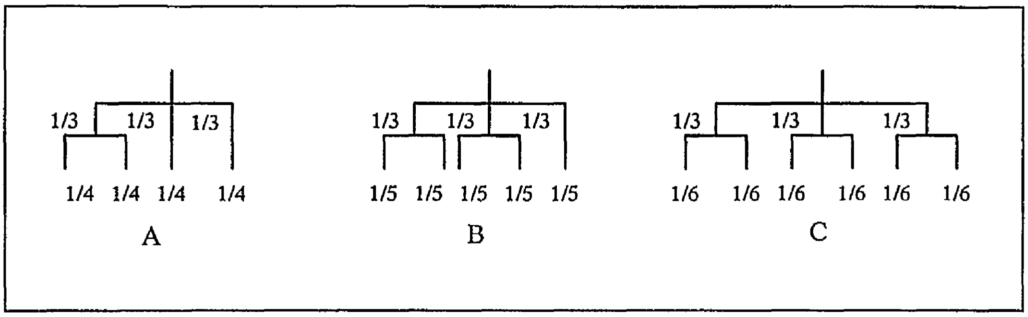


Figure 4.1: Attribute Trees and Their Attribute Values

If we look at the first branch in each tree we can see how, if we use Pöyhönen and Hämäläinen's theory, the value assigned to the level two attributes changes. This can be compared to the combined value of 1/3 that they should receive, which is the value given to the top level of the tree:

Attribute Tree	Attribute Values
A	1/4 + 1/4 > 1/3
B	1/5 + 1/5 > 1/3
C	1/6 + 1/6 = 1/3

Table 4.1: Comparison of Attribute Weights in the Different Attribute Trees

The experiments carried out by Eisenführ *et al* (1988) gave similar results. The combined value given to the level two attributes of the first branch in tree A was close to a half, and larger than for tree B, which gave a higher value to the attributes than tree C. These results show that the number of attributes on each level of the tree is important and influences the attribute weights. It is necessary to structure the attribute tree so that the levels reflect groupings of the attributes and any specific trade-offs that have to be made.

4.4 Attribute Tree Structure

If there are attributes of differing importance at the same level of an attribute tree it will be very difficult for decision makers to make trade-offs between them. The tree should be structured so that attributes of similar importance are at the same level. Attributes must be specified in similar detail otherwise they will be hard to compare. To simplify the elicitation of attribute weights, it would seem sensible to limit the number of comparisons and only to require realistic comparisons. The decision makers should take part in the structuring of the attribute tree to aid their understanding of the issues involved in the decision and the trade-offs to be made.

It is helpful to work with decision makers to structure attribute hierarchies which reflect their judgements, by grouping together attributes relating to similar issues. Including the dimension of time in the attribute tree may also help. Important attributes should not be leaves at the end of highly branched parts of the tree: psychologically, they will be 'lost' if they are. The level of detail considered will depend on the context and differences between the alternatives, so that irrelevant attributes can be omitted. Keeney (1992) outlines the properties attributes should have and discusses general structuring issues.

Brugha (1997) indicates the advantages of grouping similar attributes and describes a process for eliciting their weights. He advocates starting at the bottom of the tree with similar attributes in the same sub-group, so that decision makers become familiar with the weighting process on relatively easy comparisons. After comparing grouped attributes, decision makers should be asked to compare other attributes with some similarities. Subsequently, they can be asked to make more and more difficult attribute comparisons. Brugha suggests obtaining weights for the most important attribute first and then the less important attributes to make the elicitation process easier.

Brugha (1997) claims that by performing bottom up analysis it is more likely that any attributes which were missed out of the lower level may still influence the weight of the higher level attributes. This is because the decision makers have a better understanding of the issues involved.

To illustrate the problems involved in structuring a decision, consider the attributes a decision maker may analyse when choosing a car. Figure 4.2 shows an attribute tree for a car. All of the attributes are on the same level even though it is obvious that, for example, the purchase cost of the car would be far more important than the colour. It would also be unlikely that in the real world a decision maker would compare the colour of a car with its purchase cost. The structure does not indicate similarities between any of the attributes and does not make any distinction between the importance of the trade-offs. It is not apparent from the tree that the attributes occur in different time periods. For example, although the service cost will be something that will be considered when buying the car, the cost will not be incurred until, hopefully, many months after the purchase. Insurance, for example, will be paid when the car is bought, and every subsequent year. This attribute tree would not encourage the decision maker to consider the element of time and the effect it would have on the attributes involved in the decision.

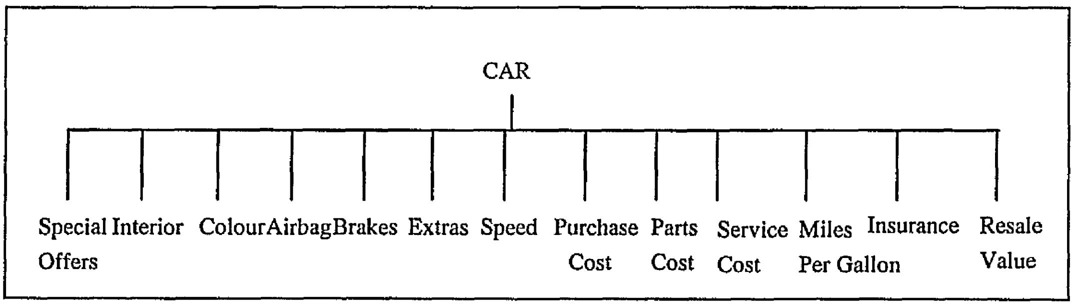


Figure 4.2: Attribute Tree for a Car

A better attribute tree is shown in Figure 4.3. Attributes of similar importance are on the same level and those with similarities are grouped together to form super groups. Time is also included in the tree.

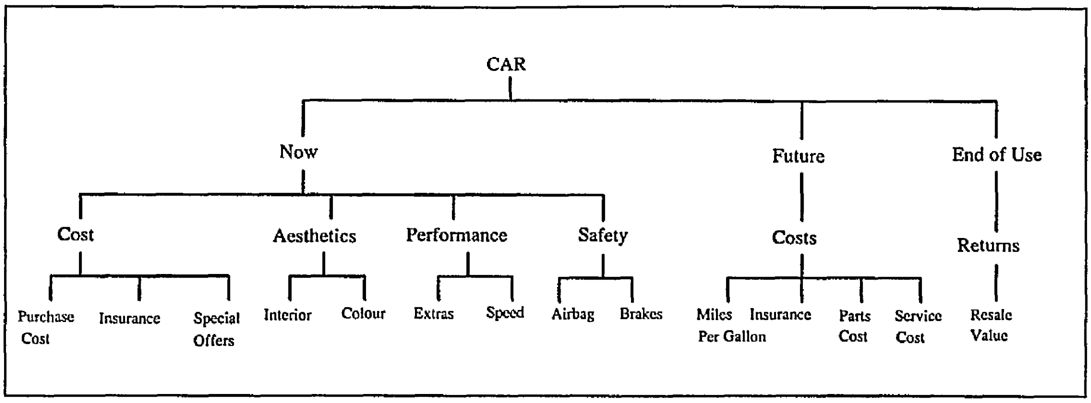


Figure 4.3: Attribute Tree for a Car Including Time and Attribute Grouping

Figure 4.3 is very simple and it may be that when starting to think about, for example, safety, the decision maker begins to consider roll bars and side impact bars.

4.5 Grouping and Weighting Attributes

One of the aims of using an attribute tree is to improve decision makers' understanding of the situation they are facing. French (1992) discusses these issues. In the car example the weights should be elicited for the bottom level first. The middle level could be used as a checkpoint, whereby the weights of the lower level attributes are summed in their super groups and the relative values of the super groups compared. The decision maker could then check that she was happy and make any necessary adjustments. The top level refers to the time trade-offs, whose values could be elicited, and then used to multiply down the tree to determine the final bottom weights. These final weights would then be analysed and modified if the decision maker felt unhappy. Sensitivity analysis could be carried out to determine the effects of the weights. The final weights used would therefore depend on time, and similarities and trade-offs between the attributes themselves.

4.6 Intertemporal Attribute Trees

In intertemporal decisions there is a definite trade-off between the present and the future, especially with very long term projects. This is usually the most controversial of all trade-offs and the one which causes the most difficulty (See Cropper and Portney, 1990; Broome, 1994 and Schelling, 1995). By structuring the attribute tree so that the important attributes in each era are made explicit, the issues involved in the trade-offs will be made apparent and therefore easier to deal with. In Figure 4.3 the trade-off between the present and the future, and the costs incurred at those times, can be seen clearly in the attribute tree.

The time trade-offs in the car purchase example are far less complicated than those in very long term decisions such as where to put nuclear waste, because the time frame is much shorter and will be within the decision makers' life times. In very long term decisions the time frame goes well beyond the lives of the decision makers and is therefore more difficult to comprehend. The trade-offs involved are also more problematic, because they deal with more controversial issues such as lives and the environment which it is unpleasant to determine a cost for, and therefore harder to work with. In these circumstances it is vital to aid the decision makers in their understanding of the issues involved and the trade-offs they have to make, and so structuring the decision is even more important.

4.7 Reasons for Including Time in Attribute Trees

Nijkamp *et al* (1989) give several reasons why time should be included in attribute trees:

- Impacts are often time dependent;
- Impacts are uncertain over time;
- Decision makers' preferences may not be constant over time;
- The preferences of future generations may be different to those of current generations;
- Current decisions may limit the options of future generations;
- Changes in time preference may occur.

In our simple example some of the attributes were time dependent, for example, service costs were not incurred immediately. In many large projects there are distinct phases in the project's lifetime each involving different issues and therefore attributes. The uncertainty surrounding the values of attributes in the future increases the more distant in time an attribute is. By dividing time into distinct frames this difference can be modelled, and the bounds on the probabilities can be increased over time to reflect the growing uncertainty.

Kornbluth (1992) has shown that people's preferences change over time, Section 4.1 highlighted how the preferences of future generations may change and how we should take this into account. Intertemporal decisions with long time frames, for example, environmental issues impact future generations. Chapter 5 discusses the importance of including long term effects in decision analysis.

To support decisions with long term consequences we propose structuring the attribute tree so that the highest level decomposition is into time eras, see Figure 4.4.

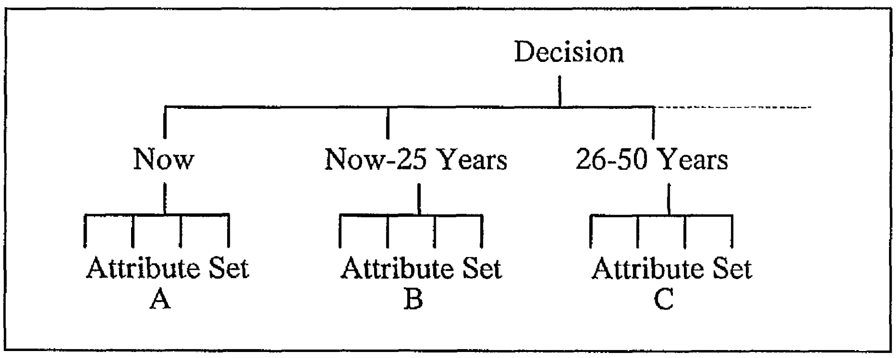


Figure 4.4: Example Attribute Tree

The lower sets of attributes for each time era may be common, but one can imagine many circumstances in which they are not. There would then be distinct sets of attributes describing the decision makers' perceptions of value in the different time eras.

4.8 Summary

This chapter has outlined some of the ways in which decision makers' opinions can be biased by the structure of the attribute tree used. Brownlow and Watson (1987) point out that using hierarchies helps decisions makers because:

- Decomposition of problems can increase understanding and performance;
- Stakeholder groups may only be involved in a subsection of the problem and the hierarchy can show where their contribution fits in.

Including time in the attribute tree can enhance these advantages.

We have shown that making attributes time dependent and including time explicitly in the attribute tree can:

- Help decision makers understand their situation better;
- Help decision makers express their opinions;
- Allow attributes, their values, relative weights and the uncertainty surrounding them to change over time;
- Highlight the trade-offs that have to be made over time;
- Focus attention on the long term aspects of a decision.

Chapter 5 Valuing The Future

The debate about how to value the future has been raging for years. Philosophers have argued about our obligations to future generations from different extremes: that we owe them everything and that we owe them nothing. At the same time psychologists have conducted countless laboratory experiments to determine 'how' people act and observed real situations to discover people's attitude to the future. Economists and proponents of 'rational decision theories' have argued for constant discount rates and consistent, logical actions. So, how 'should' we value the future? At the moment most decisions are made using constant discounting, which gives less weight to the future than to the present, but is this justifiable for long term policies?

In this chapter some of the arguments from the philosophy, psychology and economics camps are examined. The ideas are contrasted with the issues involved in very long term intertemporal decision making, and a new way of valuing the future and structuring attributes over time is developed.

5.1 Philosophical Debates

Valuing the future requires us to think about our obligations to future generations and to look at how our actions affect them. There are many different views on this and philosophers have passionately argued for each one. Routley and Routley (1982) outline some of the most popular views:

- Every person should be given the same value independent of whether they live now or in the future;
- We have some obligation to future generations, but much less than to those living now;
- We have obligations to the next generation, but none beyond that;
- We have no responsibility towards future generations.

The obligations we think we have to future generations determine how we value the future and whether we discount it. Discounting often covers three issues:

- How to value the future;
- How to value future money streams;
- How to value the negative impacts of decisions, for example, pollution.

Decision makers' opinions on these issues help to determine the discount rate used and it is often important to analyse each of the issues separately. Two important aspects that also need to be considered are:

- The ethics of the decision - the rights and wrongs of devaluing future generations;
- The effect of the discount rate on the efficiency of the option chosen.

Some argue that high discount rates are unethical because they give a low value to the future; while others have argued that low discount rates can result in inefficient projects being adopted.

Goodin (1978) has very strong views against devaluing the future and states that,

> *'future generations .... are being deprived insofar as, when making decisions, we weigh their interests less heavily than our own. And their deprivation is unjustifiable because the arguments offered in defence of this practice fail in various ways'*

Bickner (1980) says that discounting amounts to saying,

> *'the hell with the values of a generation yet unborn, or at least ten percent the hell per annum'*

Goodin (1982) claims that discounting shows favouritism to some generations and that this means treating people unequally, which is against general public policy. Kavka (1978) comments that,

> *'Location in space is not a morally relevant feature of a person determining his worthiness for consideration or aid. Why should location in time be any different?'*

Philosophers and economists have put forward many arguments as to why we have some or no obligations to future generations. In the following sections several of these arguments are discussed and their validity is examined.

5.1.1 Economic Posterity

Some people claim that future generations will be better off economically and therefore will be able to deal with any problems that we leave them. This argument assumes that money or technology can replace everything. In reality, this is not true. Goodin (1978) discredits the idea of technological advances being used to solve the problems we make. He notes that such advances are uncertain and at most will help to decrease the effects of the bad outcomes we create. It is therefore unrealistic to rely on them heavily.

Economists have argued that people will exhibit decreasing marginal utility over time. If a country's economy is growing then the benefit people will get from an extra unit of a commodity in the future will be less than the benefit they would experience today. This is because in the future people will be better off, and therefore, an increase in the goods they have will be less important, because they will have decreasing marginal utility. For example, say you have no shoes, then the first pair of shoes you receive will be worth a great deal to you, the second pair of shoes will be worth less to you, because you already have a pair, and so on. Each consecutive pair of shoes is worth less to you and you do not value them as highly as the first pair you received.

Decreasing marginal utility is sometimes used as a reason for discounting, but this assumes that per capita income is increasing. We cannot guarantee that per capita income will increase over time. In some cases interest rates can be negative, therefore, future outcomes are worth more than immediate ones. If per capita income were increasing, it would have to increase at a constant rate per year to justify a geometric discount function.

In some cases people cannot be compensated for the loss of a good by an increase in the amount of the other goods that they have. When this is true, only an increase in the actual good will give them decreasing marginal utility with respect to that good. An increase in the economy and wealth of a population cannot be used to justify discounting a non-tradable good[5.1] on the grounds of decreasing marginal utility. The discount rate of the non-tradable good will depend on how much more of that good a person will have in the future; it will reflect the rate of return of investment of that good, or its accumulation over time. The availability of some non-tradable goods, for example the environment, may be decreasing, in which case their marginal utility will actually be increasing, because there is less of them available, hence their value in the future should also increase. These are all arguments against using economic posterity and decreasing marginal utility to justify discounting goods.

5.1.2 Opportunity Costs

Sometimes the discount rate applied to a project is calculated from the opportunity cost of using the resources in the project. The opportunity cost is the potential rate of return that could have been gained from alternative uses of the resources. In the case of money it would be the interest it could have earned if it had been invested. The fact that money invested now will grow in the future, due to interest rates, is sometimes used to justify discounting the future. A pound tomorrow is worth less than a pound today because today's pound could be invested and earn interest.

[5.1] Non-tradable goods are goods that cannot be directly exchanged for other goods. For example. health cannot be exchanged for money, it is possible to buy health care, but this does not lead to a definite increase in the amount of health someone has.

Instead of spending money today to avoid harming future generations, or to protect them, money could be invested now so that it will be available in the future for future generations to spend to overcome their problems. It could be argued that future generations will have a better idea of what to spend their money on, and that we should leave them the money to deal with their own problems in the way that they think is best. It would only be efficient to do this if less money needs to be invested now to compensate future generations (after it has earned interest) than is required now to prevent the problem. This would involve setting up a trust fund and investing the money, so that it would accumulate and be available to compensate future generations.

There are many difficulties with this idea. It requires establishing some sort of trust fund. How this should be set up and maintained are difficult questions. Is it possible to guarantee a constant interest rate, to justify a constant discount rate? Trying to prove a constant opportunity cost across all periods is not easy. Inflation changes over time, as do interest rates. Banks can no longer be viewed as stable institutions, as the Baring's case showed. A more recent example is the collapse of the banks in Russia and parts of Asia. Thus, it is not possible to guarantee that money invested will give a positive interest rate in the long term. The consequences of the decisions being considered span hundreds of years, therefore it will be very difficult to guarantee a constant interest rate over the lifetime of the outcomes. This makes it unreasonable to use a constant discount rate. It is also not possible to estimate exactly how much it would cost future generations to reverse any negative consequences caused by our actions. Hence, it is hard to know how much we need to invest now, to enable future generations to cope with the troubles we leave them, so it is problematic to compare prevention costs with abatement costs in the future.

Not all damages can be converted into monetary equivalents and many valuable items, for example health, cannot be replaced by money. Setting up a trust fund will not enable us to compensate future generations for all their losses, or to rectify all the problems we leave them. The fact that not all goods are tradable undermines one of the main assumptions of this justification of discounting and so discredits the theory. The opportunity cost argument is only valid when we are able to convert all goods into their money equivalents and can determine the interest rate lost.

Goods could be traded for more of the same good. This applies to any interest bearing resource, that is, one that will increase in magnitude if it is not consumed now. Money spent now on lifesaving could instead be spent on research, which might save more lives in the future. In this way lives now could be traded for lives in the future. The opportunity cost would be the extra number of lives saved in the future by doing the research. This does not tell us whether it is acceptable to trade lives, or at what rate we should trade lives now for lives in the future. All it tells us is that if there are two future projects available the one that gives the best rate of return on lives saved is better. It does not say how to compare the present and the future. These ideas enable us to calculate the opportunity cost for a good and therefore determine its discount rate, but it is debatable whether this would be an appropriate rate or not. See Goodin (1982) for further discussions.

The theory is limited; it only applies to 'interest bearing' goods, and not all non-market goods[5.2] are 'interest bearing'. For example, plans to protect the environment do not give an increase in the amount of environment available, they just change the rate at which it is degraded. If the amount of a non-market good available will decrease in the future, then the opportunity cost argument states that we should use a negative discount rate, as the good will be more valuable in the future.

5.1.3 Uncertainty of the Future

The future is uncertain; we know that forecasting techniques are only reliable in the short term, which gives us limited ability to predict the future. The long term future is more uncertain than the present and immediate future, and therefore, some people claim that we should disregard it (Passmore, 1974; Hitch and McKean, 1960). In reality, the probabilities of outcomes do not become much more uncertain as we progress into the future. For risks, it is often the fact that there is the possibility of a risk that is important and not the size of the probability.

[5.2] Non-market goods are goods that are not traded on an open market and so do not have a clearly defined monetary value.

Williams (1978) looks at two types of uncertainty, that:

- People may die before receiving the utility;
- The utility may not be available in the future.

Although these uncertainties may apply on an individual basis, and therefore give a reason for discounting the future, on a societal basis they are invalid. It is very unlikely that the whole of the human race will be wiped out in the near future. Williams (1978) argues that the best chance of survival is to maximise available resources, which means valuing the future and preserving resources. He shows that the possibility of extinction means that it is not utility maximising for society to discount the future. It has been argued that we are unsure of the utility of future generations, while we are sure of our utility. However, Williams says that the uncertainty involved works both ways and that we are equally uncertain about how much future generations may depend on resources we currently do not depend on. Therefore, we should act cautiously with the world's resources.

The relationship between time and uncertainty will vary for different goods over different time periods. Some uncertainty may not increase over time and we may actually be more certain about some issues in the future. Even if uncertainty does increase over time, and this is why we are discounting, it would have to increase at a fixed rate per year to justify geometric discounting.

Moore (1971) and Smart (1973) argue that future outcomes will be small and therefore, negligible. They claim that the future can be discounted because the good and bad outcomes will cancel each other out. However, Goodin (1978) argues that there is an asymmetry in the outcomes of events. The bad outcomes of decisions are often far worse than the good, so much so that they do not balance out. In the case of societal intertemporal decisions this is very likely to be true. Therefore, Goodin believes it is unjust and even irrational to ignore or discount future outcomes because of the gravity of their effects.

5.1.4 Indeterminacy

Golding (1972) has argued that we only have obligations to future generations if we can reliably predict their needs. He claims that because we do not have reliable information about people living in the future we do not have obligations to them. We cannot determine accurately what effects our actions will have on future generations and what their needs will be, but we do know that there is a risk that our acts will affect them adversely. Decisions made about the present often take into account risks with very small probabilities and it is the fact that there is a risk that matters in the decision making process. There is no obvious reason why we should deal with the future in a different way. It is easy to see that future generations will still need a healthy Earth and will not benefit from an increased risk of illness. We therefore have an obligation to ensure that these things are available. To say that we are very uncertain about the needs of future generations is to give a high probability to the idea of their world being dramatically different from ours, which is in itself unrealistic.

Baier (1984) also argues that many of the 'wrongs' that we do future generations depend only on human nature and not on people's special needs. She claims that we know that future human beings will need air, and water, and food, and that their lives will be harmed by poison and toxins. Therefore, we should try to respectively preserve and reduce these things, Goodin (1978) makes the same point.

5.1.5 Unequal Distribution of Benefits and Costs

In many long term decision situations the current generation receives the benefits while the future generations incur the costs. Nuclear energy is an example of this. Current generations benefit from the electricity that it produces, but future generations are left with the waste. Cost benefit analysis using discounting can be used to justify strategies with short term benefits and long term costs because the future is discounted. This gives the costs much less value.

Even in the present generation risks are not always equally distributed, but this usually results in public outcry, and some sort of compensation, which is what 'should' happen with regards to future people. Unfortunately, future generations are unable to argue about why they should be given equal value. If we think in terms of compensation, it may actually be more equitable to give future generations more weight in our cost benefit analysis, as they will suffer involuntarily from our acts.

The Kaldor-Hicks Principle (Layard, 1992) has sometimes been used in cost benefit analysis to justify projects that have positive and negative effects on different groups in the population. It says that as long as the benefits gained by some of the population are large enough, so that even after compensating members of the population who are negatively affected, all are equally or better off than they would be without the project it is justifiable.

Unfortunately the transfer of compensation hardly ever occurs and the project does not legally bind those who benefit to making it. The principle would only help to justify an action if the compensation was somehow guaranteed to occur. This is difficult across people living in the same era and encounters even more problems when the outcomes occur in different eras. Ensuring that future generations will be compensated could only be achieved by setting up some sort of trust fund. As section 5.1.2 pointed out it is difficult to establish the cost actions will cause future generations, never mind ensuring these are met. Section 5.1.1 also pointed out that people cannot always be compensated for the loss of goods, which makes it difficult to calculate or give compensation. All these issues undermine the use of the Kaldor-Hicks principle as a way of justifying projects.

5.1.6 Non-Market Goods

The issue of discounting often depends on the object being discounted. Discounting money is usually accepted, though if the monetary sums equal a significant proportion of GDP one might argue against it. In Belarus the consequences of Chernobyl are claimed to cost on average 10-20 % GDP per annum therefore discounting may not be appropriate.

To make judgements on the marginal cost per unit dose of radiation averted by countermeasures after a nuclear accident, decision makers use a reference value for the cost of the man-Sievert[5.3]. This value is called α and creates an equivalence relationship between money and dose. Through α, units of dose equals money, therefore discounting money is equivalent to discounting dose, which may occasionally be accepted. By the linearity hypothesis dose is equivalent to expected number of years of life expectancy lost. Discounting may be acceptable because individuals do discount the last years of their lives by, for example, smoking. However, not everyone will be comfortable with this idea, and if the life expectancy is reduced by a large amount people may be even more averse to discounting. The linearity hypothesis also means that dose equals number of deaths, and as society dislikes discounting lives this is unlikely to be acceptable to decision makers. Dose also equals number of genetic defects, by the linearity hypothesis. It is doubtful whether society would discount these unless there is a guarantee of medical advances.

The above line of thought shows that in decisions concerning radiation discounting money has the effect of discounting many other factors because of the use of α and the linearity hypothesis. These result in discounting not being applicable to radiation decisions because the long term consequences reach into future generations. This is true in this particular case because there is a way of putting a monetary value on lives.

There are certain commodities that the public do not feel comfortable discounting. For example, why should the environmental welfare of an area be valued less in the future than it is now. It may be that if there is environmental degradation elsewhere, then the particular area will actually be more valuable in the future. With some commodities it will not be possible to compensate future generations with money or technology if it is lost. If this is true, then the commodity cannot be traded for money, and in this case, it should not be treated or discounted in the same way.

[5.3] A manSievert is the amount of radiation expected to increase the chance of cancer by 5%. That is, 20 manSieverts would result in an extra cancer in the population.

5.1.7 The Same Rate For All Goods Every Year

If, despite all the arguments against discounting, decision makers decide to value the future less than the present, why should the value decrease geometrically? Parfit (1981) comments that the moral importance of future events does not decrease at *n* percent per year. Psychological studies show that people do not generally exhibit constant discount rates over time and they often have different discount rates for different commodities (See Section 5.2). The argument for discounting all goods at the same rate depends on the assumption that they are all tradable, that is that, for example, lives can be completely replaced by money. In reality this is rarely true. If commodities are not completely interchangeable, then there is no reason to discount them at the same rates. Okun (1975) and Goodin (1982) argue these points. They note that only goods which are completely tradable should be discounted at the same rate. In this case, the rate to use is the highest growth rate of the interchangeable commodities. With non-market goods the discount rate which should be used is the rate at which they accumulate over time. This would result in different commodities having different discount rates.

If we have the same discount rate for both a good and money over time this implies that the future relationship between the value of the good and money is constant, and the same as it is today. In reality, the relationships between goods and money depend on whether the wealth of the society and the availability of the good is increasing or decreasing. Schieber and Poullier (1989) and Viscusi (1994) found that, as the wealth of a country increased it spent more of its GNP on health care. This suggests that the monetary value of health care is not constant, but can vary as a function of GNP. Therefore, to justify keeping the discount rates of health and money equal we would have to show that the relationship between them remains constant over time. In a similar way the relationship between the environment and money will probably change over time. As environmental commodities become rarer or polluted their value will increase. There does not seem to be any evidence to back up the assumption that the relationship between money and other commodities remains constant over time. Thus, there seems to be no reason for discounting all goods at the same rate over time. Nijkamp *et al* (1989) also point out that discounting a non-monetary good is only justifiable if there is evidence to show that the price level is a constant.

Keeler and Cretin (1983) say that, if different discount rates are used for money and health care, then no particular program will be adopted. This is because by postponing the program by one year it will become more cost effective, so they claim that no program will ever be implemented. They use this argument to justify discounting all goods at the same rate over all years. Ganiats (1994) disagrees with this argument. He notes that in general society looks at the cost effectiveness of programs, so even if a program may be more cost effective next year, if it is cost effective this year it will be adopted. This means that it is possible to use different discount rates for money and other commodities and still adopt cost-effective programs.

5.1.8 Untrue Assumptions

Kula (1997) points out the false assumptions which conventional discounting is based upon:

- People live forever, or society is one being with an eternal life;
- People do not die before the end of a project;
- It is alright to discriminate against future generations, by valuing them less.

The first and second assumptions are clearly untrue, people have a finite life expectancy and many people who are alive at the beginning of a project will die before the project ends. When the project being analysed is nuclear waste storage, which spans thousands of years, the second assumption is especially incorrect. These facts are not taken into account in the conventional discounting methods and make the methods unsound. The question about whether it is permissible to devalue future generations has been discussed in the previous sections, and the evidence shows that there are clearly situations when this is not just. These issues undermine the validity of the conventional discounting methods. Later in this chapter alternative, more realistic, assumptions are outlined.

5.2 Psychological Research

Discounting the future and the particular discount rates adopted have sometimes been justified by observations of human decisions. It has been argued that the future should be discounted on the basis of society's pure time preference alone. Psychological research has been carried out to investigate how people discount various commodities over time and what affects their discount rate. Benzion *et al* (1989) and Thaler (1981) found that:

- Small outcomes have higher discount rates than larger outcomes;
- Discount rates are higher for gains than for losses;
- People have very high discount rates for short time delays;
- Discount rates decrease as the time until the outcome increases.

Ahlbrecht and Weber (1995a) also cite evidence that:

- People want considerable compensation to delay a good outcome and yet invest at low interest rates;
- People prefer small immediate outcomes to larger delayed ones.

Cognitive theories claim that this is because people fail to picture the future adequately and are averse to waiting. The research shows that discount rates depend on the context and framing of the decision: see Loewenstein and Prelec (1992) and Atherton and French (1997) for more detailed discussions of the issues in intertemporal contexts.

In short, behavioural research suggests that discount rates depend on the time until the outcome. People often have discount rates that decrease as the time to the outcome increases. Yet, normative theories of intertemporal choice assume that discount factors are, and should be, constant. Changing discount rates violate the stationarity axiom of Discounted Utility Theory (DUT). The axiom states that the preference for two outcomes is independent of the time when the outcomes are evaluated. The preference should therefore depend only on the absolute time difference between the outcomes. However, as Benzion *et al* (1989) discovered, this does not accord with the value judgements exhibited, and there are persuasive reasons why it should not (French, 1986 and Atherton and French, 1997). Hyperbolic discount rates (Harvey, 1995) do allow decision makers to give more weight to the very long term future than with constant discount rates, and allow the discount rate to change with time.

The situation that applies to individuals is very different from that facing society as a whole. Individuals are finite and have a short life span in comparison to the human race. Society as a whole (it is hoped) will last for much longer and the risks it faces are very different. Therefore, it does not seem logical to use personal discount rates for valuing societal decisions.

5.2.1 Dynamic Consistency and Stationarity

When thinking about decisions which have consequences in the future, there are two times that need to be taken into consideration:

- When the preferences are stated and the decision made;
- When the outcome occurs.

Stationarity requires that if a decision maker prefers £100 in period 10 to £110 in period 11 (when evaluating the options in period 0 i.e. now), then she should prefer £100 in period 0 to £110 in period 1 (when evaluating now). Stationarity demands that the trade-off between two periods depend on the temporal distance of the periods. Hence a constant discount factor should be applied between two consecutive periods, regardless of whether they are close to the present or a long way in the future (assuming that preferences about the future are stated now). A discount function with a constant discount rate obeys stationarity because the trade-off between the periods is constant. Non-constant discount rates do not obey stationarity.

Dynamic consistency says that if a decision maker prefers £100 in $t + m$ periods of time to £110 in $s + m$ periods of time, evaluated at time 0, and with $t < s$; then she should prefer £100 in t periods of time to £110 in s periods of time evaluated at time m. This implies that decision makers should know their future preferences today, but, as people and their circumstances change over time, this may not be feasible or even desirable. See Appendix A1 for the axioms.

Varying discount rates can lead to a violation of dynamic consistency, which means that decisions would depend upon when they were made, even if in all other respects the situation was identical. If a constant discount rate is used, options are ranked in the same order, independent of whether they are evaluated now or any time in the future. Relative and absolute changes in time give the same rankings to the options. If a non-constant discount rate is used then relative and absolute time changes do not always give the same rankings of the options. If options are evaluated at a future date, then their rankings may change.

Ahlbrecht and Weber (1995b) discuss what conditions must hold for dynamic consistency and stationarity to be equivalent. If decisions are binding for the future then dynamic consistency and stationarity are not equivalent and dynamic consistency arguments are inappropriate. Therefore stationarity is not a requirement of rationality.

In many decision situations, for example, where to build a nuclear power plant, the decision is irreversible and will not be re-evaluated in the future. In such cases dynamic consistency is irrelevant and therefore stationarity is not a requirement of rationality. Once again this emphasises that the decision about whether to use constant or non-constant discounting should depend on the decision maker's time preference and the decision being made. It would seem unreasonable to use constant discounting if it does not reflect the decision maker's preferences and if stationarity is not an issue.

5.2.2 Affinity to Time Frames

Figure 5.1 shows how we can think about long time frames in the context of decision makers and their offspring.

Now	Very imminent and imaginable	Very Important
Now - 25 years	Affects the decision maker and their children	
26 - 50 years	Affects decision maker's children & grandchildren	
51 - 100 years	Affects grandchildren and great grandchildren	Important
101 - 500 years	Some distant descendants	
501 - 1000 years	World will have changed dramatically	
1001 - 5000 years	Will human race still be around?	Not that Important

Figure 5.1: People's Affinity to Different Time Periods

People tend to section future plans into distinct eras with differing importance. For example, they often discount the latter years of their life by smoking or not exercising. In this way they trade off current pleasures for future problems, sometimes putting a very low value on the distant future. In the same way people often buy cheap electrical appliances which in the end cost more to run (Benzion *et al*, 1989). Their affinity to the future can also be affected by the people that they know who will be living at that time. As time passes they will have fewer relations who they know still living and so may care less about the future.

Loewenstein (1987) found that people instinctively value the present more than any other time in history. In light of this, and the fact that people tend to discount hyperbolically, it seems logical that the evaluation of attributes and alternatives should be time dependent and that the discount rate should change over time if this reflects the decision makers' time preference.

Apart from the obvious difference in affinity people will show for the different time periods, because of the lives of their descendants, it is also true that the world will be changing dramatically in these different periods and probably at an increasing rate of change. The speed of development will greatly impact the effects of a decision on society. In the next 25 years technology may progress rapidly, but many near future inventions could be predicted now, and some inventions already have tentative time scales for their completion. In the years 25 to 50 there is more uncertainty about how technology will progress as this will be built on what has been developed in the first 25 years. As time progresses, the uncertainty about the future increases and the ability to predict what the outcome of a decision will be is more difficult. For example, few people 100 years ago would have predicted that many, then killer, diseases would be almost wiped out or that space travel would be possible. Technology now is developing at a much faster rate than ever before and so it is now even more difficult to predict the future. Consequently people tend to be less concerned about the future because they cannot imagine what it will be like. This may not be logical or desirable in social decisions, but is often how people act in private decisions.

Even though it is true that people discount the later years of their lives and the future of others, recent political imperatives are changing. Green movements and concern for the environment have focused the public's attention on the long term consequences of actions, far more than in previous generations. This change in focus is making long term issues more important and, therefore, increasing the need to consider them in decision analyses. As people become more aware of the long term effects of their actions they generally want to take them into account in their decision making.

5.3 Economic Discount Models

Many different models have been developed to determine discount rates. Some have been descriptive and have been developed to predict and model actual human behaviour, while some have been normative and created to show 'how' future outcomes should be valued. In the following sections three particular models are compared and comments on their appropriateness for long term intertemporal decisions are made. The axioms underpinning these models are discussed in Appendix A1.

In DUT the value of an outcome stream $(x_1, x_2, \ldots, x_n)$ is:

$$V(x_1, x_2, x_3, \ldots\ldots x_n) = x_1 + dx_2 + d^2 x_3 + \ldots\ldots\ldots + d^{n-1} x_n \qquad (1)$$

Where d is the discount function such that:

$$d = \frac{1}{(1+r)} \qquad (2)$$

and r is the discount rate.

Harvey (1995) suggests a varying discount rate which could 'devalue the future' at a much slower rate.

$$V(x_1, x_2, x_3 \ldots, x_n) = \left(\frac{b}{b+1}\right)^r x_1 + \left(\frac{b}{b+2}\right)^r x_2 + \left(\frac{b}{b+3}\right)^r x_3 \ldots + \left(\frac{b}{b+n}\right)^r x_n \qquad (3)$$

Where $b > 0$ is the *temporal mid-value*, that is, the point in the future given half the value of the present; and $-\infty < r < \infty$, reflects how the ratio of the outcomes is related to the ratio of the time effects. As time tends to infinity expression (3) decays to 0 slower than (1) and therefore gives relatively more importance to the long term outcomes. The model looks at the ratio between two time periods and not the absolute difference in their time.

To use Harvey's model it is necessary to determine b and r for a decision maker. If the decision maker gives an initial discount rate d then $b = 1/d$; alternatively the decision maker can be asked to give their *temporal mid-value*. Assuming that the present is given a value of 1, then the *temporal mid-value* will be given a value of 0.5. This point in time is the value of b. Harvey advises asking the decision maker for their *temporal mid-value* to determine b, as this encourages them to think about the whole lifetime of a project and determine the middle of that range with respect to importance.

The factor r is obtained by analysing how the ratio of outcomes is related to the ratio of time trade-offs. $r = 0$ if the outcomes have the same ratio as their indifferent extra waiting times. See Appendix A1 for the axioms underpinning the model. In this case the time weights are:

$$a(t) = \frac{b}{b+t} \qquad (4)$$

The model is then called a Proportional Discounting Model and is the one that will be used in this thesis.

Kula (1981) created what he calls the Modified Discount Model (MDM). This, he claims, gives far more weight to the future. The theory is based on the idea of using cohorts (the people born each year) to determine the weight that should be given to the future. Kula assumes that people in the United Kingdom live to the age of 73, see Kula (1984). The function has two parts; one that looks at those who are alive before the project starts, and one that looks at those who are born after the project starts. The value given to people already living is discounted to the start of the project, while the value given to people who are born after the project begins is discounted to their year of birth.

The method is based on the following assumptions for the United Kingdom:

- A cohort (generation) is the people born in a particular year;
- The population size is a constant;
- The life expectancy of the population is 73;
- There are the same number of people in each generation;
- The number of births equals the number of deaths each year;
- Benefits are shared equally between all the generations.

The first assumption is just a definition, the second assumption, although true for developed countries, may not be true for developing countries whose population sizes are often increasing at a very fast rate. In many developed countries life expectancy is increasing, people are tending to live longer and then deteriorating very quickly at the end of their lives. This is changing the demands made on health care and the distribution of health care over people's lives. This however is not taken into account in the model. Assuming that there are the same number of people in each age group is slightly dubious, however, Kula does point out that the parameters in the model can be changed to give more weight to certain generations if they have more people in them. The assumption about births and deaths will again depend on whether the country is developed or not. The final assumption will depend on the project and a weighting factor could be introduced if it is not true.

The model mixes normative and descriptive assumptions together. The discussion about the principle of value judgements with regards the future is normative, but the assumption about life expectancy is descriptive. Some of the descriptive assumptions put very tight constraints on the population growth model, which are not necessarily true. If the assumptions are weakened they can give unrealistic population model patterns. Separating the normative and descriptive elements of the model may improve its validity.

The function is shown below:

$$\frac{1}{n}\left[\frac{1}{(1+s)^t}*(n+1-t)+\sum_{i=1}^{t-1}\frac{1}{(1+s)^t}\right] \qquad t \leq n \qquad (5)$$

$$\frac{1}{n}*\sum_{i=1}^{n}\frac{1}{(1+s)^t} \qquad t > n \qquad (6)$$

n is the life expectancy of the population;

s is the social discount rate;

t is the age of the project.

Kula suggests that the social discount rate should be based on the social time preference rate, also known as the consumption rate of investment. This measure is based on:

- A mortality based pure time discount rate;
- The growth rate of per capita consumption in real terms;
- The elasticity of marginal utility of consumption.

See Kula (1987) for the derivation of the consumption rate of investment for the United Kingdom. He estimates the rate to be about 2.6%. Yaffey (1997) has investigated the validity of Kula's assumptions for the United Kingdom and the effect on the model of changing them. He points out that:

- There are different numbers of people in each cohort group;
- Not everyone dies aged 73;
- The population is not stable, but decreasing.

Among existing cohorts the perturbations do not matter because the age distribution does not affect the weights. Similarly, any decrease in total population size does not affect unborn cohorts because it is the relative sizes of the groups which matter. Yaffey adjusted the cohort weights to reflect the differences in cohort groups. He found that the final discount function was not significantly different from the one given by Kula. Therefore, Kula's assumptions seem to be adequate for the United Kingdom.

Bellinger (1991) has proposed a Multigenerational Value Formula, which is similar to Kula's MDM, but allows decision makers to apply different discount rates to intra and intergenerational issues. He also points out the importance of the type of good being analysed, and the effect this should have on its discount rate.

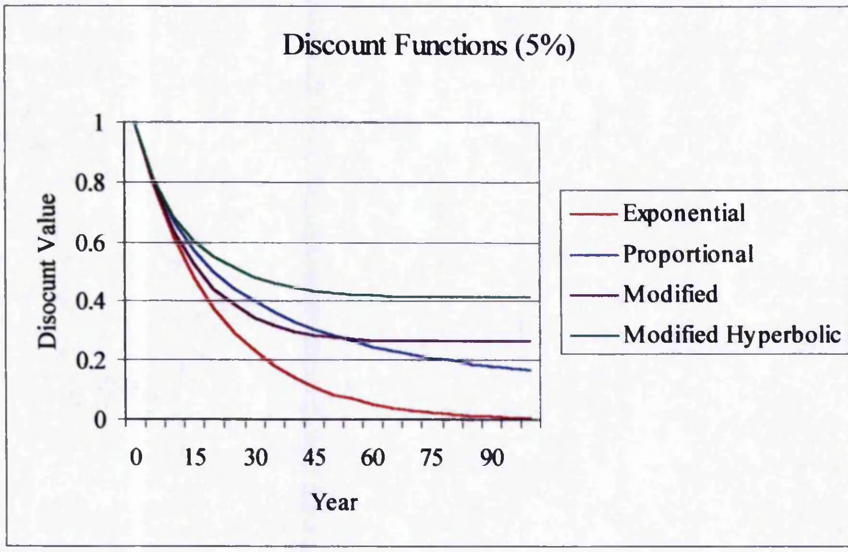
Kula's MDM has been criticised by several authors. Price (1989) argues that MDM gives inconsistent results when decisions are reviewed at a later date. As discussed in the section on dynamic consistency, this is only important if the decision is reversible and will be re-evaluated in the future. In the context considered this is not an issue. Price also states that a low discount rate should be used for long term projects rather than modifying the discounting method. This can still be unreasonable when the decision spans hundreds of thousands of years. In such cases Price advocates not discounting at all, but this means assuming that there is no trade-off between the present and the future, which is clearly untrue.

Thomson (1988) argues that decision makers must bow to pressure from present generations. He says that these people want benefits and not costs now. Chapter 6 shows that even though people may discount the future, the rate used is sometimes far less than that advocated by constant discounting.

As has been noted earlier, after the project year reaches the life expectancy of the population the discount rate does not decrease. Bateman (1989) questions the implications of this. He says this assumes that after a certain point in time it is the size of an outcome that matters, and not when it occurs. This may be true for very long time frames, for example, after a thousand years, but it is unclear whether this is true for shorter time frames. In Kula's model this would happen after 73 years, for the United Kingdom.

Another possibility is to combine Harvey's model with Kula's model. A hyperbolic discount function would be used instead of a constant discounting function in Kula's model. This would give a social discount function that decreases more slowly over time.

Graph 5.1 shows how the different discount functions change over time. A discount rate of 5% is used in line with general government policy. Using a discount rate of 5% means that in the proportional discounting model *b* is 20. The graph shows that the modified hyperbolic discount model gives more weight to the future throughout the life of a project. It is clear that the constant discounting model tends to zero very quickly and so gives very little weight to the future.



Graph 5.1: Discount Functions with a 5% Discount Rate

The table below shows how the discount rates change over time.

Year	Constant 5%	Proportional 5%	Modified 5%	Modified Hyperbolic 5%
5	0.784	0.8	0.789	0.805
10	0.614	0.667	0.6356	0.684
50	0.0872	0.286	0.2776	0.428
100	0.0076	0.167	0.266	0.413
200	0	0.091	0.266	0.413
500	0	0.039	0.266	0.413

Table 5.1: The Values Given to the Future by the Discount Functions

Table 5.1 shows that with constant discounting, after only 50 years very little weight is given to events that happen. With the proportional discount model more weight is given to the long term future, but this is still negligible after 200 years or so. The proportional discount model gives more weight to the short term than either the modified discount model or constant discounting. However, after 50 years the modified discount model gives more weight to events than the proportional discount model. The modified hyperbolic model gives the most weight to the future at all times. All the years after the estimated age of the population (in this case 73) are given the same weight with the modified discount model and the modified hyperbolic model. This means that the long term future is given far more weight than with the other two models.

Comparing the standard modified discounting method with the modified hyperbolic discount method shows that the value given to the future when using the hyperbolic rate decreases more slowly. The underlying discount function also reflects more accurately the way that people discount future events, see Ahlbrecht and Weber (1995b). The weight given to the long term future is also higher when the modified hyperbolic discounting method is used.

With constant and modified discounting the decision maker only has to define the discount rate. The range of justifiable values for the discount rate is limited; the value used is usually the market interest rate, or the social rate of time preference taken from studies. The proportional discount model gives decision makers more scope. They can define the discount rate by defining their *temporal mid-value*. This means that they can use much lower discount rates. All three methods, however, limit decision makers to valuing the future less than they value the present. They are confined to decreasing future values.

5.4 Time Eras and Time Era Weights

An alternative method might be to use time era weights, whereby each year, or time era is given a weight to reflect its importance. The method would allow decision makers to increase the weight they give to the future. They could also specify values which increase over time. The rate of decrease is also more under the decision makers' control. They can define weights that decrease quickly at first and then level out, or which do not decrease at all. The discount values used can therefore match the decision makers' preferences exactly, and would not tie them to a set of values that they did not necessarily agree with.

If we think, for example, about a cost that is incurred during every year of a project, then it could be viewed as *n* separate attributes, one for each year. Figure 5.2 shows this diagrammatically in the form of an attribute tree.

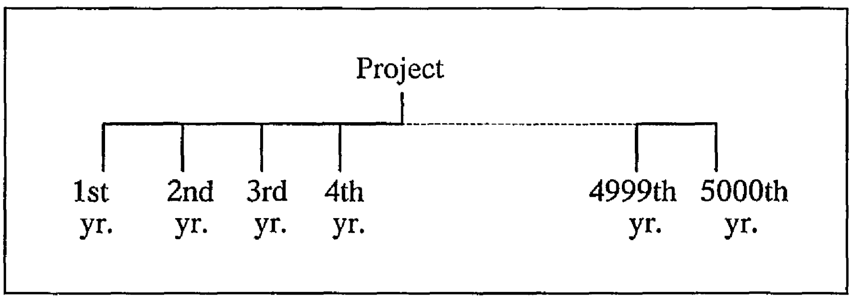


Figure 5.2: Attribute Tree for Costs Sectioned into Years

This is not very cognitively intuitive, so the question is how to rearrange the attribute tree so that it is. It would be difficult to think about year 4999, for example, and to attach an importance weight to that year. Using a constant discount rate prevents decision makers from having to make such difficult valuations. However, it limits how people can value the future it ties them into giving the future less weight than the present, which may not be what they want to do.

Grouping the years into time eras may be more cognitively intuitive for decision makers. Instead of having to think about individual years they are required to think about groups of years and must attach a value weight to each group of years. Section 5.2 discussed how people section time into distinct eras and how their affinity for periods of time changes. The attribute tree would then become that shown in Figure 5.3.

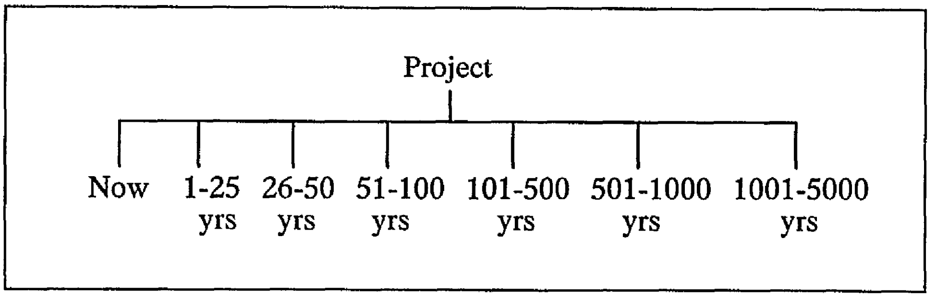


Figure 5.3: Attribute Tree for Costs Sectioned into Time Eras

The time eras could be determined according to several different factors, for example, the affinity of the decision makers to the different eras, changes in attributes or their values, or changes in the probability of the scenarios. Once defined it is relatively easy to elicit decision makers' opinions about the importance of these eras.

Structuring decisions in this way would give decision makers all the benefits outlined at the end of Chapter 4. It would also give them the ability to give more value to the long term future of their projects. If their opinions and preferences were in line with the axioms underpinning constant discounting, then a constant discount rate could be used, and the time eras could be used purely for modelling purposes. If, however, the decision makers' opinions do not conform to the constant discounting axioms then they could use another discounting model, for example, the hyperbolic model or even the time era weights idea suggested.

This chapter has discussed some of the debates surrounding the trade-offs to be considered in intertemporal decision making. The validity of the views with respect to very long term decisions involving society have been investigated. Several models for valuing the future have been examined and a new way of structuring attributes over time and valuing them has been presented, along with some of the advantages it may give. The following chapter contains applications of the new structuring and reports on how the idea of time era weights has been investigated in several situations.

Chapter 6 Applications of Time Era Weights

This chapter describes several experiments that were carried out to determine the validity of the time era weights model and the idea of structuring attributes over time.

The initial investigation involved working with several experts in the area of nuclear waste disposal to create a hypothetical decision scenario. All the work was carried out via face to face interviews with individuals and groups. The elicitation of preferences was done on a one to one basis with Simon French. The results obtained using the time era weights model were compared with other discounting methods. Analysis of the data showed that the model is compatible with the hyperbolic discounting model created by Harvey (1986).

To investigate the acceptability of the structuring to a wider audience, a simplified version of the nuclear waste decision was placed on the World Wide Web. Appendix A3 contains the pages that the participants were presented with. They were asked to perform a multi-attribute decision analysis and give relative weights to the different time eras. These were supplied interactively via HTML forms on the Web pages. The responses are in Appendix A4. The experiment gave some interesting results and most of the subjects felt comfortable with the idea of using time era weights and having attributes change over time. The decision situation was unrealistic in that the subjects were presented with the attributes they had to value. However, no one commented that they felt important attributes were missing. Results of the experiment are presented in this chapter. It is noted that World Wide Web experiments are difficult to perform, as there is no direct interaction between the analyst and the subject. The advantage is that they are cheap to set up and give access to a wide spectrum of subjects.

Another World Wide Web page was created to investigate the structuring further. This asked participants to divide a thousand years into eras, and weight the eras. Most of them found the ideas intuitive and commented positively about the concepts investigated. Appendix A5 contains the World Wide Web pages and Appendix A6 contains the subjects' responses.

It may seem that the World Wide Web experiments were carried out in the wrong order, but the second experiment was motivated by the comments received about the first experiment.

In this chapter we also report how our structuring ideas have been applied to a climate change model that was created by Valverde *et al* (1998).

The aim of the chapter is to show the applicability of the structuring and its compatibility with other models. It also demonstrates that subjects found the method intuitively appealing and easy to comprehend.

6.1 Hypothetical Nuclear Waste Decision

To investigate the idea of time era weights a hypothetical decision was created. It was concerned with facilities for nuclear waste storage and had six disposal alternatives. Descriptions of the different, hypothetical facilities were created which were realistic enough to be considered sensibly. Each alternative needed to contain enough technical information to be realistic but still understandable to non-technical experts. Descriptions of the facilities were based on discussions with Nirex and Scientists from the University of Manchester with experience in nuclear waste disposal, and on Freeman (1988), Keeney and Merkhofer (1987) and Keeney and von Winterfeldt (1994). Scenarios of the future, with the probability of their occurrence for each facility, were also created, with reference to the same papers. Each of the facilities was analysed with respect to several attributes, some of which depended on time and the scenario that occurred. It was assumed that the site for the facility had already been chosen and that the waste to be deposited would be the same in each case. The only decision to be made was therefore which facility to build.

The initial facility descriptions were presented to several scientists who had experience in dealing with nuclear issues. The first task was to discuss the viability of the model. It was clear that assumptions had to be stated more clearly and that some important information had been omitted. Some of those present were geologists and engineers who had experience on the technical side of dealing with nuclear waste. They indicated several factors that were of importance, for example, the half-life[6.1] of the isotopes and the nature of the rock the facility would be built on or in. Changes were made in the model to include this information and the probabilities were modified to reflect the opinions and experience of those present. Figure 6.1 shows the influence diagram for the model.

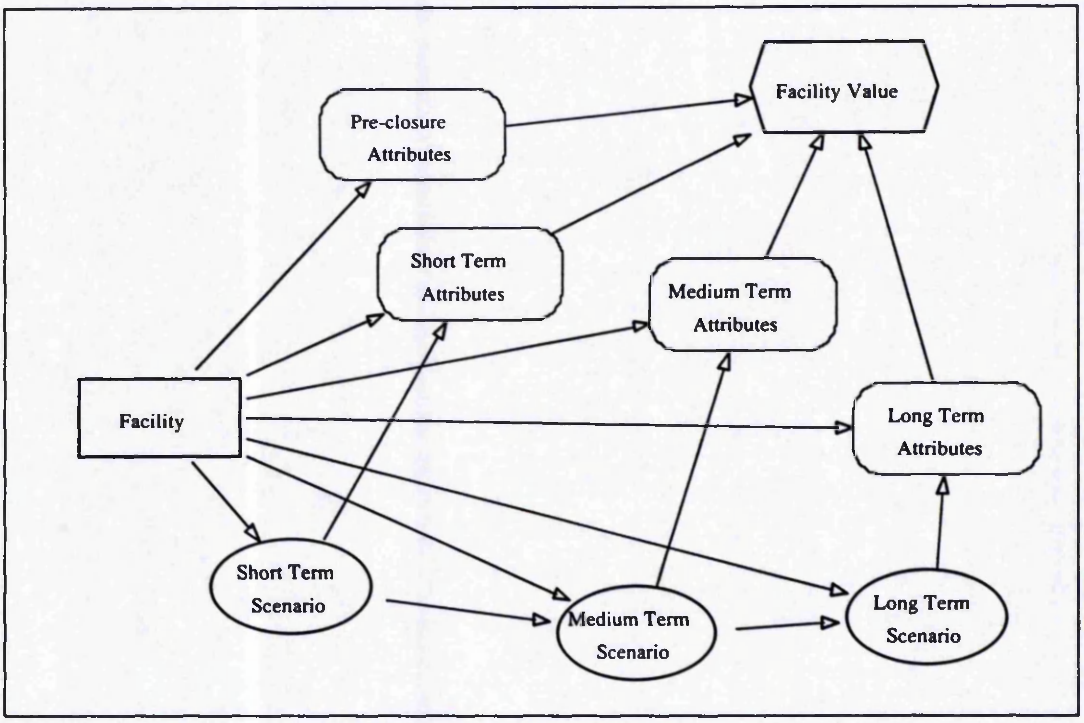


Figure 6.1: The Influence Diagram for the Model

Appendix A2 describes the elements of the model in detail, including all the data used. The following sections give a brief overview.

[6.1] The half-life of an isotope is the time it takes for half of the radiation to decay.

6.1.1 The Facilities

The decision consisted of the following alternatives:

(1) On Site Storage

This would involve putting the radioactive waste in sealed concrete containers and placing them in a secured building. The building would also be sealed to prevent radioactive release and would be protected by security systems.

(2) Burial with Reburial

This would involve placing the waste in a buried pit, which would be reopened every 50 years to check the conditions and the safety of the waste inside it. It would require the construction of a chamber to allow re-access into the pit.

(3) Permanent Burial with no Drainage

An underground pit would be created to store the radioactive waste. However no complex structure would be created for drainage. Also no cut-off walls would be used.

(4) Permanent Burial with Drainage

This would be as above but with drainage included. The drainage is expected to function for the first 200 years.

(5) Permanent Burial with Drainage and Cut-off Walls

As above but with cut-off walls included.

(6) High Tech option

This facility would have cut-off walls, a more complex drainage system and a high technology closure system.

6.1.2 Scenarios of the future

Several scenarios were created to reflect what could happen once the facility had been built. They were developed from earlier papers of Freeman (1988), Keeney and Merkhofer (1987), Keeney and von Winterfeldt (1994) and reports from Nirex and British Nuclear Fuels plc. (BNFL)[6.2]. The probability of these scenarios occurring depended on the facility being considered and changed with time. They are mutually exclusive and collectively exhaustive. The scenarios are described below.

- Waste management facility operates as planned with no unforeseen leakage.
- Containers become unstable resulting in radiation leakage. With on site storage (1) this would cause radiation leakage into the environment; with the other facilities it would result in radiation leakage into the storage facility. Therefore the consequences of this scenario are more severe for facility 1 and 2. No damage to facility otherwise.
- Ground water contamination occurs, small subsequent chance of corrosion to containers.
- Structure becomes damaged with small subsequent chance of ground water contamination.
- Incomplete sealing of shafts and the repository or, for facility 1, problems with the housing structure.
- Intrusion into structure, including accidental damage and terrorist damage.
- The radioactive material is no longer a problem. For example, medical advances find cures for cancer and other radiological health risks, a use is found for the fuel, the waste is blasted to the sun, the waste is transformed into a safe material, or some other reason.

The scenario that occurred would determine the value of the attributes, for example, the accident costs would depend on the scale of the accident.

[6.2] BNFL operate the radioactive waste disposal site at Drigg in the UK.

6.1.3 Attributes

The facilities were analysed with respect to several time dependent attributes. The set of relevant attributes changes over time as, for example, construction costs are incurred immediately, while operating costs are only incurred after the facility is closed. The attribute values depended on which facility was built; many of the values also depended on the scenario that occurred. Figure 6.3 to Figure 6.5 show which time eras the attributes occur in. Different attributes are used in different time eras.

Construction Costs

The cost of creating the structure for the waste storage. The cost varied for each facility. Measured in millions of pounds.

Collective Worker Dose

The expected collective dose workers will be exposed to while the facility is being constructed and the waste deposited into it. Measured in manSieverts[6.3] (manSv).

Collective Public Dose

The expected collective dose the public will be exposed to while the facility is being constructed and the waste deposited into it. Measured in manSv.

Worker Deaths (Non Radiological)

The expected number of deaths caused by non-radiological hazards, for example, construction deaths.

Immediate Environmental Impacts

A constructed attribute (See Section 1.2.5) was created to measure the environmental impact. This related to the initial disturbance the facility would cause to the area. A scale was devised that described and ranked the outcomes that occurred.

[6.3] A manSievert is a measure of radiation dose. One manSievert leads to an increased chance of cancer of 5%. That is, 20 manSieverts would result in an extra cancer in the population.

Public Acceptance, Local and Distant, Long and Short Term

A constructed attribute was used to measure public acceptance. This consisted of a scale from 1 to 6, with 1 indicating most public support and 6 the least. The scale is based on public perceptions of safety, environmental impacts and socio-economic impacts. It is split into local and distant regions to reflect the importance of, and any differences in, the opinions of the people living close to and a far from the facility. The long term elements reflect how the community feels now about how publicly acceptable the facility will be to people in the future. The scales for the different groups and over the various time periods also differ.

Operating Costs

The yearly cost of operating the facility, in normal conditions, once it has been constructed. Measured in millions of pounds and varying for each facility.

Accident Costs

Costs incurred due to adverse circumstances, for example, an intrusion into the structure. To measure this a constructed attribute was created which expressed the attribute levels in terms of a scale. The score on this attribute is uncertain because it depends on the scenario that occurs. The costs included the cost of rebuilding and re-location and any intervention strategies applied to protect people.

Long Term Environmental Impacts

The long term impacts depend on which scenario occurs after the facility has been built, therefore they are uncertain and rely on the probability distribution for the scenarios. A constructed attribute scale was used to describe and rank the outcomes. The attribute reflected loss of land, either agricultural or wild, and animals and their habitats because of an accidental release.

Accident Impacts

In the final time era it was thought unrealistic to be able to estimate the costs of an accident. To avoid having to do this a constructed attribute was created called *Accident Impacts*. This was used to reflect the environmental and social impacts on the community from an accident; a non-linear scale defined it. The attribute is uncertain, and depends on the scenario that occurs.

Likely Maximum Individual Dose Close to the Facility

This is measured in milliSieverts[6.4] per year. It changes over time to reflect differences in the radiation content due to decay and the stability of the facility. The level is uncertain and depends on the scenario that occurs, as this would determine how much radiation was accidentally released to the environment. The population considered was that living within 20 km of the facility.

Collective Dose to the Nation

This was measured in manSv and is the dose the UK population is expected to receive.

Costs in the Model

Costs in the future are difficult to estimate due to changes in technology and inflation. *Accident Costs* were therefore included on a scale that indicates the severity of the outcome instead of giving unrealistic estimates in monetary terms. *Operating Costs* were also only considered for the first 500 years after the facility was closed, as estimates of the cost after this date would be too unrealistic.

6.2 Structuring the Decision

Section 5.2 discussed why people view time in segments and how their feelings towards events in those periods change. In the model, the attributes considered were time dependent and there were several distinct time periods. The events in the model were grouped into unequally sized intervals, one pre-closure[6.5], and four different time intervals post-closure[6.6]. A large time frame was considered because radioactivity from nuclear waste has a very long half-life; some waste taking thousands of years to decay to safe or stable by-products.

[6.4] A milliSievert is one thousandth of a manSievert.

[6.5] Pre-closure is the time before the facility has had the waste deposited in it, and includes the construction of the building.

[6.6] Post-closure is after the facility has been completed and the waste deposited in it. The facility is then 'closed' up.

- Pre-closure;
- Short Term Post-closure, 0-100 years;
- Medium Term Post-closure, 101-500 years;
- Long Term Post-closure, 501-10,000 years;
- Very Long Term Post-closure, 10,001-1,000,000 years.

The meeting with the scientists indicated that they were more interested in the technical issues than the human issues, especially when looking at the distant future. The participants were much less confident talking about effects which occurred after 500 years, and even commented that, 'Life will be so different then that there is no way we can predict with any accuracy what will happen in the future; so there isn't much point trying.' In light of these opinions the final time interval was removed.

6.2.1 The Model Attribute Tree

As noted earlier, one of the most difficult issues in intertemporal decision making is how to trade-off the present with the future. In the model the attributes are time dependent, some have consequences which occur immediately, while some have consequences which occur in the future. For example, construction accidents occur now, whereas accident costs are a future cost that will span over the whole life of a facility. The measurable attributes change over time, as does the probability of an accident occurring, so it seemed logical to section future attributes to reflect the way they depend on time. By creating an attribute tree that depended on time, it was also possible to model the preferences people had for the future.

Figure 6.2 shows the top level of the attribute tree. This structure enabled decision makers to see explicitly the time trade-offs that had to be made. The attribute tree was divided into the time eras agreed with the scientists.

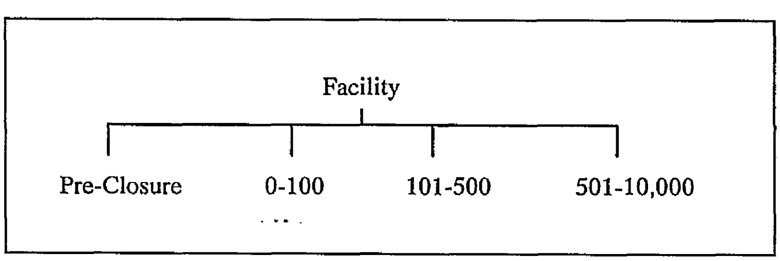


Figure 6.2: The Top Level Time Eras

The attributes which were important in each time period varied, Figure 6.3 to Figure 6.5 show the attribute trees for each of the time periods. By structuring the attribute tree in this way the decision makers could see which attributes were relevant in each time period and how the alternatives' scores on the attributes changed over time. The decision makers indicated that this helped them to understand the trade-offs that they had to make and enabled them to consider sensible comparisons between related attributes. The scientists wanted to be able to change the attribute scores over time and the probabilities attached to the events. Dividing the tree into distinct periods allowed them to do this. (As the attribute trees for 0-100 years and 101-500 years are very similar only one of them is shown.)

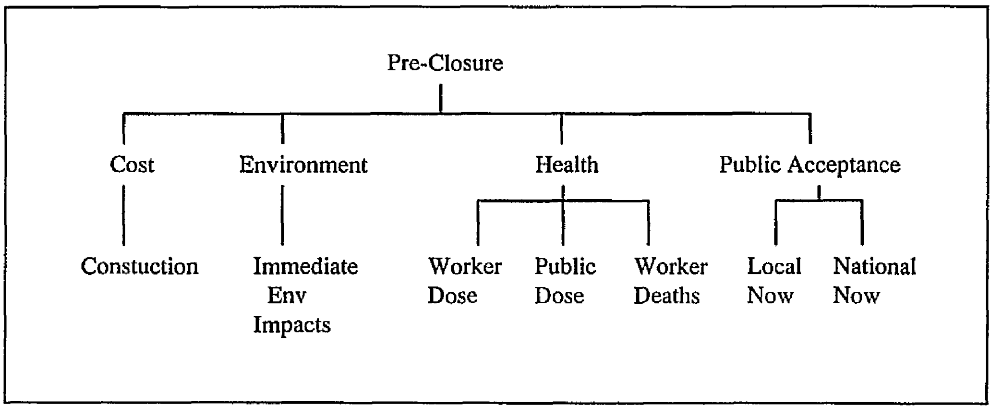


Figure 6.3: Pre-Closure Attribute Tree

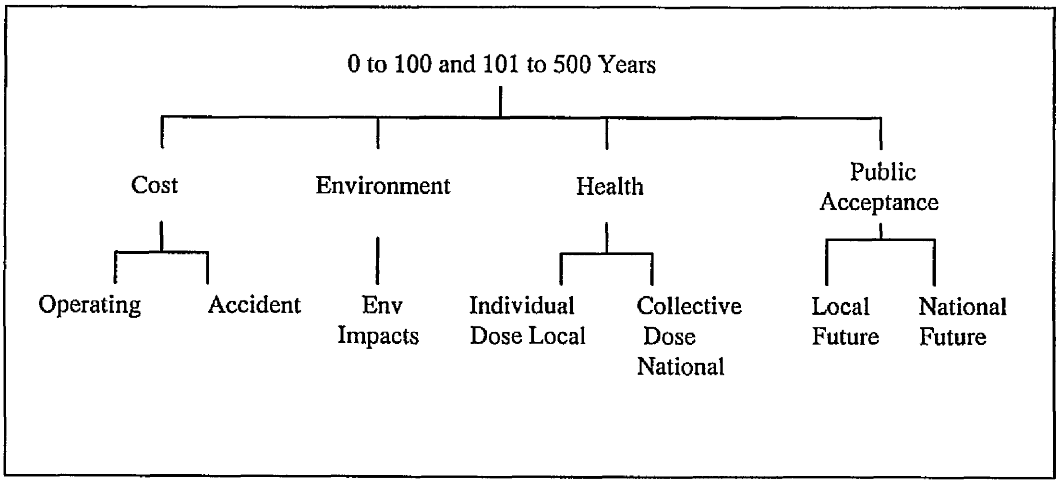


Figure 6.4: Attribute Tree for 0 - 100 and 101 - 500 years

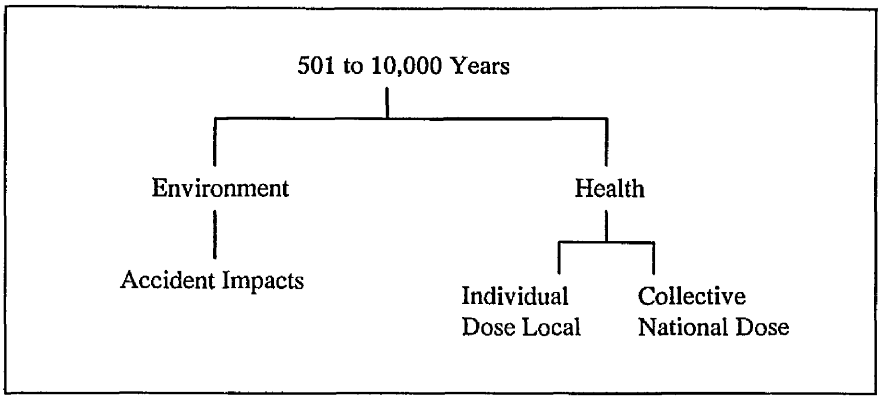


Figure 6.5: Attribute Tree for 501 - 10,000 Years

6.2.2 Eliciting Decision Makers' Attribute Weights

The original plan was to work with a scientist and a philosopher to elicit their preferences and opinions. Initially two separate meetings were held with Dr K who is a philosopher and Dr L who is a chemist. Attempts to elicit specific attribute weights were unsuccessful. Dr K felt that it was unprofessional as a philosopher to state specific weights and Dr L did not feel qualified to do so. Both meetings, however, gave insight into the model and changes that needed to be made. Chapter 2 discussed why the participants may have been reluctant to express their opinions.

Simon French (SF) was present at both meetings, which helped to shape his thoughts about the model and the issues involved. Weights were elicited from SF and discussed with people working in the radiation protection field. SF has worked on the International Chernobyl study and therefore has a reasonable idea of the sort of costs incurred after a nuclear accident. He has also worked with many decision makers to elicit their attribute weights and so understands the issues about attribute range and weights.

The attribute scales that SF assigned to the original scales, and the weights that he gave to the attributes are in Appendix A2.

The attribute weights were elicited in an order that was expected to help the decision maker and swing weighting was used. The probability distributions affecting the model and the need to take these into account were emphasised. Bottom level weights were elicited first, starting with the pre-closure attributes. This avoided the decision maker having to think about the time issues immediately. He was reminded that the time trade-offs would be elicited later, and to focus on the relative importance of the attributes being studied. Weights for attributes in the other subgroups were elicited next, and then comparisons were made between related attributes, not in the same subgroups.

The middle level of the attribute tree was used to check the bottom level weights by summing the weights of the attributes in the same subgroups. The top level weights, i.e. the time trade-offs, were then elicited and used to multiply the bottom level weights. The weights were then checked and sensitivity analysis performed. All this was conducted with post-it notes and a white board; no computer package was used. Once all the weights and values had been elicited, they were input into an Analytica model (Analytica, 1998). This enabled sensitivity analysis to be carried out quickly and easily. The weights were not re-normalised to sum to 100 at all stages of analysis, as normalisation does not fit naturally with swing weighting elicitation. The software used does not normalise automatically and rather than introducing errors with superfluous extra coding, the model was analysed with non-normalised weights. The aim was to rank the available alternatives, therefore normalisation was not necessary.

For attributes relating to dose levels, their monetary value, according to the Nuclear Regulation Protection Board (NRPB)[6.7] calculations, was stated. A monetary value was also attached to worker deaths, using insurance claims information. During the analysis the ranges of the attributes were stated explicitly to reinforce their importance to the attribute weights.

[6.7] NRPB advise the UK government on radiation protection issues.

6.2.3 Time Era Weights

SF was asked to give weights to each of the different time eras to reflect their relative importance. The logic behind the weights assigned is as follows. SF believed that the weight that should be given to the *Pre-closure* and *0 to 100 years* eras should be the same as he saw them as equally important, he gave both eras a value of 1. He believed that the *101 to 500 years* era was only 1/4 as important as the first two eras and so assigned a value of 0.25, the last era he thought to be 1/10 as important and so gave it a weight of 0.1.

6.3 Valuing the Future in the Model

SF's values were used in three models. Each model used the same attribute values and weights, but applied different discount functions. One had constant (exponential) discounting, another used SF's time era weights and one used proportional discounting. In order to allow comparisons between the models, all of the attributes have been treated in the same way and subjected to the same discount method. This is not in line with the author's views, (See Chapter 5) but makes the models comparable.

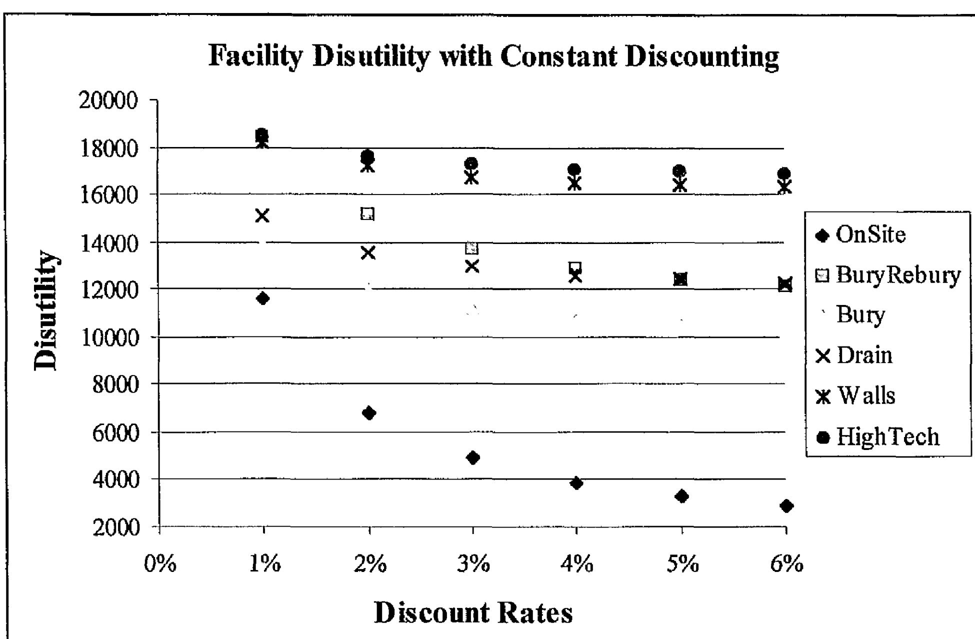
Some of the monetary outcomes (*Accident Costs*) in the model were uncertain, as was the time of their occurrence. To take this into account and allow discounting of these uncertain values, the model was modified so that only one accident could occur in a time era. This seemed to be acceptable to the scientists who helped to create the model, as they thought that an accident would completely change the facility situation and would result in a new facility being built. The time that the accident occurred in an era was determined by a variable. This was used to calculate the year of the accident. The expected cost of the accident was then discounted from that time to the present.

The model that used the decision maker's time weights did not need to deal with this problem. An accident occurring in any of the eras was simply weighted by the time weight for that era, so its exact time of occurrence was not important. All the attributes measured 'costs' and so the model measured the expected disutility of a facility. The aim was to minimise the total disutility; the 'best' facility was therefore the one with the lowest value.

6.3.1 Constant Discounting

An initial discount rate of 6% was used to discount all of the attributes (Note: this is roughly the current rate used by the UK treasury in planning). This is not the view that the author holds, but was done in order to allow comparisons to be made between the different models (See Chapter 5 and Atherton and French, 1997). This resulted in the 'On Site' facility having the 'best' score, which seemed unreasonable to the decision maker. The reason for this result is that constant discounting only gives weight to the short term outcomes. The 'On Site' facility has very low initial costs, but high long term costs, which are ignored by constant discounting models.

The discount rate was then decreased and the model was run again. The facility ranks remained the same until the discount rate had been decreased to 1% (See Graph 6.1). Even then, only the rankings of the 4th to 6th placed facilities change. Given the economic arguments behind discounting it is hard to sustain a case for a 1% discount rate, therefore the analysis in this case is not justifiable. As the case for any low discount rate needs to be more than purely economic we began to look at other discounting methods.



Graph 6.1: Disutility with Different Constant Discount Rates

6.3.2 Relative Weights Given to the Different Eras

Instead of using discounting, one model gave different weights to the eras to reflect their relative importance. The weights used were the time era weights elicited from SF and therefore represented his opinions exactly. These weights were multiplied by the attribute weights in an era and the attribute value scores for the facilities, to give an overall weight. Using this value system the 'Bury' facility had the 'best' score. (See Table 6.1 for the facility rankings)

6.3.3 Proportional Discounting

A third model was created in which Harvey's proportional discounting method (See Section 5.3 and Appendix A1) was used to discount all of the attributes. The *temporal mid-value* was determined by plotting SF's time era weights and finding the point in time at which the weight was 0.5. This occurred at 200 years. In an analysis where the decision maker is not so connected with the researchers, one would ask questions to determine if their time weights were proportional, as defined in Section 5.3. For example, suppose the decision maker was indifferent to paying £100 in one year and £125 in two years. The analyst would check if they would also be indifferent to paying £100 in 2 years and £125 in 3.25 years. Many other questions of this type could be asked. All the attributes in the model are 'costs' and are therefore to be seen as negative outcomes, so all the questions to determine the time trade-offs would relate to paying amounts of money. The discounting weights used in the model were:

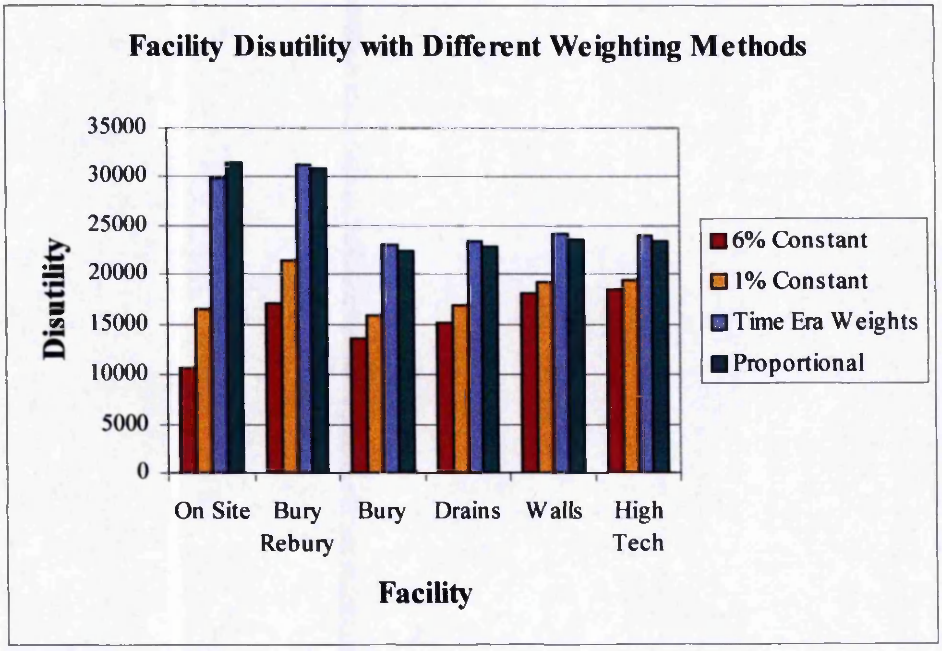
$$a(t) = \frac{b}{b+t} = \frac{200}{200+t}$$

Where t is time.

For uncertain outcomes, the model determined t. Using these discounting weights the 'Bury' facility came out the 'best'. The disutility of the different facilities is very similar to those obtained from using the time era weights model. This shows a high degree of consistency between the two models. See Graph 6.2.

6.4 Discussion

The graphical results from the different models are shown Graph 6.. It can be seen that constant discounting gives results which are very different from the results obtained using SF's time era weights, whereas, the results from proportional discounting are very similar. As time era weights and proportional discounting give higher weights to the distant future, the disutility of the facilities is higher in these models. This suggests that more information is being taken into account and that the models are encapsulating more of the issues and attributes involved.



Graph 6.2: Disutility Rankings with Different Weighting Methods

Rank	6% Constant	1% Constant	Era Weights	Proportional
1st	Onsite	Onsite	Bury	Bury
2nd	Bury	Bury	Drain	Drain
3rd	BuryRebury	Drain	Hightech	Hightech
4th	Drain	Walls	Walls	Walls
5th	Walls	BuryRebury	Onsite	BuryRebury
6th	Hightech	Hightech	BuryRebury	Onsite

Table 6.1: Facility Rankings with the Different Time Weighting Methods

6.4.1 Sensitivity Analysis

Sensitivity analysis was performed, to check how stable the results were when the weights given to the different time eras changed. In the time era weights model the weights given to the medium and long term eras were modified. Table 6.2 shows the effects on the rank of the facilities. (* indicates that the weight is at its original value.)

	Time Era Weights, Immediate and Short Term Weights = 1				
Rank	Medium=0.25* Long=0.1*	Medium=0.25* Long=0.2	Medium=0.3 Long=0.15	Medium=0.35 Long=0.05	Medium=0.35 Long=0.1*
1st	**Bury**	Bury	Bury	Bury	Bury
2nd	**Drain**	Hightech	Hightech	Drain	Hightech
3rd	**Hightech**	Walls	Drain	Hightech	Drain
4th	**Walls**	Drain	Walls	Walls	Walls
5th	**Onsite**	BuryRebury	BuryRebury	Onsite	BuryRebury
6th	**BuryRebury**	Onsite	Onsite	BuryRebury	Onsite

Table 6.2: Facility Rankings with Different Time Era Weights

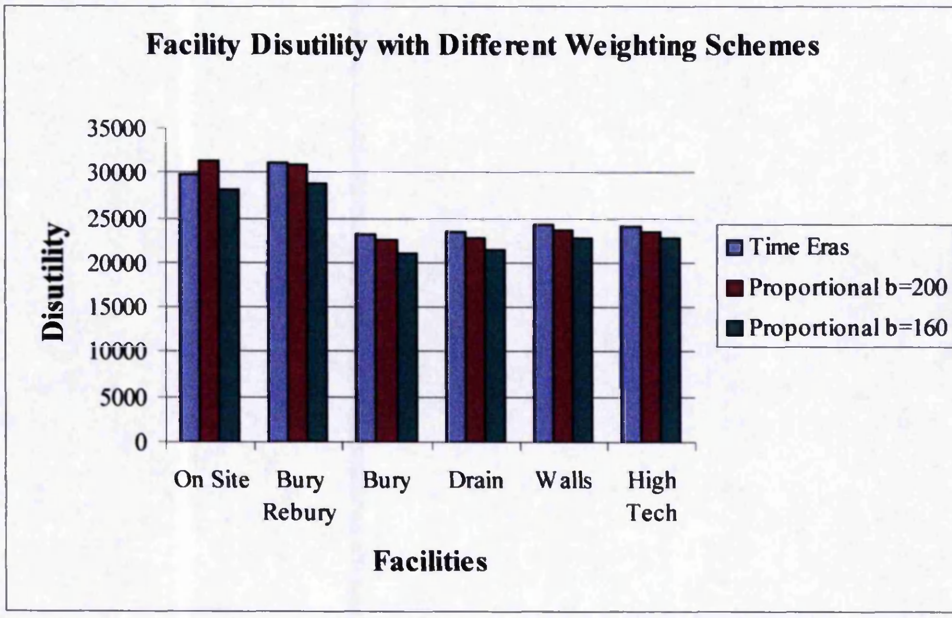
Table 6.2 shows that the choice of facility does not change when the time era weights are changed, however, the rank of the second to sixth facilities does change. This suggests that the choice of facility is stable to changes in time era weights while the ranking of the other facilities is not so stable.

Sensitivity analysis was also performed on the proportional discounting model. The value of b in the formula was changed. (* indicates that b is at its original value.)

	Value of *b* in the Proportional Discounting Model			
Rank	160	**200***	300	325
1st	Bury	**Bury**	Bury	Hightech
2nd	Drain	**Drain**	Hightech	Bury
3rd	Hightech	**Hightech**	Drain	Walls
4th	Walls	**Walls**	Walls	Drain
5th	Onsite	**BuryRebury**	BuryRebury	BuryRebury
6th	BuryRebury	**Onsite**	Onsite	Onsite

Table 6.3: Facility Rankings with Different Values of *b*

The results show that when *b* is 160 the ranking of the facilities is exactly the same as in the time era weights model. Setting *b* to 160 decreases the *temporal mid-value*, therefore giving less weight to the long term future, which favours the Onsite option more than the BuryRebury option, therefore changing the ranking. When the value of *b* is increased to 300 the ranking of the second and third facilities changes. Making *b* equal to 300 increases the *temporal mid-value* by 50% and gives much more weight to the long term future, which favours the Hightech option. Increasing the value of *b* by more than 60% changes the ranking of the first four facilities. The results show that the choice of facility is stable to significant changes in the *temporal mid-value*.



Graph 6.3: Facility Rankings with Time Eras and Proportional Discounting

Graph 6.3 shows that although the rank of the facilities, are the same, using proportional discounting and the time era weights model, when *b* is 160 the disutility values differ more than when *b* is 200. The results show that it is possible to adjust the *temporal mid-value* slightly in the proportional discounting model and obtain the same rankings as with time era weights. The average percentage difference between the time era weights model and the proportional discounting model with *b* at 200 is only 3%. When *b* is 160 the difference is 7%. Both these values are very small and show how similar the two models are.

6.4.2 Comparison of the Time Era and Proportional Discounting Models

Several comparisons were carried out to determine what time era weights the proportional discounting model would correlate with. Research has argued that it is unreasonable to discount non-market goods (See Chapter 5). In line with these ideas the proportional discount rates in the following comparisons were only applied to monetary attributes. Time era weights were used to weight the non-market goods. The weights given to the medium term era (M) and the long term era (L) were modified. The value of *b* was calculated by plotting the time era weights and determining the point in time when the weight was 0.5.

Table 6.4 shows the ranking of the facilities obtained with the different time weights and discount functions. Table 6.5 shows the percentage difference between the disutilities of the time era weight models and the proportional discounting models. The percentage difference was calculated as:

$$\text{Average}\left(\frac{|\text{Time Era Result - Proportional Result}|}{\text{Time Era Result}}\right)\times 100$$

	M=0.1 L=0 b=237		M=0.4 L=0.1 b=300		M=0.5 L=0.25 b=350		M=0.6 L=0.1 b=1230	
Rank	**Time Era**	**∝ Discount**	**Time Era**	**∝ Discount**	**Time Era**	**∝ Discount**	**Time Era**	**∝ Discount**
1st	Bury	Bury	High Tech	High Tech	High Tech	High Tech	High Tech	High Tech
2nd	Drain	Drain	Bury	Bury	Walls	Walls	Walls	Walls
3rd	Onsite	High Tech	Drain	Drain	Drain	Drain	Drain	Drain
4th	High Tech	Walls	Walls	Walls	Bury	Bury	Bury	Bury
5th	Walls	Bury Rebury	Bury Rebury	Bury Rebury	Bury Rebury	Bury Rebury	Bury Rebury	Bury Rebury
6th	Bury Rebury	Onsite	Onsite	Onsite	Onsite	Onsite	Onsite	Onsite

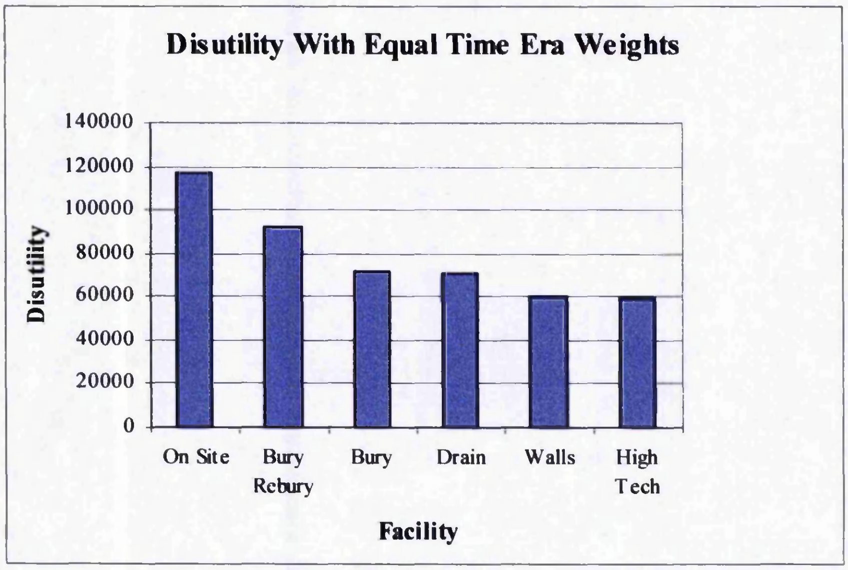
Table 6.4: Comparison of Facility Rankings with Different Time Era Weights

The results show that if the decision maker's weights are future orientated, then the time era weights model and the proportional discounting model are in agreement and the ranking they give to the facilities is very similar. However, the percentage difference between the disutilities of the two models varies quite considerably.

Time Weights & b	**Weight Given to Time Eras**			**Percentage Difference**
	0-100 Years	**101-500 Years**	**501-10,000 Years**	
Time Era Weights Model	1	0.25	0.1	0%
b=200	0.8	0.4	0.037	3%
M=0.1 L=0 b=237	0.825	0.1	0	15%
M=0.4 L=0.1 b=300	0.857	0.4	0.1	1%
M=0.5 L=0.25 b=350	0.875	0.5	0.25	34%
M=0.6 L=0.1 b=1230	0.961	0.6	0.1	26%

Table 6.5: Percentage Difference Between Time Era Model and Proportional Discounting

The model was also run with no discounting, the outcomes are shown in Graph 6.4.



Graph 6.4: Facility Rankings with no Discounting

The results are unsurprising. Not discounting puts more emphasis on the long term impacts of the project. The High Tech option performs better than the other options over the whole of the project duration. When discounting is used this is devalued and so the option does not always come out 'best', because it has high initial costs. With no discounting the full benefits of the High Tech option are shown.

6.5 Summary of the Findings

Our research shows how proportional discounting can be used to model a decision maker's time preferences in an intertemporal decision. The results obtained using proportional discounting matched those obtained with time era weights specified by the decision maker. Assessing the trade-offs between different time periods is very difficult. Psychological studies have shown some of the 'biases' and inconsistencies people exhibit (See Chapter 3). These issues are heightened when the decision spans very long time periods. In such cases it is even more important to help decision makers to understand the impact of time trade-offs.

Thinking about different time eras seemed natural to the people involved in the decision structuring. Separating the attributes into distinct time frames helped them to think about the trade-offs that had to be made and enabled the attributes to change over time. Uncertainty surrounding the values of attributes could be varied in the different eras, and the measurable attributes could also change.

Using constant discounting gave results that were not acceptable to the decision maker. He felt more comfortable using time era weights, and this method gave acceptable results. By using the time era weights in Harvey's model it was possible to use proportional discounting to give the same results. If discounting is only used for monetary outcomes, and the time era weights are used on non-tradable attributes, then the model results are even more similar. Time eras are easier for decision makers to think about than discount rates, since they naturally section future time periods, as explained in Chapter 5. Using time era weights in the proportional discounting model enabled the decision maker to think about the whole lifetime of the project and give discount rates in a relatively simple way. The attribute hierarchy helped to make the differences between the eras explicit and so helped the decision maker to determine the relative importance of the eras.

Using the values obtained from analysing different time eras in the proportional model to discount monetary outcomes, and using the time era weights to trade-off non-monetary outcomes, may give a way of finding a compromise between those who argue for discounting and those who disagree with it. Combining these two methods could provide an alternative solution to determining the value of the future in intertemporal decisions.

The sensitivity analysis shows that the results are very stable and that the rankings of the facilities only change when the time era weights are changed significantly. In the time era weights model, the choice of facility does not change when the weights are changed. In the proportional discounting model a slight decrease in the value of b changes the rank of the fifth and sixth facilities to place them in line with the time era model. A 50% increase in b changes the rank of the second and third facilities, but this is a large change in the value. It may be that the methods are only stable because of the nature of the decision and further research will need to be carried out to determine how stable they are with different models.

In intertemporal decisions there are many different stakeholders, such as environmental and public interest groups, economists and the government. For those less interested in quantitative analysis and more interested in the long term future (e.g. Greenpeace) the idea of time era weights may be more justifiable than constant discounting and will certainly give more weight to the long term future. Showing them how these weights can be used in another time weighting model (e.g. proportional discounting with time era weights) to give more long term focused discount rates, may be more palatable than constant discounting. For the economists, who would like to use the normative theories, it will be necessary to prove that stationarity is not important in decisions that are not going to be reviewed. If they accept this, then non-constant discounting models with time era weights could be applied. The time era weights could be used to determine a discount rate for Kula's model or the *temporal mid-value* in Harvey's model. This may be more acceptable than time era weights on their own. It is possible that this method will create a compromise between the two groups and therefore decrease the confrontation.

If decision analysis is going to be used successfully, and the choices made implemented, the decision model must accurately reflect the opinions of the decision makers. If their time preferences do not conform to constant discounting, and the decision is such that stationarity is not a requirement for rationality, then the time weights should not restrict decision makers to a mathematical model they do not agree with. Making attributes time dependant enables their values, and the uncertainty surrounding them, to change over time. It also makes it easier to determine the time trade-offs that need to be made. The assessment of the relative importance of different time eras may be simplified by separating the attributes into the time eras they occur in. Combining these ideas with proportional discounting (if it models the decision makers' time preferences) may give a more transparent way of resolving the value of the future.

6.6 World Wide Web Experiment One: The Hypothetical Decision

A World Wide Web page was designed as an interactive experiment for a simplified version of the decision outlined in Appendix A2. The pages used in the experiment are in Appendix A3. The idea was to investigate how intuitive people found the idea of time era weights and how they wanted to value the future.

A description of the decision situation was provided, along with brief outlines of the alternatives available. The subjects were asked to rank the facility designs holistically, based on the small amount of information supplied.

Scenarios of the future, detailed descriptions of the attributes and the scores of the alternatives on the different attributes were then presented. Participants were asked to enter the weights they thought should be given to the different attributes. The idea that the range of an attribute should affect its value was introduced. The main monetary attribute was used as an anchor, all the other attributes were compared to it to give a 'ball park' figure to start with. The participants were then given reasons why they might want to increase or decrease the weight. An equal number of reasons were given for changing the weight and the order of their presentation was periodically changed.

Progression to the next section was not allowed until values for all the attributes in a time era had been supplied. After considering the attributes, the subjects were asked to weight the different time eras. A summary of their entries was then presented and subjects were given the opportunity to make revisions. Finally, their opinions were processed in an Analytica model and the results emailed to them. Subjects could go back to the World Wide Web page after their initial analysis and modify their previous values. The entries that people gave are in Appendix A4.

6.6.1 The Participants in Experiment One

In all, forty nine people entered values into the World Wide Web page, however three sets of results had to be discarded because the participants had not completed the questions properly. This left a sample size of forty-six. The average age was twenty-nine, with a range from twenty-one to fifty. There were nine women and thirty-seven men. Of those taking part, thirty-three were students, eleven people worked in universities at post-doctoral levels and higher, and two worked outside academia. Table 6.6 shows the countries of origin of the participants and Table 6.7 shows their ages.

Country of Origin	Number of Participants	Country of Origin	Number of Participants
Australia	1	Netherlands	2
Belgium	1	Norway	1
China	1	Sweden	1
France	1	U.K.	33
Germany	2	U.S.A.	2
Iran	1		

Table 6.6: Country of Origin of Participants

Age	Number of Participants	Age	Number of Participants
20	3	30	1
21	8	31	2
22	2	32	2
23	3	33	1
24	2	35-39	2
25	4	40-44	2
26	2	45	3
28	4	46-50	3
29	2		

Table 6.7: Age of Participants

Three of the participants entered two or more sets of values. In these cases their last set of values were used in the analysis.

6.7 Experiment One Results

The facilities were presented to participants in the order: On Site (1), Bury-Re-bury (2), Bury (3), Bury with Drains (4), Bury with Walls (5) and High Tech (6). In the initial ranking of the facilities five of the participants gave the order as 6, 5, 4, 3, 2, 1, rankings of 1 to 6 were given by four subjects and rankings of 6, 5, 4, 3, 1, 2 were also given by four subjects. There were twenty-seven other rankings given by, at most, two subjects.

Table 6.8 shows the rankings of the facilities after the multi-attribute decision analysis.

Facility Rankings	Number of Subjects
6,5,4,3,2,1	17
5,6,4,3,2,1	23
5,6,4,3,1,2	1
1,6,5,2,3,4	1
1,6,3,2,5,4	1
1,6,3,2,4,5	1
1,6,2,3,5,4	1
1,6,2,3,4,5	1

Table 6.8: Final Facility Rankings

Over 80% of the participants chose the long term options. It appeared that thinking about the trade-offs over time had focused the participants' attention on the risk to future generations and they thought that it was important to spend money now to avoid risks in the future. They did not seem to be heavily influenced by the opportunity costs incurred by current generations in order to cover the building costs. To try to determine the accuracy of this hypothesis, an email message was sent to all the participants, including those who chose the less expensive options, to gather their opinions.

There seemed to be two lines of thought. One was that some participants thought that technology would advance and wanted to leave themselves with the flexibility to be able to take advantage of this in the future, or that this would help future generations deal with the problems we leave them. Other subjects believed that we are morally obliged to look after future generations, because they do not have a say in the decisions we make, and we should not leave them with a dangerous legacy. Some responses were:

'To spend an extraordinary amount of money 'now' to insure against every eventuality in the future (i.e. the next ten thousand years) seems to me a policy of significant overkill. I wonder if most people actually had to fork out the funding for such protection whether they would even consider the state of the project 100 years after they die let alone many hundreds.'

'I would be willing to spend the money because that's my only direct way of being able to help future generations, who have no voice themselves. At some point, the current generation has got to make sacrifices or the cycle of the next generation having to deal with inherited problems will continue.'

'It seems unfair to leave future generations with an unsafe legacy through our own carelessness.'

'I was willing to spend more money now if I could be convinced it would increase safety in the long term. However, I also felt that the technology to increase safety in the long term was probably not available now, so I was most focused on preserving flexibility so that newer technology could be inserted for the long term.'

6.7.1 The Importance of the Time Eras

When asked to give the relative importance of the time eras the participants gave the following responses.

Direction of Time Era Weights	Number of Subjects
Increasing	4
Equal	8
Decreasing	24
Increasing & Decreasing	10

Table 6.9: Direction of the Subjects' Time Era Weights

Since the sample size was relatively small, it was not possible to differentiate responses with respect to age, sex or country. The values supplied by the twenty-four subjects with decreasing time era weights were used in further analysis. Their attribute weights were entered into two more models; one using the idea of time era weights and hyperbolic discounting, as outlined in Atherton and French (1998), and one using constant discounting on all the monetary attributes. The hyperbolic discount model is based on the ideas proposed by Harvey (1992), see Chapter 5.

Of the twenty-four subjects with decreasing time era weights the hyperbolic discounting model gave exactly the same facility rankings for twenty-three of them. The other result only differed in the ranking of the fifth and sixth facility. The percentage difference between the facility scores for the hyperbolic model and the time era weights model ranged from 0.33% to 36.7%, with the average difference being 10.9%.

Comparing the time era model with a model using a constant discount rate gave very different results. Only one of the subjects' values gave the same rankings with both models. The similarity was achieved because the subject had given very high weights to the long term attributes, which outweighed the effect of discounting. Two other subjects had only two facilities that ranked differently in the two models and these were the lower ranked facilities. The range of difference between the time era model and the constant discounting model was from 8.9% to 90%, with the average difference being 68%. These results show that the weights given to monetary attributes, using constant discounting, did not comply with those given by the subjects.

	Time Era and Mid-Point			
Model	**Now**	**0-100**	**101-500**	**501-10,000**
	Now	**50**	**300**	**5250**
Time Era Weights	0.98	0.88	0.612	0.322
Hyperbolic Discounting	1	0.97	0.83	0.26
Constant Discounting 6%	1	0.05	0	0

Table 6.10: Values of the Future with Different Weighting Schemes

Table 6.10 shows that the average weight given to the long term future by the time era weights model and the hyperbolic discounting model is very similar and far greater than the constant discounting model.

6.7.2 Value of a Life

The experiment required people to give a value for a statistical life. The average values for lives in the different eras are shown in Table 6.11.

	Time Era			
	Now	0-100 Years	100-500 Years	500-10,000 Years
Value of Life (Millions of Pounds)	10	5	3	5

Table 6.11: Average Value Given to a Human Life

These values are far higher than those currently used in social decisions. To check whether subjects had understood the implications of their weights, they were sent an email asking for an explanation of the thinking behind their answers. The replies received showed that subjects felt that lives were currently being undervalued, and that they believed that lives are worth more than the ball park figure of 100,000 to 1 million pounds, which has been used in cost benefit analysis (See Lefaure, 1995). Some subjects stated that they wanted to increase the value given to a life over time, because future generations will suffer involuntarily. Others wanted to decrease its value, reasoning that technology may have advanced and risks from radiation may be easier to deal with. Opinion seemed to be divided between those subjects who felt that we have obligations to future generations and those who felt that technological advances would deal with the problems we cause. Some comments were:

> *'I do think that governments are currently underestimating the value of life, I think it should be valued at about £2 million per statistical life.'*

> *'I wanted to represent the cost of a life rising over time, as I don't think it is fair to future generations for them to have to pay.'*

'I felt that technology would advance and therefore thought that it would cost less to save lives in the future.'

6.8 Conclusions From Experiment One

The time era weights provided a tractable way of working with participants. Using the weights with hyperbolic discounting gave a model that was closer to how they valued the future than constant discounting. The subjects seemed to have two lines of thinking. There were those who believed that technology would advance and so based their valuations on assumptions about how they thought the future would be. Others thought that we have an obligation to future generations and should act in order to avoid them inheriting our problems. This was more of a value judgement.

It could be argued, as one participant did, that people would be less willing to opt for the more expensive, but safe, facility designs if they really understood what sacrifices they would have to make in order to build them. When people are themselves, asked to pay, they are usually less willing to spend money. However, in the case of societal decisions it is difficult to estimate this effect.

6.9 World Wide Web Experiment Two: Valuing the Future

The first World Wide Web experiment was context specific and involved the subjects making difficult and unfamiliar judgements. To try to investigate opinions about time in a context free setting, with simpler questions, another experiment was set up. The idea was to investigate how people wanted to value the future, and how they would section time, given the choice. The questions that were set are shown in Appendix A5. Participants were first asked to divide a thousand years into time eras and then give a weight to the eras they defined. Next they could give the motivations behind their weights and, finally, how their weights would alter if the issues changed.

6.9.1 The Subjects in Experiment Two

Country of Origin	Number of Participants	Country of Origin	Number of Participants
Australia	1	Germany	4
Austria	1	Greece	1
Belgium	19	Malta	1
Brazil	1	Portugal	6
Canada	1	Switzerland	2
Colombia	1	U.K.	30
France	3	U.S.A.	5

Table 6.12: The Country of Origin of the Participants

Age Group	Number of Participants	Age Group	Number of Participants
< 20	1	41-45	9
21-25	14	46-50	4
26-30	22	51-55	5
31-35	11	56-60	0
36-40	9	61 +	1

Table 6.13: The Age of the Participants

Job	Number of Participants	Job	Number of Participants
Academic	12	Programmer	1
Economist	2	Researcher	15
Engineer	5	Scientist	4
Environmental	5	Student	12
Director	4	Technician	2
Manager	9	Other	3
Medical	2		

Table 6.14: The Occupation of the Participants

As Table 6.12 to Table 6.14 show, the subjects came from various backgrounds and several countries.

6.10 Experiment Two Results

Time Era Sizes	Percentage of Subjects
Decreasing	3%
Equal	16%
Increasing	75%
Increasing & Decreasing	6%

Table 6.15: The Time Eras Sizes

Direction of Time Era Weights	Percentage of Subjects
Decreasing	64%
Equal	12%
Increasing	7%
Increasing & Decreasing	17%

Table 6.16: The Weight Given to the Time Eras

Most of the subjects (75%) gave increasing time era weights. As time progressed they grouped larger numbers of years together. A significant number (64%) also gave less weight to the future than to the present, although the weight they gave to the future was much large than that prescribed by constant discounting.

Question	Weight Given to 100 years (Percentage of Subjects)		
Would you give less, the same or more weight to year 100 if:	**Less**	**Same**	**More**
The project spans 100 years	19%	56%	25%
The project spans 2000 years	12%	71%	17%
Would you give less, the same or more weight to the future if the project has:	**Weight Given to the Future (Percentage of Subjects)**		
Negative outcomes in the future	1%	53%	46%
Positive outcomes in the future	8%	72%	20%
Positive outcomes now, negative in the future	22%	52%	26%

Table 6.17: How Time Era Weights Would Change

Not all the participants gave answers to the final sets of questions, so there are some that have less than seventy-six responses. The majority of subjects did not feel that changes in the project length or the outcomes would affect the weights that they gave to the future. The only exception was when there were negative outcomes in the future. In that case, about half the subjects felt that they would give more weight to the future. These results may be due to the assumptions that people made in their own minds about the type of project that was being considered in the original analysis. When the project was said to give good outcomes initially, and then bad ones, about half the subjects did not feel they would change their weights, while the other half were divided almost equally between those who would increase their weights and those who would decrease them.

Question	Yes	No
Would the outcomes of the project affect the weights you gave to the future?	32%	68%
Would the context of the problem affect the weights you gave to the future?	44%	56%

Table 6.18: The Effect of Project Changes on the Time Era Weights

Almost 70% of the subjects did not feel that the outcomes of the project would affect the weights that they gave to the future. Just over half of them thought that the context of the project would affect their weights. This may be because they felt that the context would determine the length of the project and its impacts.

Question	Weight Given to the Future		
	Less	Same	More
If the project involved nuclear waste how would your weights change?	4%	57%	39%

Table 6.19: Time Era Weight Changes for a Nuclear Project

Nearly 60% of the participants felt that they would give the same weight to the future if the project involved nuclear issues, while nearly 40% said they would give more weight to the future.

6.10.1 The Subjects' Motivations

Subjects were asked to explain what had motivated them to give the time eras and weights that they did. Their reasons seemed to fall into four categories:

- Affinity to the people living in different eras;
- Obligations to the future;
- Developments in technology;
- Increased uncertainty relating to future events.

Table 6.20 shows the number of participants giving each response.

Category	Percentage
Affinity	52%
Obligation	23%
Technology	9%
Uncertainty	16%

Table 6.20: What Motivated Subjects' Time Era Weights

Of those expressing an opinion over half said that their lives and the lives of their descendants were their main concern. Those motivated by their affinity to people, or their obligations to others, were making a kind of value judgement about their own importance and that of other people. Those stating technology and uncertainty as their motivations were basing their values on assumptions about how the future would be.

The results were grouped into the motivation categories and the time eras and their weights were analysed to determine if there were any similarities or differences between the groups. The data was analysed over the whole of the project's lifetime, then over the first hundred years, then beyond. The data was divided in this way as people seemed to have changed the way they valued the future after the first hundred years and also because, if they were motivated by the lives of their families and descendants, this would probably be a natural cut-off point.

Category	Size of Time Eras 0 - 1000 Years			
	Decreasing	Equal	Increasing	Increasing & Decreasing
Affinity	0	2	28	0
Obligation	0	4	9	0
Technology	1	1	2	1
Uncertainty	0	0	9	0

Table 6.21: The Time Era Sizes for 0 - 1000 Years

Category	Time Era Weights 0 - 1000 Years			
	Decreasing	Equal	Increasing	Increasing & Decreasing
Affinity	24	0	3	3
Obligation	5	7	0	1
Technology	4	0	0	1
Uncertainty	7	2	0	0

Table 6.22: The Time Era Weights for 0 - 1000 Years

Category	Size of Time Eras 0 - 100 Years			
	Decreasing	Equal	Increasing	Increasing & Decreasing
Affinity	0	6	24	0
Obligation	0	5	8	0
Technology	0	2	3	0
Uncertainty	0	1	8	0

Table 6.23: The Time Era Sizes for 0 - 100 Years

Category	Time Era Weights 0 - 100 Years			
	Decreasing	Equal	Increasing	Increasing & Decreasing
Affinity	20	6	2	2
Obligation	1	9	2	1
Technology	2	2	0	1
Uncertainty	7	2	0	0

Table 6.24: The Time Era Weights for 0 - 100 Years

Category	Size of Time Eras 100 Years Onwards			
	Decreasing	Equal	Increasing	Increasing & Decreasing
Affinity	0	4	25	1
Obligation	0	4	9	0
Technology	1	1	2	1
Uncertainty	0	0	9	0

Table 6.25: The Time Era Sizes for 100 Years Onwards

Category	Time Era Weights 100 Years Onwards			
	Decreasing	Equal	Increasing	Increasing & Decreasing
Affinity	24	2	3	1
Obligation	5	7	0	1
Technology	4	0	0	1
Uncertainty	7	2	0	0

Table 6.26: The Time Era Weights for 100 Years Onwards

To see if there was any correlation in the results the Fisher Freeman Halton test was performed on the data using StatXact 3 software by Cytel Software Corporation.

Time Eras	Exact p Value
0 - 1000 Years (Table 6.21)	0.0049
0 - 100 Years (Table 6.23)	0.3643
100 Years + (Table 6.25)	0.0452

Table 6.27: Exact Test Results on the Time Era Sizes

Time Era Weights	Exact p Value
0 - 1000 Years (Table 6.22)	0.0059
0 - 100 Years (Table 6.24)	0.0059
100 Years + (Table 6.26)	0.0146

Table 6.28: Exact Test Results on the Time Era Weights

Table 6.27 shows that there was no significant variation in the way the subjects in the different groups divided the first hundred years. However, the way in which they divided the subsequent years was different. More of the subjects divided the time into periods of increasing length. Looking over the whole lifetime of the project shows that there were notable differences between the groups. Most of the subjects divided time into periods of increasing length, but a larger proportion of the subjects who stated obligations to the future or technology changes as their motivations divided time into equal eras.

All of the time era weights of the groups are significantly different. A larger proportion of the subjects who believed that we have obligations to future generations gave equal weights to all the periods of the project. Most of the subjects in the other groups gave decreasing time era weights to the periods.

6.10.2 Modelling the Time Era Weights

The decreasing time era weights were fitted to exponential and hyperbolic discount functions to determine which function modelled the weights better. For the hyperbolic model the *temporal mid-value* was calculated for each subject by finding where their time era weights were half the value they gave to the present. Regression was used to compute the subjects' discount rates and fit an exponential curve to their weights. Sixteen of the subjects had weights that were better modelled by a hyperbolic function, twelve were closer to an exponential function and one fitted equally well with either function.

The average discount rate given by the subjects when their weights were fitted to an exponential curve was 0.21%, which is well below the 6% discount rate often used in Treasury planning. This discount rate gives far more weight to the long term future than is normally prescribed by an exponential discount function.

6.10.3 Differences in Age Groups

The data was divided into those under the age of thirty and those over thirty to investigate whether there were any differences in how the two age groups wanted to value the future, or what was motivating their thoughts about the future. Of those with decreasing time era weights there was no notable difference between either the average discount rate in the exponential model or the factors in the hyperbolic model. Appendix A6 shows the data divided into these age groups and the results of the exact p value tests.

6.11 Experiment Two Conclusions

World Wide Web experiments give researchers access to subjects of various ages and backgrounds from all around the world. The disadvantage is that they do not allow interaction between the subject and the researcher. Therefore, there is a greater risk of the subject misunderstanding the task they are completing, because there is no guidance from the researcher other than the instructions written on the Web page. The study may be biased, because the subjects are more technically minded than the general population in light of the fact that they use the Internet.

Despite these caveats the experiment provided some interesting results. Most of the subjects felt comfortable with the idea of dividing time into distinct eras and giving a weight to those eras. Nearly all of the feedback from the subjects was positive. In line with the hypothesis, 75% of the subjects divided time into eras of increasing length. The majority gave more weight to the long term future than is prescribed by constant discounting.

When the decreasing weights were modelled with an exponential function, the average discount rate was 0.21%, which is far less than the 5-6% often used in societal decisions. A hyperbolic function gave a better fit to the subject's time era weights than an exponential function. Both these findings show that the subjects wanted to give more weight to the long term future than is prescribed by an exponential discounting function.

There were several issues motivating the participants to give the time era weights that they did. The most prominent ones were their lives and the lives of their family. However, some subjects also felt that we have obligations to future generations and wanted to compensate, or at least take into account, their needs and concerns. Both of these views are value judgements and highlight what the participants felt was important. The other two motivations were uncertainty and technology. These subjects were basing the values they gave to the future on their assumptions about how the world would change.

There was no significant variation in how subjects of different ages valued the future, or what was motivating them to give their values. It seems that when people of different ages think about personal decisions they may value the future differently, although our subjects seemed to want to value the future similarly when thinking about a societal decision.

The methodology seemed to be instinctive to the subjects and they felt comfortable giving their opinions in the way required. The values they gave were also significantly different from those prescribed by exponential discounting. Structuring time in this way may encourage decision makers to focus on the trade-offs they have to make between time eras and the events that occur in them. Grouping years together helps to highlight the changes in the project that will occur over time. It could also move the debate away from the search for a discount rate and towards what is motivating people to think the way that they do. Research has shown that it is values that motivate people (Keeney, 1992 and French *et al*, 1992) and helping them to express these will encourage discussion and increase understanding. This is especially important when there are multiple stakeholders.

6.12 Climate Change Decision

The idea of using time eras was compared with traditional discounting in a sequential decision, looking at greenhouse gas abatement. The problem consisted of two decisions about which abatement policies to implement to decrease global warming. Many decisions are sequential and depend on making optimal choices at subsequent points in time, as new information becomes available. Thinking about decisions as sequences emphasises their long term impacts and the need to consider the effects on later choices.

The first decision runs from the year 2000 to 2010, the second from 2011 to 2050. It is assumed that any uncertainty surrounding the response of the climate system to the abatements is resolved before the second decision is made. The model used was created by Valverde *et al* (1998) and is based on data from Yang *et al* (1996). Although the decisions are taken in the year 2000 and 2010, the model needs to include data from the previous periods, so the lifetime of the project runs from 1985 to 2050. See Yang *et al* (1996) for a detailed explanation of the way that the model works. The project duration was divided into distinct eras defined by the timing of the decisions, as shown in Figure 6.6.

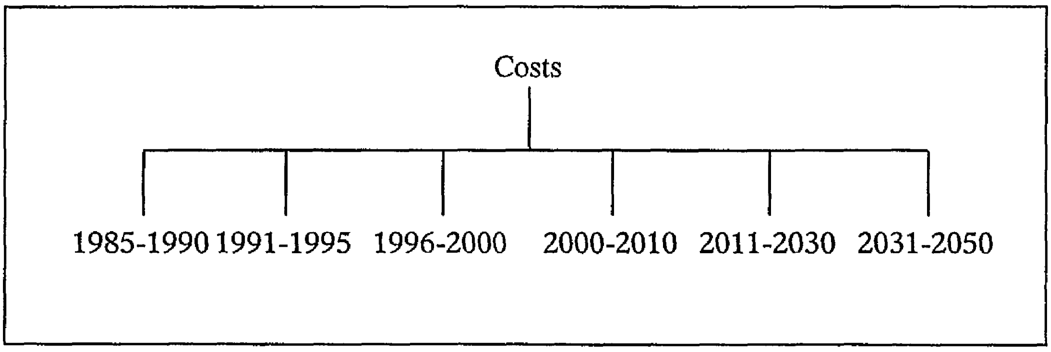


Figure 6.6: The Time Eras in the Climate Change Decision

Discount Method	Time					
	1987	1993	1998	2005	2020	2040
Constant 5%	0.907	0.711	0.530	0.377	0.181	0.068
Optimist	1	1	1	0.9	0.75	0.5
Impartialist	1	1	1	1	1	1
Precautionist	0.5	0.5	0.5	0.75	1	1

Table 6.29: The Different Weighting Schemes Applied in the Model

Several time era weights were used in the analysis and compared against the use of a 5% discount rate, Table 6.29 shows the weighting schemes used. Atherton and Valverde (1999) contains a detailed report of the analysis. The results showed that using the time era weights did not change the choice of abatement strategy and that the decision was very robust.

In this decision situation, costs from previous eras have to be taken into account. Discounting all costs back to 1985 may not be acceptable to the decision makers. Earlier costs, will in effect be sunk costs when the decision is made and discounting back to 1985 means giving very little weight to the present and short term future. In the constant discounting model, events in 1998 are only given a weight of 0.53, yet this is effectively the present and, as research has shown, is often viewed by decisions makers as the most important point in time. One of the reasons for using sequential decisions is to focus on the long term impacts of projects. However, combining this modelling technique with constant discounting seems to defeat the objective. When using a constant discount function, the periods in the model at which the decisions are taken are given very little weight, which seems hard to justify. Using the idea of time era weights would allow decision makers to value the past and the future in more logical ways and enable them to give more weight to the long term in accordance with the ideas of sequential decision making.

6.13 Summary

This chapter has shown that the time era weights model is appealing to decision makers and subjects. The World Wide Web experiments indicate that people often want to value the future differently to constant discounting and the factors they consider are not necessarily the economic arguments used to justify discounting. Subjects seemed to be motivated by four issues:

- Their affinity to people living in the future;
- Obligations to future generations;
- The development of technology to solve the problems we make;
- Changes in the uncertainty surrounding the decision.

The first two are value judgements while the others are based on assumptions about how the world will change over time. The subjects generally wanted to give more weight to the future than is prescribed by constant discounting, even with very low rates. Their discount functions were more compatible with Harvey's hyperbolic discounting model than with the constant discounting model. The rankings of the alternatives were also more in line with one another when using the time era model or the hyperbolic model.

The next chapter draws together the results of the experiments together with previous research in the area and discusses the implications for future decision analysis and research.

Chapter 7 Conclusions

7.1 The Process of Decision Analysis

Decision analysis is an iterative process of information gathering and development. Few decision makers start an analysis with a clear idea of the facts or how they feel about the situation they are facing. The overall aim of decision analysis is to develop the decision makers' understanding, both of themselves and their circumstances. It is important that decision makers view the process as iterative, otherwise they may not feel comfortable developing their ideas or searching for new views of the situation. Chapter 1 outlined what has come to be accepted as good practice and indicated ways in which decision makers can be helped to create alternatives and think carefully about their decision.

Often the most crucial stage of the analysis is the structuring of the decision. In the examples in Chapter 2 it was often the longest phase of the whole decision process. If completed successfully it can give enough insight into the situation that the decision makers do not need to perform any more analysis. If performed badly it can result in the analyst looking at the wrong problem and missing the most important issues facing the decision makers. It is essential to look at the big picture and investigate the impacts of the situation on people not involved in the analysis. This can often give more insights into the decision and may create more alternatives. Unless the analyst and decision makers are clear about the situation that is facing them there is scope for misunderstanding and difficulties later in the process.

Decision makers often come to the analysis knowing more about what options are available than what they want to achieve. As noted in Chapter 1, this limits their ability to develop innovative alternatives. Values are what people care about and it is important to use them as the driving force in decisions. Alternatives should be created to achieve the goals of the decision makers and should be evaluated with respect to what they feel is important. Focusing on decisions in this way will help decision makers to look beyond the situation they face and create solutions which actually achieve what they want to. These ideas follow Keeney's (1992) 'Value Focused Thinking', which focuses on what people want rather than what is available.

Observing and performing the analyses described in Chapter 2 gave the author the opportunity to learn from experienced analysts and encounter, first hand, the issues involved. This revealed several important points:

- People react differently to real and hypothetical decisions;
- Decision makers need to feel safe and comfortable if they are going to address sensitive issues;
- Structuring the decision is often the most important and time consuming part of the analysis;
- Long term decisions are more complicated, as their implications are often more substantial;
- Decision makers find it harder to give opinions when the decisions have long term implications;
- Judgements about lives and related issues are very difficult.

The first point highlights that it may not be possible to generalise from laboratory experiments to the real world and the difficulty of working with hypothetical situations. The decision makers in the hypothetical analyses were less committed to looking for a solution than those involved in the real decisions. This does not mean that hypothetical analyses are a waste of time: they can give valuable insight into how decision makers may act in real situations and provide the opportunity for experimentation and learning. The scenarios used in hypothetical decision situations need careful construction and must be realistic, see Simpson (1998). Subjects with decision making experience in the area of research should be used, so they are capable of performing the tasks.

The reactions of the decision makers in Chapter 2 varied depending on the complexity of the decision situation. In the hypothetical nuclear waste decision they were willing to provide technical, objective information, but were reluctant to give subjective opinions. The participants in the World Wide Web experiments gave their opinions willing, possibly because they enjoyed anonymity or felt they could make a contribution to the debate. If decision makers feel their involvement will benefit themselves or others they are more committed to the situation, see Armour (1996) and Harms (1996).

7.2 Biasing the Decision Makers' Opinions

Since decision makers rarely have clearly defined opinions when they start their analysis, it is very easy for analysts to bias their opinions. Decision analysts must become aware of the ways in which they can bias decision makers' opinions and techniques they can use to minimise these problems.

Normative theories outline the axioms people should conform to if they are to make rational decisions. However, they do not allow for people's feelings or misunderstandings. Chapter 5 showed that the normative axioms may not be applicable to all decision situations and should only be used when they are.

Descriptive theories highlight how decisions makers' opinions can break the normative axioms, how they can be biased and what can cause this to happen. There are parallels between how decision makers view time and probability, and the anomalies they exhibit. Chapter 3 outlined some of the descriptive research in this area. The main issues are:

- The frame that the decision makers are using;
- What information is presented to the decision makers;
- How questions are asked.

What the decision makers view as the status quo determines how they interpret the options presented to them. Chapter 3 discussed research which shows that people react differently to gains and losses. Unless the analyst understands the decision makers' reference points these differences may be seen as anomalies and not valid opinions.

Omitting information can bias decision makers' opinions, especially if only one view of an outcome is presented. It is important to present information in a neutral frame and to show both the good and bad outcomes. This allows the decision makers to focus on what they think is the most important information and not just what is presented. Changing the way information is measured may also help. For example, looking at changes in life expectancy and the probability of survival may help decision makers to understand the issues involved more clearly.

Different questions elicit different preference information. Recognising this will help analysts to distinguish between anomalies in decision makers' preferences and different data sets. Using choice instead of matching questions may help to decrease the number of anomalies people exhibit. If they are asked choice questions, decision makers may be less tempted to focus on only a few aspects of the information and not suffer from the Compatibility Effect, see Chapter 3.

Not all descriptive research can be generalised. Sometimes very small samples of unqualified subjects are used or the decision is badly defined. Caution must be exercised when interpreting some results and it should be remembered that there is a citation bias; negative results are more likely to be reported than research showing decision makers being rational.

Chapter 3 discussed ways in which the descriptive research on how views are biased can be combined with normative theories, via prescriptive analysis. By changing the way that preferences are elicited analysts can reduce the anomalies that occur. They can also help the decision makers to focus on all the aspects of the decision and not just the most prominent ones.

7.3 Difficulties with Long Term Decisions

Many of the difficulties inherent in short term decisions are magnified when the decision has long term consequences. Moving away from personal, short-term decisions introduces lots of complexities. Long term societal decisions include the problem of involving stakeholders in the decision process. Who the stakeholders are and how to include them in the analysis can be a decision problem in itself.

Intertemporal decisions are difficult because:

- Situations are dynamic;
- Decisions can span generations;
- Policies and people change;
- Equity is difficult to measure over time;
- People are biased towards the status quo;
- The present is often seen as more important than any other point in time;
- People find it hard to hypothesise about the future.

Analysts need to help decision makers imagine and take into account the long term impacts of their decisions. Decision makers often have very short sighted views of the future and are biased towards the present. The issues of information presentation and the questions posed play a vital role in decreasing the anomalies people exhibit, and the difficulty they have in taking the future into account.

7.4 Involving Stakeholders as Decision Makers

Once a decision has been made about which stakeholders to involve, there is the problem of working with them. Chapter 1 discussed research which suggests that first presenting the decision situation to all the stakeholders, and then working with them individually, helps to encourage them to think independently and air any extreme views. Decision conferencing techniques can then be used to discuss common ground and any serious differences in opinion. It is essential to focus on the values of the stakeholders, especially if the public are to be involved in the process. Concentrating on technical issues can alienate them and make them feel antagonistic towards the process.

The public are demanding more democratic decision making processes and it is important to find ways of involving them in the analysis. Using inclusive decision processes has helped to decrease the time needed to implement decisions in Canada, see Armour (1996). It may be more difficult to obtain that level of success in Britain, as the public have a lack of trust in the government. The public need to feel that they are actively involved in the process and have power to influence the decision. The government or regulatory body must be a stakeholder in the decision, and not the decision owner, or the process will seem biased and the other stakeholders will feel they have limited power.

7.5 Valuing the Future

Chapter 5 discussed some of the arguments that have been used to justify the use of a constant discount rate for all goods over all the time periods of a decision. It highlighted when the assumptions underpinning these ideas may not be valid. In decisions with very long time frames using even a small constant discount rate, effectively disregards the long term future. This may not be acceptable to the public or those impacted by the decisions. This is especially the case when the decision spans thousands of years.

Arguments against non-constant discount rates often focus on efficiency issues and the problem of dynamic consistency. Chapter 5 showed that using a non-constant discount rate can still lead to efficient decisions and highlighted when dynamic consistency is not a requirement of rationality. If decisions will not to be reviewed in the future or are in some way binding, then dynamic consistency is not essential and so a non-constant discount rate can be used.

Research has shown that people do not always have constant discount rates and that their discount functions are closer to hyperbolic curves than exponential ones (See Section 5.3). It is important to model decision makers' preferences and not force them into using a model that does not represent how they feel. Models should be used because of their descriptive validity and not their perceived rationality.

7.6 An Alternative Way of Modelling the Future

7.6.1 Including Time in Attribute Trees

Chapter 4 showed how the structure of an attribute tree affects the weights that are given to the attributes. It discussed ways in which the weights that attributes receive can be biased. In intertemporal decisions what is important or what is measurable may change over time and this needs to be encapsulated in the attribute tree. For example, construction accidents occur while building a facility, but operating accidents happen once it is being used. Even if the attributes do not change over time, their relative weights, or the scores the alternatives achieve on them, may. The model should capture all of these things.

By including time explicitly in the attribute tree it is possible to:

- Allow attributes to change over time;
- Change the scores alternatives achieve on the attributes;
- Vary the relative weights of the attributes;
- Allow the uncertainty surrounding the attributes to change;

This in turn may help decision makers to:

- Understand their situation better;
- Express their opinions;
- Highlight the trade-offs that have to be made over time;
- Focus attention on the long term aspects of a decision.

One of the main aims of attribute trees is to increase the decision makers' understanding of their situation. This can only be achieved if the tree includes all the information available and if the attributes are assigned to the eras they occur in. Including time explicitly in the tree will aid cognition and will make the important issues more prominent and easier to comprehend.

7.6.2 Dividing Time into Distinct Eras

Standard discounting models divide time into equal, usually year long, intervals and apply a discount rate that decreases on a yearly basis. Instead of dividing time in this way, Chapter 6 suggested using time eras of possibly unequal length. These could be defined because of:

- Changes in the decision makers' affinity to people or situations;
- Attribute changes;
- Changes in the probability of the scenarios;
- Changes in the decision situation.

Decision makers would give a weight to the eras instead of a discount rate for the whole project. More weight could be given to the future if decision makers wanted to compensate future generations for any problems they might inherit. The weights they give do not have to decrease uniformly over time, as is the case with other discount functions, and decision makers could give equal weights to all the periods if they so wished.

Focusing on the weight given to different eras may help multiple decision makers discuss what is important to them and the time trade-offs they have to make. Standard discounting functions concentrate on one discount rate and the process can become very heated as stakeholders argue about the appropriate rate and not what is important to them. Making the time trade-offs explicit might help to defuse this situation.

7.7 Applications of Time Era Weights

The ideas of including time in the attribute tree and weighting time periods, instead of applying a discount rate, have been investigated via several experiments, as reported in Chapter 6. The results showed that the subjects found the ideas intuitive and that they helped them to understand the decision and their opinions better.

Although the World Wide Web experiments were uncontrolled, and therefore the results are difficult to generalise, they did give some interesting insights into people's opinions. Several issues seemed to be motivating the subjects:

- Their affinity to future generations;
- Obligations to future generations;
- Advances in technology;
- Changes in the uncertainty surrounding the outcomes.

The first two issues are value judgements, while the others are based on assumptions about the future. Using time eras helped subjects to express these concerns and may enable real decision makers to discuss these and other issues and reach a consensus.

The research in Chapter 6 showed that time era weights are at least as intuitive a way of valuing the future as discount rates. The subjects wanted to give more weight to the long term future than is prescribed by exponential discounting. This suggests that the idea of time era weights may help decision makers to focus on the long term issues and trade-offs in a decision. In some of the experiments the choices made were radically different to those using exponential discounting and showed just how biased towards the short term these models can be.

7.8 Implications for Decision Analysis

It is important for analysts to use decision models because they capture the decision makers' opinions, rather than because of their mathematical validity. This may mean moving away from traditional discounting models to enable decision makers to give more weight to the long term future.

The public are demanding more inclusive decision making processes which involve them and take their opinions into account. This highlights the need to find more democratic decision making techniques. It is important to find ways of discussing the complicated issues involved in a decision analysis without becoming too technical and therefore excluding some stakeholders. The use of time eras and time era weights may provide a way of helping decision makers discuss the time trade-offs they have to make. The methodology makes the trade-offs explicit and enables decision makers to see which parts of the decision change over time. Instead of focusing on the search for a discount rate it allows decision makers to discuss what is motivating their opinions and search for common understanding.

When working with stakeholders, using a mixture of group and individual meetings, will help them to express their opinions and come to a shared understanding of the problem. It is essential in societal decisions to remember the importance of individual opinions and perspectives of a situation and to work towards capturing these whilst decreasing conflict and misunderstanding.

Societal decisions often have long term impacts; those involving nuclear waste or the environment can have repercussions over hundreds of thousands of years. Decision makers need to consider all the impacts of their decision. However, using a constant discount rate disregards the long term future, giving virtually no importance to events that occur after the first fifty years. This does not seem reasonable and Chapter 5 argued why we should take the long term future into account. The public are becoming more environmentally aware and more concerned than ever before about the long term impacts of decisions. The participants in the experiments reported in Chapter 6 wanted to give far more weight to the long term future than is advocated by a constant discount rate. Using time eras may provide a way of doing this.

The concept of time era weights has two potential applications. The weights elicited from the decision makers could be fitted to one of the discount functions described in Section 5.3, and used to value the future in the model. Initially, time era weights would help the decision makers express their opinions and consider the trade-offs they have to make, before searching for a specific discount function. The discount function would be selected because of its descriptive validity and match the decision makers' opinions most accurately.

Another alternative is to use time era weights instead of a discount function. In this case the weights given to periods in the model would match the decision makers' opinions exactly. Unlike other value functions, time era weights do not restrict decision makers to placing less importance on the future than the present. Time eras could be assigned equal, increasing or decreasing weights, as desired.

These two uses of time era weights emphasise their flexibility and use as a discussion motivator and/or modelling tool. Both uses will help with the structuring and modelling of long term decisions.

7.9 Future Research

Despite the developments in OR modelling (Soft Systems, Cognitive Mapping, Strategic Choice, Hypergames, see Rosenhead, 1989) and the work on attribute tree modelling (Keeney, 1992 and Belton *et al*, 1997) there is little research and advice on modelling long term decision problems. In particular, only a small amount of work has been done on the issue of involving stakeholder groups. Investigating how decision makers can be helped to structure the decisions they face will help them to make better, more informed decisions. Chapter 1 shows clearly that it is beneficial to concentrate on what decision makers care about, that is, their values, in line with Keeney's 'Value Focused Thinking'. At all levels of the process it should be values that drive the analysis and decision makers should be encouraged to think about what they want to achieve.

Additional research needs to be carried out into 'democratic' decision making and stakeholder involvement. The public are demanding increased accountability from the government and increased involvement in the decisions that affect them. One way of achieving this is to make decision processes more transparent and inclusive. It is no longer sufficient to consult the public they need to be involved as decision makers if policies are to be implemented smoothly and with public acceptance. In Britain there is already a high level of mistrust between the public and government organisations removing this will require time and effort, but involving local communities in decisions that affect them will be a positive start. All these points have been noted by the Parliamentary Office of Science and Technology (1997), who have been investigating how societal decision making can be improved.

The World Wide Web is becoming increasingly accessible. In the experiments reported in Chapter 6 it gave access to a variety of subjects of different ages from all over the world. This medium may become a useful way of testing tentative hypotheses easily and cheaply before spending money on laboratory experiments. The cost of setting up a World Wide Web experiment in an academic department is very small, and subjects can be obtained by advertising the page on related or interested news groups.

It is difficult to regulate Web based experiments, and the analyst has no contact with the subjects except via the instructions on the Web site. This makes the design of the Web pages crucial to the success of the experiment. As it may not be possible to control the sample of subjects completing the experiment, it may be difficult to generalise the results obtained, as they may be biased. However, the results may give insights into laboratory experiments that should be conducted, or refine a hypothesis.

More work should be undertaken to bridge the gaps between normative and descriptive theories of decision analysis. Descriptive theories are concerned with how decision makers' opinions can be biased and the issues that affect their opinions. These results need to be fed back into decision analysis and used to modify elicitation processes. This will help decision makers to make more rational decisions and will guide them towards the normative ideals. Prescriptive analysis already tries to bridge the gap between the other two schools, but it is important to tailor decision models and the elicitation process to the situation being faced and only use normative models if they are descriptively appropriate.

Further experiments need to be carried out to investigate the acceptability of time eras to the general public. The subjects in the World Wide Web experiments could be considered more technically minded than the general public, simply because of their familiarity with the Internet. Introducing the ideas to public interest groups and investigating their views could be a useful next step.

References

M. Ahlbrecht, J. Ehrhardt and S. French (1995), 'Designing the Evaluation Module in RODOS/RESY: Execution and Analysis of Elicitation Exercises with Emergency Management Teams', *Internal Report*, School of Computer Science, University of Leeds.

M. Ahlbrecht and M. Weber (1995a), 'An Empirical Study on Intertemporal Choice Under Risk', *Working Paper*, University of Mannheim.

M. Ahlbrecht and M. Weber (1995b), 'Hyperbolic Discount Models in Prescriptive Theories of Intertemporal Choice', *Zeitschrift fur Wirtschafts - Sozialwissenschaften*, **115**, 535-568.

G. Ainslie (1975), 'Specious Reward: A Behavioural Theory of Impulsiveness and Impulse Control', *Psychological Bulletin,* **82**, 463-509.

G. Ainslie (1985), 'Beyond Microeconomics. Conflict Among Interests in a Multiple Self as a Determinant of Value', in *The Multiple Self*, 133-175, Edited by J. Elster, Cambridge University Press, Cambridge.

Analytica (1998), Roderick Manhattan Group Ltd., Manhattan House, Disraeli Road, London.

A. Armour (1996), 'Modernizing Democratic Decision-Making Processes From Conflict to Co-operation in Facility Siting', *The Environment in the 21st Century: Environment, Long-term Governance and Democracy*, Abbey de Fontevraud, France, Sept. 8-11.

E. Atherton and S. French (1997), 'Issues in Supporting Intertemporal Choice', in *Essays in Decision Making*, 135-156, Edited by M. Karwan, J. Spronk and J. Wallenius, Springer-Verlag, Berlin.

E. Atherton and S. French (1998), 'Valuing the Future: A MADA Example Involving Nuclear Waste Storage', *Journal of Multi-Criteria Decision Analysis*, 7(6), 304-321.

E. Atherton and J. Valverde (1999), 'Valuing the Future in Environmental Decision-Making: Implications for the Greenhouse Debate', *LSE Working Paper*, London School of Economics.

A. Baier (1984), 'For the Sake of Future Generations', in *Earthbound: Introductory Essays in Environmental Ethics*, 214-246, Edited by T. Regan, Waveland Press Inc., Prospect Heights, Illinois.

C. Banville, C. Boulaire, M. Landry and J. Martel (1997), 'A Stakeholder Appraoch to Multi-Criteria Decision Analysis', *13th International Conference on Multicriteria Decision Making*, Cape Town, South Africa, Jan. 6-10.

I. Bateman (1989), 'The Modified Discounting Method: Some Comments', *Project Appraisal*, 4(3), 104-106.

L. Beach, V. Barnes and J. Christensen-Szalanski (1987), 'Assessing Human Judgement: Has it been Done, Can it be Done, Should it be Done?', in *Judgmental Forecasting*, 49-62, Edited by G. Wright and P Ayton, John Wiley and Sons Ltd., Chichester.

D. Bell, H. Raiffa and A. Tversky (1988), *Decision Making: Descriptive, Normative and Prescriptive Interactions*, Cambridge University Press, Cambridge.

W. Bellinger (1991), 'Incorporating the Future Multigenerational Value: Modifying the Modified Discounting Method', *Project Appraisal*, 6(2), 101-108.

V. Belton, F. Ackermann and I. Shepherd (1997), 'Integrated Support for Problem Structuring Through to Alternative Evaluation Using COPE and V.I.S.A.', *Journal of Multi-Criteria Decision Analysis*, 6(3), 115-130.

U. Benzion, A. Rapport and J. Yagil (1989), 'Discount Rates Inferred from Decisions: An Experimental Study', *Management Science*, 35(3), 270-284.

R. Bickner (1980), 'Pitfalls in the Analysis of Costs', *Pitfalls of Analysis*, 57-69, Edited by G. Majone and E. Quade, Wiley, Chichester.

L. Boiney and L. Maguire (1994), 'Resolving Environmental Disputes: A Framework Incorporating Decision Analysis and Dispute Resolution Techniques', *Journal of Environmental Management*, **42**, 31-48.

K. Borcherding and M. Weber (1993), 'Behavioural Influences on Weight Judgements in Multi-attribute Decision Making', *European Journal of the Operational Research Society*, **67**, 1-12.

J. Broome (1994), 'Discounting the Future', *Philosophy and Public Affairs*, **20**, 128-156.

M. Brown, G. Pitz and N. Sachs (1980), 'Eliciting a Formal Problem Structure for Individual Decision Analysis', *Technical Report, Applied Experimental Psychology*, Southern Illinois University, Carbondale, **2**(2).

S. Brownlow and S. Watson (1987), 'Structuring Multi-attribute Value Hierarchies', *Journal of the Operational Research Society*, **38**(4), 309-317.

C. Brugha (1997), 'Differentiating Attributes of Decision Alternatives from Criteria of Decision Makers in Multicriteria Decision Making', *Working Paper*, Department of Management Information Systems, University College Dublin.

D. Buede (1986), 'Structuring Value Attributes', *Interfaces*, **16**(2), 52-62.

J. Casey, C. Gettys, C. Manning and R. Pliske (1987), 'An Evaluation of Human Act Generation Performance', *Organizational Behaviour and Human Decision Processes*, **39**, 23-51.

G. Chapman and A. Elstein (1995), 'Valuing the Future: Temporal Discounting of Health and Money', *Medical Decision Making*, **15**(4), 373-386.

R. Cooke (1991), *Experts and Uncertainty: Opinion and Subjective Probability in Science*, Oxford University Press, Oxford.

R. Cooke (1995), *UNICORN: Methods and Code for Uncertainty Analysis*, Delft University of Technology.

R. Cooke and R. Waij (1986), 'Monte Carlo Sampling for Generalized Knowledge Dependence With Application to Human Reliability', *Risk Analysis*, **6**(3), 335-343.

J. Creighton (1986), 'Final Keynote Address', in *Public Involvement: The Critical Path in Siting Controversial Facilities*, Washington DC: U.S. Department of Energy: 98.

M. Cropper and P. Portney (1990), 'Discounting in the Evaluation of Lifesaving Programs', *Journal of Risk and Uncertainty*, **3**, 369-379.

H. Dyckhoff (1988), 'Zeitpräferenz', *Zeitschrift für Betriebswirtschaftliche Forschung*, **40**, 989-1008.

W. Edwards and D. von Winterfeldt (1986), *Decision Analysis and Behavioural Research*, Cambridge University Press, Cambridge.

F. Eisenführ, M. Weber and D. Von Winderfeldt (1988), 'The Effects of Splitting Attributes on Weight in Multi-Attribute Utility Measurement', *Management Science*, **34**(4), 431-445.

B. Fischhoff, S. Lichtenstein and P. Slovic (1978a), 'Accident Probabilities and Seat Belt Usage: A Psychological Perspective', *Accident Analysis and Prevention*, **10**, 281-285.

B. Fischhoff, S. Lichtenstein and P. Slovic (1978b), 'Fault Trees: Sensitivity of Estimated Failure Probabilities to Problem Representation', *Journal of Experimental Psychology: Human Perception and Performance,* 4(2), 330-344.

P. Fishburn (1984), 'Equity Axioms for Public Risks', *Operations Research,* **32**(4), 901-908.

T. Freeman (1988), *Disposal of Radioactive Waste in Seabed Sediments*, Graham and Trotman Ltd., London.

S. French (1986), *Decision Theory: An Introduction to the Mathematics of Rationality*, Ellis Horwood, Chichester.

S. French (1992), 'The Role of Sensitivity Analysis in Decision Analysis', in *Executive Information Systems and Group Decision Support*, 99-123, Edited by C. Holtham, Chapman and Hall, London.

S. French (1996), 'The Framing of Statistical Decision Theory: A Decision Analytic View', in *Bayesian Statistics 5: Proceedings of the Fifth Valencia International Meeting on Bayesian Statistics*, 147-164, Edited by J. Berger, J. Bernardo, A. David and A. Smith, Oxford University Press, London.

S. French, J. Ehrhardt, J Lochard, J. Morrey, M. Sinnko and A. Sohier (1999), 'What Sort of Support is Needed in Nuclear Emergency Management?', *5th International Conference of the Decision Sciences Institute,* Athens, Greece.

S. French, E. Hall and D. Ranyard (1995), 'Equity and MCDA in the Event of a Nuclear Accident', School of Computer Studies, University of Leeds, RODOS(B)-RP(95)-04.

S. French, M. Harrison and D. Ranyard (1997), 'Event Conditional Attribute Modelling in Decision Making When There is a Threat of a Nuclear Accident', in *The Practice of Bayesian Analysis*, 131-150, Edited by S. French and J. Smith, Arnold, London.

S. French, N. Kelly and M. Morrey (1992), 'Towards a Shared Understanding - How Decision Conferencing Helped Structure Decision Problems in the International Chernobyl Project', *O.R. Insight*, 5(4), 23-27.

S. French, L. Simpson, E. Atherton, V. Belton, R. Dawes, W. Edwards, R. Hämäläinen, O. Larichev, F. Lootsma, A. Pearman and C. Vlek (1998), 'Problem Formulation for Multi-Criteria Decision Analysis: Report of a Workshop', *Journal of Multi-Criteria Decision Analysis*, 7(5), 242-262.

T. Ganiats (1994), 'Discounting in Cost Effectiveness Research', *Medical Decision Making*, 14(3), 298-300.

D. Getches (1996), 'Watershed Governance: Natural Boundaries for Natural Resources Decision Making', *The Environment in the 21st Century: Environment, Long-term Governance and Democracy,* Abbey de Fontevraud, France, Sept. 8-11.

M. Golding (1972), 'Obligations to Future Generations', *Monist*, **56**, 97-98.

R. Goodin (1978), 'Uncertainty as an Excuse for Cheating our Children: The Case of Nuclear Waste', *Policy Sciences*, **10**, 25-43.

R. Goodin (1982), 'Discounting Discounting', *Journal of Public Policy*, **2**(1), 53-72.

D. Griffin, P. Slovic and A. Tversky (1990), 'Compatibility Effect in Judgement and Choice', in *Insights in Decision Making*, 5-27, Edited by R. Hogarth, University of Chicago Press, Chicago.

C. Handy (1993), *Understanding Organizations*, Oxford University Press, New York.

H. Harms (1996), 'Citizen Participation - A Response to the Crisis of Representative Democracy', *The Environment in the 21st Century: Environment, Long-term Governance and Democracy,* Abbey de Fontevraud, France, Sept. 8-11.

C. Harvey (1986), 'Value Functions for Infinite Period Planning', *Management Science*, **32**(9), 1123-1139.

C. Harvey (1992), 'A Slow Discounting Model for Energy Conservation', *Interfaces*, 22(6), 47-60.

C. Harvey (1995), 'Proportional Discounting of Future Costs and Benefits', *Mathematics of Operational Research*, **20**(2), 381-399.

L. Hausmann, H. Jungermann and I. von Ulardt (1983), 'The Role of the Goal for Generating Actions', in *Advances in Psychology: Analyzing and Aiding Decision Processes*, 223-236, Edited by P. Humphreys, O. Svenson and A. Vari, New York Press, North-Holland.

J. Heerboth, G. Pitz and N. Sachs (1980), 'Procedures for Eliciting Choices in the Analysis of Individual Decisions', *Organizational Behaviour and Human Performance*, **26**, 396-408.

C. Hitch and R. McKean (1960), *The Economics of Defence in the Nuclear Age*, Harvard University Press, Cambridge.

J. Ho and L. Keller (1988), 'Decision Problem Structuring: Generating Options', *IEEE Transactions on Systems, Man, and Cybernetics*, **18**(5), 715-728.

J. Horowitz (1988), 'Discounting Money Payoffs: An Experimental Analysis', *Working Paper*, Department of Agriculture and Resource Economics, University of Maryland.

D. Isenberg (1986), 'Thinking and Managing: A Verbal Protocol Analysis of Managerial Problem Solving', *Academy of Management Journal*, **29**, 775-788.

D. Kahneman, J. Knetsch and R. Thaler (1991), 'The Endowment Effect, Loss Aversion, and the Status Quo Bias', *Journal of Economic Perspectives,* **5**(1), 193-206.

D. Kahneman and A. Tversky (1981), 'The Framing of Decisions and the Psychology of Choice', *Science*, **211**, 453-458.

D. Kahneman and A. Tversky (1984), 'Choice, Values, and Frames', *American Psychologist*, **39**(4), 341-350.

D. Kahneman and A. Tversky (1991), 'Loss Aversion in Riskless Choice: A Reference-Dependent Model', *Quarterly Journal of Economics*, **106**, 1039-1061.

G. Kavka (1978), 'The Futurity Problem', in *Obligations to Future Generations*, 186-203, Edited by B. Barry and R. Sikora, Temple University Press, Philadelphia.

E. Keeler and S. Cretin (1983), 'Discounting of Life-Saving and Other Non Monetary Effects', *Management Science*, **29**(3), 300-306.

R. Keeney (1986), 'Creating Alternatives Using Value-Focused Thinking', *Decision Analysis Series Working Paper*, University of Southern California, Systems Science Department, Institute of Safety and Systems Management, Los Angeles, CA.

R. Keeney (1988), 'Structuring Objectives for Problems of Public Interest', *Operations Research*, **36**, 396-405.

R. Keeney (1992), *Value Focused Thinking*, Harvard University Press, Harvard.

R. Keeney and M. Merkhofer (1987), 'A Multiattribute Utility Analysis for the Disposal of Nuclear Waste', *Risk Analysis*, 7(2), 173-194.

R. Keeney and H. Raiffa (1976), *Decisions with Multiple Objectives: Preferences and Value Trade-offs*, John Wiley and Sons Ltd., New York.

R. Keeney and D. von Winterfeldt (1994), 'Managing Nuclear Waste from Power Plants', *Risk Analysis*, **14**(1), 107-130.

R. Keeney and R. Winkler (1985), 'Evaluating Decision Strategies for Equity of Public Risks', *Operations Research*, 33(5), 955-970.

J. Knetsch (1989), 'The Endowment Effect and Evidence of Nonreversible Indifference Curves', *The American Economic Review*, **79**(5), 1277-1284.

J. Kornbluth (1992), 'Dynamic MCDM', *Journal of Multi-Criteria Decision Analysis*, **1**, 81-92.

D. Krantz, R. Lucs, P. Suppes and A. Tversky (1971), *Foundations of Measurement*, Academic Press, New York and London.

E. Kula (1981), 'Future Generations and Discounting Rules in Public Sector Project Appraisal', *Environment and Planning A*, **13**, 899-910.

E. Kula (1984), 'Discount Factors for Public Sector Investment Projects Using the Sum of Discounted Consumption Flows - Estimates for the United Kingdom', *Environment and Planning A*, **16**, 689-694.

E. Kula (1987), 'Social Interest Rate for Public Sector Appraisal in the United Kingdom, the United States and Canada', *Project Appraisal*, **2**(3), 169-174.

E. Kula (1997), *Time Discounting and Future Generations*, Quorum Books, Westport, Connecticut.

R. Layard (1972), *Cost Benefit Analysis*, Penguin Books, Harmondsworth.

C. Lefaure (1995), 'Monetary Values of the Man-Sievert: International Perspective', *Risk and Prevention*, **15**, 1-3.

G. Loewenstein (1987), 'Anticipation and Valuation of Delayed Consumption', *The Economic Journal*, **97**, 666-684.

G. Loewenstein (1988), 'Frames of Mind in Intertemporal Choice', *Management Science*, **34**, 200-214.

G. Loewenstein and D. Adler (1995), 'A Bias in the Prediction of Tastes', *The Economic Journal*, **105**, 929-937.

G. Loewenstein and D. Prelec (1992), 'Anomalies in Intertemporal Choice: Evidence and an Interpretation', *Quarterly Journal of Economics*, **107**(2), 573-597.

G. Loewenstein and D. Prelec (1993), 'Preferences for Sequences of Outcomes', *Psychological Review*, **100**(1), 91-108.

B. McNeil, S. Pauker, H. Sox and A. Tversky (1986), 'On Elicitation of Preferences for Alternative Therapies', in *Judgement and Decision Making,* 386-393, Edited by H. Arkes and K. Hammond, Cambridge University Press, Cambridge.

R. Meyer (1976), 'Preferences Over Time', in *Decisions With Multiple Objectives: Preferences and Value Tradeoffs*, 473-514, Edited by R. Keeney and H. Raiffa, John Wiley and Sons Ltd., New York.

E. Mishan (1967), 'Criteria for Public Investment: Some Simplifying Suggestions', *Journal of Political Economy*, 75, 139-145.

G. Moore (1971), *Principia Ethica*, 152-154, Cambridge University Press, Cambridge.

A. Nicholas (1969), 'On the Social Rate of Discount: Comment', *American Economic Review*, **59**, 909-911.

P. Nijkamp, H. Schaffers and J. Spronk (1989), 'Multiple Futures and Multiple Discount Rates in Multiple Criteria Analysis', *Project Appraisal*, **4**(1), 2-8.

NRPB (1989), *Living With Radiation*, HMSO Publications, London.

A. Okun (1975), *Equality and Efficiency*, Brookings Institution, Washington DC.

D. Parfit (1981),'An Attack on the Social Discount Rate', *QQ - Report from the Centre for Philosophy and Public Policy*, University of Maryland, 1, 8-11.

The Parliamentary Office of Science and Technology (1997), *Radioactive Waste – Where Next?*

J. Passmore (1974), *Mans Responsibility for Nature*, Duckworth, London.

L. Phillips (1982), 'Requisite Decision Modelling: A Case Study', *Journal of the Operational Research Society*, 33, 303-311.

L. Phillips (1984), 'A Theory of Requisite Decision Models', *Acta Psychologica*, 56, 29-48.

M. Pöyhönen and R. Hämäläinen (1996), 'Notes on the Weighting Bias in Value Trees', *Research Report A63*, Helsinki University of Technology, Systems Analysis Laboratory.

D. Prelec and G. Loewenstein (1991), 'Decision Making Over Time and Under Uncertainty: A Common Approach', *Management Science*, 37(7), 770-786.

C. Price (1989), 'Equity, Consistency, Efficiency and New Rules for Discounting', *Project Appraisal*, 4(3), 58-65.

H. Rachlin and A. Raineri (1992), 'Irrationality and Selfishness as Discount Reversal Effects', in *Choice Over Time*, 116-138, Edited by J. Elster and G. Loewenstein, Russell Sage Foundation, New York.

F. Roberts (1979), *Measurement Theory*, Addison Wesley, Reading, Massachusetts.

J. Rosenhead (1989), *Rational Analysis for a Problematic World*, John Wiley and Sons Ltd., Chichester.

R. Routley and V. Routley (1982), 'Nuclear Power - Some Ethical and Social Dimensions', in *And Justice For All: New Introductory Essays in Ethics and Public Policy*, 116-138, Edited by T. Regan and D. Van DeVeer, Rowman and Littlefield, Totowa, New Jersey.

R. Sarin (1985), 'Measuring Equity in Public Risk', *Operations Research*, 33(1), 210-217.

T. Schelling (1995), 'Intergenerational Discounting', *Energy Policy*, 23(4/5), 395-401.

G. Schieber and J. Poullier (1989), 'International Health Care Expenditure Trends', *Health Affairs*, 8, 169-177.

L. Simpson (1998), 'Supporting Decision Analysis: A Pragmatic Approach', *PhD Thesis*, School of Computer Studies, University of Leeds.

J. Smart (1973), 'An Outline of a System of Utilitarian Ethics', in *Utilitarianism: For and Against*, 3-74, Edited by J. Smart and B. Williams, Cambridge University Press, Cambridge.

A. Stirling (1996), 'On the Nirex MADA: Proof', *in Radioactive Waste Disposal at Sellafield, UK*, 93-108, Edited by R. Haszeldine and D. Smythe, University of Glasgow.

L. Temkin (1992), 'Intergenerational Inequality', in *Justice Between Age Groups and Generations*, 99-121, Edited by P. Laslett and J. Fishkin, Yale University Press, New Haven.

R. Thaler (1981), 'Some Empirical Evidence on Dynamic Inconsistency', *Economic Letters*, 8, 201-207.

K. Thomson (1988), 'Future Generations: The Modified Discounting Method - A Reply', *Project Appraisal*, 3(3), 171-172.

J. Valverde, H. Jacoby and G. Kaufman (1998), 'Sequential Climate Change Decisions Under Uncertainty: An Integrated Framework', *LSE Working Paper Series LSEOR 98.24*, OR Department, London School of Economics.

W. Viscusi (1994), 'Risk-Risk Analysis', *Journal of Risk and Uncertainty*, 8, 5-17.

M. Williams (1978), 'Discounting Versus Maximum Sustainable Yield', in *Obligations to Future Generations*, 169-185, Edited by B. Barry and R. Sikora, Temple University Press, Philadelphia.

M. Yaffey (1997), 'Modified Discount Model Revisited', *Project Appraisal*, 12(2), 79-88.

Z. Yang, R. Eckaus, A. Ellerman and H. Jacoby (1996), 'The MIT Emissions Prediction and Policy Analysis Model', *Technical Report 6*, MIT Joint Program on the Science and Policy of Global Climate Change, MIT.

Appendix A1 Axioms for Decision Analysis

This appendix is included for completeness it contains the axioms for the decision model underlying the generic structuring. The axioms used in the other discounting models discussed in the thesis, for example in Harvey's proportional discounting model, are also presented. For a detailed explanation of decision axioms see French (1986).

A1.1 Multiple Attributes

In multiattribute decision analysis the decision maker is often dealing with many different and often conflicting attributes. The decision maker's preferences over these attributes must comply to the conditions outlined in French (1986) and also to the conditions set out in the following sections.

A1.1.1 Continuity

$$\text{For } a,b,c \in X \text{ if } a > b > c \text{ then } \exists\lambda \text{ s.t. } 0 < \lambda < 1 \quad \& \quad \lambda a + (1-\lambda)c \sim b$$

This is assured if X is finite. As λ varies between 0 and 1 the point λa + $(1-\lambda)c$ creates the straight line between a and c. If $a > b > c$ then it should always be possible to find a point on the line ac that is indifferent to b. That is that the indifference curve for b should intersect the line ac, see Figure A1.1. The axiom is a solvability condition on the alternatives. Roberts (1979) gives a more detailed proof of the axiom.

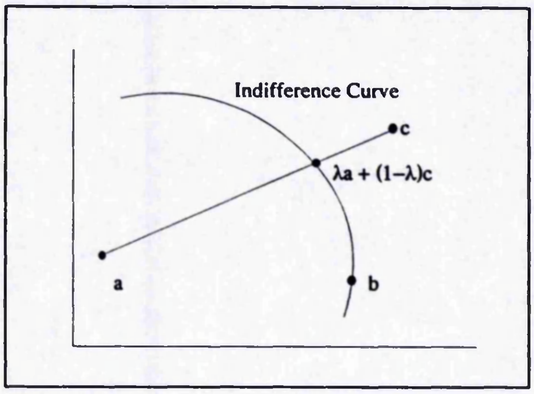


Figure A1.1: Continuity Diagram

A1.1.2 Essentiality

The attributes included in the analysis are essential to the decision making process. If an attribute was not essential to the decision process then there would be no reason for analysing it. Its inclusion in the model would not help the decision maker to decide which alternative to choose and would only result in the decision being more complex than it needed to be.

A1.1.3 Preferential Independence

Attribute X is preferentially independent of attribute Y iff

$$\forall x, x' \in X$$
$$(x,\alpha) \geq (x',\alpha) \text{ for some } \alpha \in Y\ Y$$
$$\Rightarrow \quad (x,\beta) \geq (x',\beta) \text{ for some } \beta \in Y$$

Similarly for Y

$$\forall y, y' \in X$$
$$(\alpha, y) \geq (\alpha, y') \text{ for some } \alpha \in X$$
$$\Rightarrow \quad (\beta, y) \geq (\beta, y') \text{ for some } \beta \in X$$

This means that the preferences over X do not depend on the level of Y if it is the same in both outcomes. It is difficult to think of a situation when this would not be true. It is unlikely that if more X is preferred to less at a low level of Y that less X would be preferred to more at a higher level of Y. If this was not true the attributes would depend on each other and would be very difficult to evaluate. In this case it would be better to redefine the attributes to ensure independence.

The axiom also says that the decision maker should be able to focus her attention on the aspects of the alternatives which differentiate them from one another and ignore any similarities. In this way the decision maker would be able to focus on the important aspects of an alternative, which would help the decision process. (See Edwards and von Winterfeldt (1986) for a graphical explanation)

If there is preferential independence it is possible to define **Marginal Partial Orders** over the individual attributes:

$$\text{eg.} \quad \geq_x \text{ over } X \Rightarrow x \geq_x x' \Leftrightarrow (x,\alpha) \geq (x',\alpha) \alpha \in Y$$

A1.1.4 Strength of Preference Independence

$$\forall x, x' \in X \text{ and } \forall y, y' \in Y$$
$$(x,y) \rightarrow (x',y) \sim (x,y') \rightarrow (x',y')$$

This defines similar ideas to preferential independence, but with strengths of preference. For the same reasons outlined above it is beneficial that the strength of preference on one attribute should not depend on the level of another attribute.

A1.1.5 Additive Value Function

A value function with three or more attributes is an additive value function if it complies with the following conditions:

- Weak Preference Ordering
- Preferential Independence
- Archimedian Condition

If there are only two attributes the value function must also satisfy the

A1.1.6 Thompsen Condition

$$\left.\begin{array}{l}(x_0,y_1) \sim (x_1,y_0) \\ (x_2,y_0) \sim (x_0,y_2)\end{array}\right\} (x_2,y_1) \sim (x_1,y_2)$$

This implies that:

$$\left.\begin{array}{l}V(x_0) + V(y_1) \sim V(x_1) + V(y_0) \\ V(x_2) + V(y_0) \sim V(x_0) + V(y_2)\end{array}\right\} V(x_2) + V(y_1) \sim V(x_1) + V(y_2)$$

This can be seen by adding the two equations on the left-hand side and cancelling common terms:

$$V(x_0)+V(y_1)+V(x_2)+V(y_0) \sim V(x_1)+V(y_0)+V(x_0)+V(y_2)$$
$$\Rightarrow V(x_2)+V(y_1) \sim V(x_1)+V(y_2)$$

For a detailed explanation of this condition see French (1986) and Krantz *et al* (1971).

A1.2 Preferences and Time

In intertemporal decision making the outcomes of the decisions span over several time periods. In order for the preferences of a decision maker to be rational they have to conform to the conditions outlined below.

A1.2.1 Mutual Preference Independence

$$\forall I \subset T \text{ and all } a,b,y,z \in X$$
$$a_I y_{\neg I} \geq b_I y_{\neg I} \Leftrightarrow a_I z_{\neg I} \geq b_I z_{\neg I}$$

The first two alternatives have all outcomes in times $\neg I$ in common, that is the outcomes in those periods are y. *Mutual Preference Independence* requires that the outcomes in $\neg I$ are ignored and that the preference depends only on comparing the outcomes of a and b in time I. In the same way the z outcomes in the second preference statement should also be ignored, and the preference should again only depend on the a and b. Therefore the preference statements should be the same.

The axiom states that identical components should not influence the choice between two alternatives, this is the same principle as *Preferential Independence*, but is applied to outcomes in different time periods the same arguments for its inclusion apply.

A1.2.2 Mutual Difference Independence

$\forall a,b,y,z \in X$ Where a_t means a is received at time t

$(b_t, y_{-t}) \rightarrow (a_t, y_{-t}) \sim (b_t, z_{-t}) \rightarrow (a_t, z_{-t})$

This requires decision makers to be able to make strength of preference statements concerning outcomes in one period independent of outcomes in other periods. If this was not true then the decision maker would have to refer to all the periods of the outcomes when making a decision and this would make the analysis difficult. It is difficult to think of a situation when a decision should depend on all the outcomes if only one of them is different in each alternative. We would expect the decision maker to focus on the differences in the alternatives and ignore their similarities arguments for the benefits of doing this are outlined in the *Preference Independence* discussion.

A1.2.3 Decision Weights

Decision weights specify the relative importance of different time periods to a decision maker.

$$w_t \in \Re \,\&\, w_t > 0 \qquad v_t : X \rightarrow \Re \qquad \text{s.t.}$$

$$V(a_0, \ldots\ldots\ldots a_{T(a)}) = \sum_{t=0}^{T(a)} w_t v_t(a_t)$$

v_t is a period value function for outcomes in period t, such that if n is a neutral outcome $v_t(n) = 0$ and $\max_{a \in X} v_{t(a)} - \min_{a \in X} v_t(a) = 1$. Different v_ts mean different value functions for an attribute in each period. For example an extra life in period 50 may be valued more or less than an extra life now.

Some people have argued that value functions for attributes should be the same for all the periods. In this case the function would be:

$$V(a_0, \ldots\ldots a_{T(a)}) = \sum_{t=0}^{T(a)} w_t v(a_t)$$

This would require the decision maker to hold to certain rationality assumptions, which may not be true, these are discussed later.

A1.2.4 Arguments for and Against Constant Value Functions

Dyckhoff (1988) looked at the relationship between marginal rates of substitution between periods and the value functions and period decision weights. His results depend on the condition that the value functions are differentiable:

$$MRS_{t,t+1}(x) = \frac{w_t}{w_{t+1}} \frac{v_t'(x)}{v_{t+1}'(x)}$$

Dyckhoff showed that if the marginal rate of substitution was independent of the derivatives of the v_ts then all the v_ts would be the same. This would give a *Constant Marginal Rate of Intertemporal Substitution*:

$$\forall t \in T \text{ and } \forall x \in X$$

$$MRS_{t,t+1}(x) = \frac{w_t}{w_{t+1}}$$

If X is finite then the v_ts are **not** differentiable, therefore the marginal rate of substitution cannot be defined and therefore we cannot use this method to show that all the v_ts are the same. In the model we are using the planning horizon is finite and therefore so are the value functions, therefore we cannot show that all the v_ts are the same by this method.

Say that X is infinite then it is not necessarily true that all the value functions would be the same. It would be rational to assume that if v_t is an increasing function in one period that it would also be increasing in another period, however, it may be true that the curve of v_t is different in different time periods. For example increases in exposure to radiation now may be very important because there is no guaranteed cure to cancer. In 50 years time it may be possible to cure cancer and therefore increases in radiation exposure would be less important. In this case the value function would be less steep in the future than it is now.

Ahlbrecht and Weber (1995b) assume C*onstant Preference Differences* as a rationality requirement.

A1.2.5 Constant Preference Differences

$\forall\, s, t \in T$ and all $a, b, c, d \in X$

Where a_t means a is received in period t

$$b_t \rightarrow a_t \geq d_t \rightarrow c_t \quad \Leftrightarrow b_s \rightarrow a_s \geq d_s \rightarrow c_s$$

That is, if there is a strength of preference it should not change with time. This means that if the decision maker prefers to move from b to a in period t to moving from d to c, then they should prefer the same change in period s. For example say X is lives saved, and assume that there is decreasing marginal value. If b=0 and a=10, while d =1000 and c=1010 then there is no reason why the decision maker should change their preference with time. Say b=20, a=100, d=30, c=90, it is difficult to think of a situation when the preferences may change with time unless for example the price of saving lives increases dramatically, in which case the decision maker may then prefer less to more due to external circumstances, though ideally she would still prefer more to less if money was not an issue. All other things being equal it seems unlikely that the decision maker's strength of preference should change over time. The relative strengths may change with time, but this axiom does not require that relative strengths remain the same. For example changes in the number of lives saved may be less important in the future as the steepness of the value function may change but the direction of the function should not, so more would still be preferred to less.

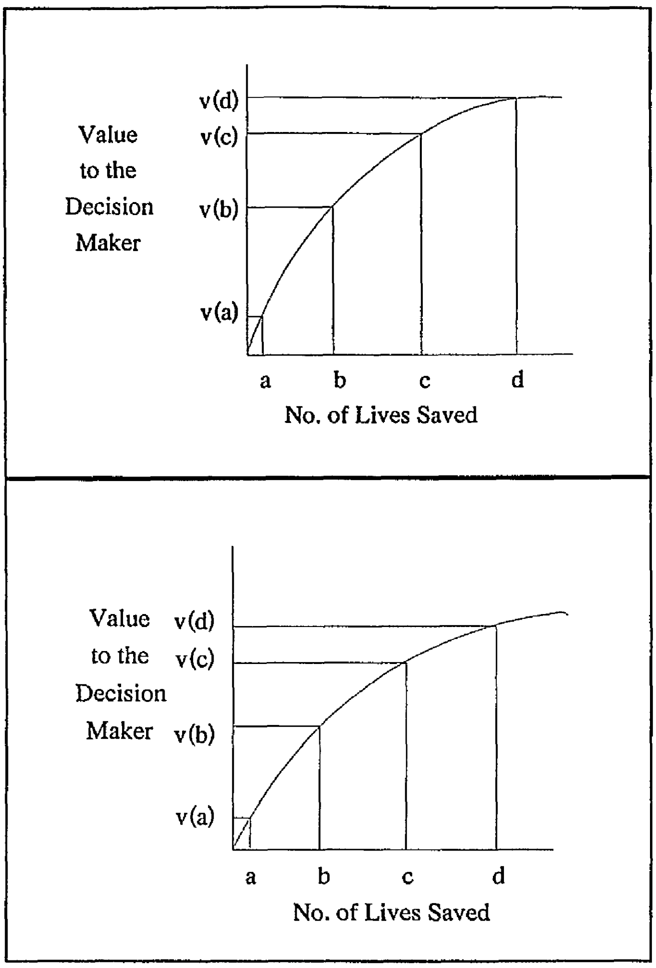


Figure A1.2: Value Functions With the Same Direction and Different Gradients

The graphs show two value functions which have the same direction but different gradients. It can be seen that with both functions the difference between *a* and *b* is larger than the difference between c and *d*. This is because the functions both have decreasing marginal value and the same direction i.e. more is better than less even though their gradient differs.

These issues become more acute the further into the future the decision frame extends, it may be possible to assume that the value function is the same over short periods of time, but this may not be true over very long periods of time. Over long periods of time the decision makers may change or the situation or legislation may change which may affect the value function. In all these situations however, it is unlikely that if originally more was preferred to less that this would change.

A1.2.6 Discounting and Decision Weights

If we define the decision weights as follows:

$$w_t = \frac{1}{(1+i)^{\alpha(t)}}$$

$w_t \neq 0$ as all the time periods are important, therefore it is always possible to find $\alpha(t)$ and i in R which satisfy the equation. It is possible to normalise the weights so that $w_0 = 1$, therefore $\alpha(0) = 0$ and $w_t > 0$ gives $i > -1$. This would give the following value function.

$$(a_0, \ldots\ldots, a_{T(a)}) = \sum_{t=1}^{T(a)} \frac{v(a_t)}{(1+i)^{\alpha(t)}}$$

Time preference is described by the constant discount rate $(1+i)$. The discounting of the future value $v(a_t)$ depends on how far in the future t is perceived to lie. Perception of t depends on $\alpha(t)$. The only restriction necessary on $\alpha(t)$ is that it is such that periods in the future are perceived to be temporally more remote:

$$t \geq t' \Leftrightarrow \alpha(t) \geq \alpha(t')$$

A1.2.7 Patience and Impatience and the Decision Weights

Decision makers can hold very different perceptions of time:

Impatience	$(w_0, \ldots\ldots\ldots, w_{T(a)})$	decreasing	$i > 0$
Timing indifference	$(w_0, \ldots\ldots\ldots, w_{T(a)})$	constant	$i = 0$
Patient	$(w_0, \ldots\ldots\ldots, w_{T(a)})$	increasing	$i < 0$

Given these relationships it is necessary to determine $\alpha(t)$ to determine the discount function for a decision maker.

A1.2.8 Linear Time Perception

Psychological research has shown that time changes in the distant future are viewed as less important than time changes in the near future. This goes against the principle of stationarity which states that people should have constant relative time trade-offs and that preferences should only depend on the absolute time difference between outcomes. The following sections outline the principles of stationarity and dynamic consistency and the reasons why they are **not** being applied in the model.

A1.2.9 Stationarity

For the model used it is **not** necessary for *stationarity* to hold.

For all $t, s, l \in T$ and all $a, b \in X$

Where a_t means a is received at time t

$$a_t \geq_0 b_t \iff a_{t+l} \geq_0 b_{t+l}$$

This would require the decision maker to know their future preferences today, and that they do not change with time. It may not reflect the decision maker's preferences over time because they may not have constant relative trade-offs between consecutive time periods. The evaluations take place in the present and yet require the decision maker to be able to predict their future time preferences. Psychological literature has shown that people have less affinity for the future the more remote it is, see Chapter 4 and 5. For many individuals stationarity will not reflect their preferences as they will view time changes in the distant future as less important than time changes in the near future. For example:

say $t = 2, s = 4$

The time difference is 2 so waiting until s means waiting twice as long as waiting until t.

say $l = 50$, so $t + l = 52$, $s + l = 54$

The time difference is still 2, but now waiting until $s + l$ only requires the decision maker to wait 2/52 of the time $t + l$ more. If the decision maker perceives the choices in this way then when l is added the time difference between $t + l$ and $s + l$ will seem much smaller and therefore be less important. This way of viewing time is called concave time perception, it is similar to the idea of decreasing marginal values of goods. It means the longer the initial waiting period the less significant a small increase in delay is.

Stationarity requires that the trade-offs between two periods depends only on the temporal distance of the periods in these cases $s - t$, so there should be no change in preferences in the two choices. This would lead to a constant perception of temporal distance between two consecutive periods which would lead to a constant discount function. This would be applied independent of whether the outcomes are close or remote.

If stationarity holds then the value function would be as follows:

$$V(a_0, \dots\dots\dots, a_{T(a)}) = \sum_{t=0}^{t=T(a)} \frac{v(a_t)}{(1+i)^t}$$

Where i is the discount rate

Stationarity also implies that decision weights are of the form:

$$w_t = \frac{1}{(1+i)^t}$$

In the decision model used this is not assumed, as we do not think that it is realistic to assume that individuals have linear time preference.

A1.2.10 Dynamic Consistency

For all $t, s, l \in T$ and all $a, b, \in X$

$$a_{t+l} \geq_0 b_{s+l} \Leftrightarrow a_t \geq_l b_s$$

Say the decision maker prefers to save $a_{t+l} = 100$ lives to $b_{s+l} = 80$ lives when the decision is evaluated at time $t = 0$. Say time passes and period l comes. The decision maker then re-evaluates the decision, but this time from the perspective of period l. Now $t + l$ is t periods away and $s + l$ is s periods away. The decision is reframed from a_{t+l} and b_{s+l} in period 0 to a_t and b_s in period l. Dynamic consistency demands that the same preference still holds. This would mean that comparing $t + l = 52$ and $s + l = 54$ at time zero and $t = 2$ and $s = 4$ at time l would give the same time preference. This requires that the decision maker's time preference has not changed, that is the decision maker has:

A1.2.11 Constant Time Preferences

If a_t means that a is received in t units of time from the point of evaluation then:

For all $t, s, l \in T$ and all $a, b, \in X$

$$a_t \geq_0 b_s \Leftrightarrow a_t \geq_l b_s$$

This means that if the decision maker prefers to receive a in t units of time, to b received in s units of time when the time of evaluation is 0 then she should hold the same preference when the time of evaluation is l. This does not necessarily hold and if it does not hold then *dynamic consistency* and *stationarity* are not equivalent. Therefore, *constant time preferences* are crucial for the argument that *stationarity* is a requirement of *dynamic consistency*. Time preferences are likely to change with age and circumstances. To have dynamic consistency future preferences need to be known today. It can be argued that this is unrealistic, because preferences may change with circumstances, in which case dynamic consistency is meaningless. It may be important to make some statement about future preferences in which case it may be logical to say that preferences do not change with time but to make this a requirement of rationality is unrealistic (See Ahlbrecht and Weber (1995b).

The decision contexts we are thinking about are those in which the decision made is binding for the future, for example the countermeasures to take after a nuclear accident or where to put a nuclear waste plant. In these cases the decision will not be re-evaluated in the future and changed, therefore dynamic consistency is a meaningless concept, and so is stationarity. The only reason a decision maker should hold to the axioms giving stationarity in these cases would be when she found that her preferences were correctly described by the axioms. In this case the axioms would be used because of their descriptive validity and not because they are assumed rational.

A1.2.12 Harvey's Alternative to Stationarity

Harvey (1995) defines preferences as ***decreasing timing averse*** if they are:

A1.2.13 Timing Averse

A decision maker is timing averse if :

For any positive outcome x and any times $s<t$:

$$(x,s) > (x,t)$$

and if for any $s<t$ and any positive outcomes $x<y$ and any $h>0$:

$$(x,s) \sim (y,t) \Rightarrow (x,s+h) < (y,t+h)$$

Harvey says that as time recedes into the distant future people may care less and less as to whether an outcome occurs at one time in the distant future or another time, later in the distant future. In this way preferences tend towards timing neutrality as the times $s+h$ and $t+h$ tend to infinity.

Harvey (1986) defines ***Relative Timing Preferences*** to be when changes in time are measured not as absolute changes in time that is $h>0$ but as relative changes with respect to the past or present time $t^* = -b$. Harvey measures changes as $m(b+t)$ where $m>0$ is called a percent. Two relative changes in time $m(b+t)$ and $m(b+s)$ are judged to be equally important.

Harvey's model coincides with the concept of concave time perception. If a time interval is pushed into the future, a stretch proportional to how far it lies in the future will leave the perception of that interval constant. For example say:

$$\begin{array}{ll} m=5, b=6, s=0, t=10, x \,\&\, y>0 \text{ if} & \\ (x,s)\sim(x,t) \Rightarrow (x,0)\sim(y,10) & \text{Then} \\ (x,s+m(b+s)) \sim (y,t+m(b+t)) & \Rightarrow \\ (x,0+5(6+0)) \sim (y,10+5(6+10) & \Rightarrow \\ (x,30) \sim (y,90) & \end{array}$$

In this case the time weights are of the form:

$$a(t)=\left(\frac{b}{b+t}\right)^{r} \qquad t\geq 0,\ b>0,\ -\infty<r<\infty$$

Where b is the *temporal mid-point,* that is the point in time in the future which is half as important as the present; and r reflects the relationship between the ratio of outcomes and the ratio of the time trade-offs.

If we generalise the findings:

$$(x,s_0) \sim (y,t_0) \Rightarrow (x,s=s_0+\Delta s) \sim (y,t=t_0+\Delta t)$$

Stationarity requires that $\Delta s = \Delta t = h$ and that $t - t_0 = s - s_0$ with relative timing consistency $\Delta s = m(b+s_0)$ and $\Delta t = m(b+t_0)$ and $t + b / t_0 + b = s + b / s_0 + b$.

A1.2.14 Proportional Discounting

Harvey defines proportional discounting to be when, if the benefits x and y have a specified ratio then the indifferent extra waiting times Δs and Δt for the benefits x and y have the same ratio. For example if $y/x = 3$ (y is three times as desirable as x), then $\Delta t/\Delta s = 3$ (we are willing to wait three times as much extra time for y than for x).

In this case the time weights are:

$$a(t)=\frac{b}{b+t} \qquad t\geq 0$$

A1.3 Uncertainty in Decision Making

A1.3.1 Lotteries

Simple Lotteries	One chance mechanism is played and the prize is determined.
Compound Lotteries	Some or all of the prizes of the lottery are entries into further lotteries.

A1.3.2 Utility Functions

Given states S_j with probability of occurring $P(S_j)$, actions a_i and v_{ij} the value obtained when action i is chosen and state j occurs the expected utility of an action is:

$$(a_k) = \sum_{j=1}^{s} P(S_j) v_{kj}$$

In order for the decision maker's preferences to be rational they must comply to certain conditions. We want the utility function to be such that:

$$a_k \geq a_m \quad \Leftrightarrow \quad u(a_k) \geq u(a_m) \qquad \text{for any } a_k, a_m \text{ in } A$$

If $p_i \geq 0$ is the probability of obtaining a_i the utility function should be such that:

$$\langle p_1, a_1; p_2, a_2; \ldots..; p_n, a_n \rangle \geq \langle p'_1, a_1; p'_2, a_2; \ldots..; p'_n, a_n \rangle$$

$$\Leftrightarrow \sum_{i=1}^{r} p_i u(a_i) \geq \sum_{i=1}^{r} p'_i u(a_i)$$

Where $\sum_{i=1}^{r} p_i = 1$

We require a weak ordering as defined in French (1986).

A1.3.3 Reduction of Compound Lotteries

If the lottery l gives entry into other lotteries l_1 to l_s such that:

$l = (q_1, l_1; q_2, l_2; \ldots\ldots; q_s, l_s)$ and

$l_j = (p_{j1}, x_1; p_{j2}, x_2; \ldots\ldots; p_{jr}, x_r)$ for $j = 1{:}s$

Let l' be the simple lottery

$l' = (p_1, x_1; p_2, x_2; \ldots\ldots; p_r, x_r)$ where

$p_i = q_1p_{1i} + q_2p_{2i} + \ldots\ldots + q_sp_{si}$ for $i = 1{:}r$

The decision maker should hold:

$$l \sim l'$$

A1.3.4 Substitutability

Let $a, b \in A$ be such that $a \sim b$. Let l in A be any lottery, simple or compound such that:

$$l = \langle \ldots\ldots; q, b; \ldots\ldots \rangle$$

i.e. there is a probability of q that b is the outcome of l. If l' is constructed from l by substituting a for b while leaving all the other outcomes and all the probabilities unchanged such that:

$$l' = \langle \ldots\ldots; q, a; \ldots\ldots \rangle$$

Then the decision maker should think $l \sim l'$.

A1.4 The Decision Model

A1.4.1 Notation

Scenarios leading to different states of nature	S_k	$k = 1{:}n$
Attributes	X_j	$j = 1{:}m$
Alternatives	A_i	$i = 1{:}s$
Alternative i's score on attribute j, these depend on the scenario which occurs	x_{ij}	
Attribute weights stated by the decision maker reflecting their relative importance	w_j	
Time Eras	T_t	$t = 1{:}r$
Time Era Weights	TW_r	
Utility Function	$U(A_i)$	
Probabilities of scenarios, these depend on the facility chosen and the time period	$P_{ir}(S_k)$	

A1.4.2 The Function

$$U(A_i) = \sum_{r=1}^{t} \sum_{k=1}^{n} \sum_{j=1}^{m} TW_r * P_i * (S_k) * w_j * x_{ij}$$

Appendix 2 The Hypothetical Nuclear Waste Decision

This appendix outlines the six hypothetical facility options that were considered in the nuclear waste disposal decision and the attribute weights and values that SF gave. It was assumed that the residents of the area and the regulatory bodies had accepted the site. The information presented in this appendix is a summary of that given to the decision makers consulted for the analysis, as described in Chapters 2 and 6.

A2.1 Background

The site for the facility has already been determined, in an area with mud rock, which has a very low permeability. This means that the transport of any radiation leakage through the rock would be minimal. Background investigations have taken place to determine the suitability of the site for each option; the costs and risks involved and the public acceptability. Within a 3km radius of the site there is a population of 500 people within a 20km radius is a population of 150,000 people.

It is assumed that it will be possible to obtain licensing for any of the options when safety cases have been undertaken and the option chosen can be justified using multi-attribute decision analysis (which is when a decision is made, taking into account several, sometimes conflicting objectives). In all cases the radioactive waste will be enclosed in sealed steel/concrete containers, placed within the storage facility.

The type of waste to be buried is low-medium level radioactive waste. The isotopes in the waste include Uranium 238 with a half life of 4470 million years, Plutonium 239 with a half life of 24,000 years and Thorium with a half-life of 1.9×10^{10} years. The main isotopes are Strontium and Caesium, which decay over 100-500 years. It is estimated that after 300 years half of the radioactive waste will have decayed, the rest will decay very slowly. Therefore the concentration over the remaining period of investigation will remain virtually constant, and will result in an approximately constant release per year.

A2.2 The Facility Options

A2.2.1 On Site Storage

This would involve encasing the radioactive waste in concrete containers and placing them in a secured building. The building would be sealed to prevent radioactive release and protected by security systems.

A2.2.2 Burial with Reburial

This would involve placing the waste in a buried pit that would be reopened every 50 years to check the conditions and the safety of the waste inside it. A chamber would be constructed to allow re-access into the pit.

A2.2.3 Permanent Burial with no Drainage

An underground pit would be created to store the radioactive waste. However, no complex structure would be constructed for drainage. Also no cut-off walls would be used.

A2.2.4 Permanent Burial with Drainage

As A2.2.3 above, but with drainage included. The drainage is expected to function for the first 200 years.

A2.2.5 Permanent Burial with Drainage and Cut-off Walls

As A2.2.4 above, but with cut-off walls included

A2.2.6 High Tech option

This facility would have cut-off walls, a more complex drainage system and a high technology closure system.

A2.3 Scenarios of Future Outcomes

Several scenarios were created to reflect what could happen once the facility had been built. The probability of these scenarios occurring depends on the facility being considered, and changes with time. The scenarios are described below.

- Expected conditions occur, based on available information.
- Containers become unstable resulting in radiation leakage. With on site storage A2.2.1 this would cause contamination of the environment; with the other facilities it would result in radiation leakage into the storage facility. Therefore the consequences of this scenario are more severe for A2.2.1 and A2.2.1. No damage to facility otherwise.
- Ground water contamination occurs, small subsequent chance of corrosion to containers.
- Structure becomes damaged with small subsequent chance of ground water contamination.
- Incomplete sealing of shafts and the repository or, for the on site facility, problems with the housing structure.
- Intrusion into structure, including accidental damage and terrorist damage.
- The radioactive material is no longer a problem. For example, medical advances find cures for cancer and other radiological health risks, a use is found for the fuel, the waste is blasted to the sun, the waste is transformed into a safe material, or some other reason.

The scenario that occurs will determine the value of the attributes. For example, the accident costs depend on the scale of the accident. The following tables show the probabilities that the scenarios occur in each of the time periods for each of the facilities.

A2.3.1 Facility 1 - On Site

Scenario	Years		
	0-100	101-500	501-10000
0	0.0001	0.001	0.10
1	0.7999	0.179	0.00
2	0.0200	0.080	0.14
3	0.0400	0.120	0.12
4	0.0600	0.300	0.33
5	0.0500	0.180	0.16
6	0.0300	0.140	0.15

Table A2.1: Scenario Probabilities for On Site Facility

A2.3.2 Facility 2 - Bury & Rebury

Scenario	Years		
	0-100	101-500	501-10000
0	0.0001	0.001	0.10
1	0.6999	0.099	0.00
2	0.0200	0.080	0.14
3	0.0600	0.100	0.12
4	0.0500	0.250	0.21
5	0.1500	0.290	0.26
6	0.0200	0.180	0.17

Table A2.2: Scenario Probabilities for Bury Rebury Facility

A2.3.3 Facility 3 - Bury No Drainage

Scenario	Years		
	0-100	101-500	501-10000
0	0.0001	0.001	0.100
1	0.8499	0.299	0.000
2	0.0200	0.080	0.160
3	0.0250	0.070	0.115
4	0.0500	0.250	0.325
5	0.0350	0.170	0.155
6	0.0200	0.130	0.145

Table A2.3: Scenario Probabilities for Bury Facility

A2.3.4 Facility 4 - Bury and Drainage

Scenario	Years		
	0-100	101-500	501-10000
0	0.0001	0.001	0.100
1	0.8699	0.319	0.000
2	0.0200	0.080	0.160
3	0.0170	0.060	0.115
4	0.0450	0.240	0.325
5	0.0300	0.170	0.155
6	0.0180	0.130	0.145

Table A2.4: Scenario Probabilities for Bury and Drainage Facility

A2.3.5 Facility 5 - Bury, Drainage & Cut-Off

Scenario	Years		
	0-100	101-500	501-10000
0	0.0001	0.001	0.100
1	0.8999	0.449	0.005
2	0.0200	0.080	0.180
3	0.0100	0.040	0.110
4	0.0300	0.200	0.315
5	0.0250	0.130	0.150
6	0.0150	0.100	0.140

Table A2.5: Scenario Probabilities for Bury, Drainage and Cut-off Walls Facility

A2.3.6 Facility 6 - High Tech

Scenario	Years		
	0-100	101-500	501-10000
0	0.0001	0.001	0.100
1	0.9099	0.499	0.005
2	0.0200	0.080	0.185
3	0.0080	0.020	0.110
4	0.0250	0.200	0.315
5	0.0220	0.100	0.145
6	0.0150	0.100	0.140

Table A2.6: Scenario Probabilities for High Tech Facility

A2.4 Descriptions of Assessment Attributes

The facilities are analysed with respect to several time dependent attributes. The set of relevant attributes changes over time as for example the initial environmental impacts are concerned with the facility construction, while later environmental impacts will refer to the effects of an accident. The attribute values depend on which facility is built and many are also dependent on the scenario that occurs.

A2.4.1 Immediate Environmental Impacts

A constructed attribute has been created to measure the environmental impact. This relates to the initial impact the facility will have on the area. The scale ranks the outcomes and gives a description of the impacts involved with each level (See Table A2.7). The score of each of the facilities is shown in Table A2.8.

Level	Description
1	Minimum environmental disturbance and construction, though some aesthetic impacts, due to surface storage.
2	Major construction of a facility.
3	Major construction plus excavation to create drainage.
4	As 3 but also more aesthetic impacts due to superstructure.
5	As 2 but with disturbance every 50 years involving excavation and reconstruction.

Table A2.7: Short Term Environmental Impacts

A2.4.2 Construction Costs

The cost of creating the structure for the waste storage. The cost varies for each facility and is measured in millions of pounds. See Table A2.8.

A2.4.3 Operating Costs

The yearly cost of operating the facility in normal conditions once it has been constructed. This is measured in millions of pounds and varies for each facility. The bury and re-bury option costs £5 million per year to operate and also includes an investment of £1 million per year for 50 years to cover the cost of opening the repository for inspection every 50 years. See Table A2.8.

Facility	Construction Costs (mill £)	Operating Costs (mill £) per annum	Environmental Impact Short Term
On Site	100	6	1
Bury & Rebury	400	5 + 1	5
Bury no Drainage	350	5.5	2
Bury & Drainage	400	5	3
Bury, Drainage & Cut-off	470	4.7	4
High Tech	500	4.5	4

Table A2.8: Table of Immediate Costs

A2.4.4 Collective Worker Dose

The expected collective dose workers will be exposed to while the facility is being constructed and the waste deposited into it. This is measured in manSieverts (manSv). See Table A2.9.

A2.4.5 Collective Public Dose

The expected collective dose the public will be exposed to while the facility is being constructed and the waste deposited into it. This is measured in manSv. See Table A2.9.

A2.4.6 Worker Deaths (Non Radiological)

The expected number of deaths caused by non-radiological hazards, for example, construction deaths. See Table A2.9.

Facility	Worker Deaths in Construction	Worker Collective Dose Pre-closure (manSv)	Public Collective Dose Pre-closure (manSv)
On Site	1.5	5.00	2.00
Bury & Rebury	2.5	4.20	1.20
Bury no Drainage	2.5	4.20	1.20
Bury & Drainage	3.0	3.75	<1.00
Bury, Drainage & Cut-off	5.0	2.50	<0.75
High Tech	5.0	2.50	<0.70

Table A2.9: Immediate Human Costs

A2.4.7 Public Acceptance Local and Distant, Long and Short Term

A constructed attribute is used to measure public acceptance (See Keeney, 1992). This consists of a scale from 1 to 6, with 1 indicating most public support and 6 indicating the least. The scale is based on public perceptions of safety, environmental impacts and socio-economic impacts. It is split into local and distant regions to reflect the importance of, and any differences in, the opinions of the people living close to and far from the facility. The long term elements reflect the opinions of the present day community about how publicly acceptable they think the facility will be to people in the future. The scales for the various groups and time periods also differ. See Table A2.10.

Facility	**Public Acceptance**			
	Local, Short Term	**Local, Long Term**	**National, Short Term**	**National, Long Term**
On Site	6	6	6	6
Bury & Rebury	5	5	5	5
Bury no Drainage	4	4	4	4
Bury & Drainage	3	3	3	3
Bury, Drainage & Cut-off	2	2	1	2
High Tech	1	1	2	1

Table A2.10: Public Acceptance for the Facilities

A2.4.8 Accident Costs

These are the costs incurred due to adverse circumstances, for example, an intrusion into the structure. To measure this a constructed attribute has been created which expressed the attribute levels in terms of a scale. The score on this attribute is uncertain because it depends on the scenario that occurs. See Table A2.11. The costs include the cost of rebuilding and re-location and any intervention strategies applied to protect people.

	Facility					
Scenario	**On Site**	**Bury & Rebury**	**Bury no Drainage**	**Bury & Drainage**	**Bury, Drainage & Cut-off**	**High Tech**
0	0	0	0	0	0	0
1	1	1	1	1	1	1
2	4	3	2	2	2	2
3	4	3	3	3	3	3
4	3	3	3	3	2	2
5	5	4	3	3	3	3
6	6	5	5	5	4	4

Table A2.11: Accident Costs of Facilities for a Given Scenario

A2.4.9 Long Term Environmental Impacts

The long term impacts depend on which scenario occurs after the facility has been built. Therefore it is uncertain and depends on the probability distribution for the scenarios. A constructed attribute scale is used to describe the impacts and to rank the outcomes. The impacts were loss of land, either agricultural or wild, and animals and their habitats because of an accidental release. Table A2.12 shows the constructed scale and Table A2.13 shows the facility scores on this attribute.

Level	Description
0	Radiation is no longer a problem so the facility can be dismantled.
1	No environmental disturbance.
2	Minimum environmental disturbance, no radiation leakage, but new construction work is needed to rectify the problem.
3	Radiation reaches the environment and results in local contamination, but with minimum clean-up necessary. Construction is required to rectify the problem.
4	As 3 but a major clean-up operation is needed.
5	As 4 but long term environmental impacts occur and major re-building is necessary.
6	Relocate people and radioactive waste. The site is then unsafe for habitation.

Table A2.12: Long Term Environmental Impacts

	Environmental Impacts Level					
Scenario	On Site	Bury & Rebury	Bury no Drainage	Bury & Drainage	Bury, Drainage & Cut-off	High Tech
0	0	0	0	0	0	0
1	1	1	1	1	1	1
2	4	3	2	2	2	2
3	4	3	3	3	3	3
4	3	2-3	2-3	2-3	2-3	2-3
5	5	4	3	3	3	3
6	6	5	5	5	4	4

Table A2.13: Long Term Environmental Impacts for a Given Scenario

A2.4.10 Accident Impacts

In the final time era it was thought unrealistic to be able to estimate the costs of an accident. To avoid having to do this a constructed attribute called *accident impacts* has been created. This is used to reflect the effects of an accident on the environment and the consequences to the community. It is defined using a non-linear scale. The attribute is uncertain, and depends on the scenario that occurs. Table A2.14 shows the facility scores on this attribute.

	Accident Impacts Level					
Scenario	On Site	Bury & Rebury	Bury no Drainage	Bury & Drainage	Bury, Drainage & Cut-off	High Tech
0	0	0	0	0	0	0
1	1	1	1	1	1	1
2	4	3	2	2	2	2
3	4	3	3	3	3	3
4	4	3	3	3	2.5	2.5
5	5	4	3	3	3	3
6	6	5	5	5	4	4

Table A2.14: Accident Impacts for a Given Scenario

A2.4.11 Maximum Expected Individual Dose Close to the Facility

Table A2.15 shows the likely maximum individual doses for the critical population group within 20km of the site. These are the doses they are expected to receive if no accidental releases occur. This would be so in the case of long term environmental conditions 1 or 2. The release rate depends on the facility built. It is assumed that, under normal circumstances, as time progresses, the structure containing the waste will deteriorate, resulting in increased amounts of radiation reaching the environment. However, as some of the radioactive material will have decayed there will be less of it to leak. These factors are reflected in how the radiation releases change over time.

Environment 1 or 2 & Facility	Individual Dose over the 150,000 Population Post-Closure in milliSv Per Year		
	0-100	101-500	501-10000
1	0.00300	0.002000	0.00260
2	0.00160	0.001000	0.00130
3	0.00126	0.000660	0.00100
4	0.00080	0.000600	0.00100
5	0.00020	0.000120	0.00033
6	0.00013	0.000066	0.00026

Table A2.15: Maximum Individual Dose to the Critical Population Group

Table A2.16 shows the likely maximum individual dose received by a member of the critical population group living in the 20km around the site given environmental conditions 3 to 6. The figures reflect the probability that an incident will occur in the time interval. As time progresses the intervals being considered increase and so does the probability. However, the amount of radiation left decreases which affects the environmental impact. It is assumed that any release to the environment is slow with no short-lived source term and no airborne plume.

Environmental Impact	Individual Dose Post-Closure over the 150,000 Population in manSv Per Year		
	0-100	101-500	501-10000
3	0.26	0.7	2
4	3.3	6	9
5	66	100	150
6	180	300	480

Table A2.16: Individual Dose with Environments 3 to 6

A2.4.12 Collective Dose to the Nation

Table A2.17 shows the collective dose for the population of the UK. It indicates the dose of radiation the population is expected to receive if no accidental releases occur. This would be so in the case of the long term environmental conditions 1 or 2. The release rate depends on the facility built. It is assumed that, under normal circumstances, as time progresses, the structure the waste is contained in will deteriorate. This will result in increased amounts of radiation reaching the environment. As time progresses the intervals being considered increase and so does the probability. However, the amount of radiation left decreases which affects the environmental impact. These issues are reflected in how the radiation releases change over time.

Environment 1 or 2 & Facility	National Collective Dose Post-Closure to UK Population in manSv Per Year		
	0-100	101-500	501-10000
1	0.50	0.300	0.40
2	0.25	0.150	0.20
3	0.19	0.100	0.15
4	0.12	0.090	0.15
5	0.03	0.018	0.05
6	0.02	0.010	0.04

Table A2.17: National Dose with Environment 1 or 2

Table A2.18 shows the collective radiation dose received by people living in the UK given the environmental conditions. The figures reflect the probability that an incident will occur in the time interval. As time progresses the intervals being considered increase and so does the probability. However, the amount of radiation left decreases which also affects the environmental impact. It is assumed that any release to the environment is slow with no short lived source term and no airborne plume.

Environmental Impact	National Dose to UK Population in manSv Over the Time Period			Number of Cancers Caused Per Year in the Time Period		
	0-100	101-500	501-10000	0-100	101-500	501-10000
3	40	120	400	2	6	20
4	500	1200	2000	25	60	100
5	10000	24000	40000	500	1200	2000
6	30000	60000	100000	1500	3000	5000

Table A2.18: National Collective Dose with Environments 3 to 6

A2.5 Useful data

The following table shows some important comparison data to put the previous radiation doses into perspective.

Dose or Limit	Value
Dose to Induce 1 Cancer	20 manSv
Worker Dose Limit	50 milliSv
Principal Public Dose Limit	1 milliSv.
Average Annual Dose from Natural Radiation	2.5 milliSv
Average Annual Dose from Chernobyl	0.5 milliSv

Table A2.19: Comparison Data

A2.6 SF's Attribute Values and Weights

The following sections show the attribute values that SF gave to the original scales or scores and the relative weights he gave to the attributes. They also outline the thinking behind his weights.

A2.6.1 Pre-Closure Attribute Weights

Weights for the pre-closure attributes were considered first and the construction costs were used as an anchor giving them a weight of 100. The construction costs are in the range 100 to 500 million pounds. The weight means that an increase of 400 million pounds was given a weight of 100. SF decided that the value scale for the construction costs would be linear. Next we considered the environmental impacts. SF looked at the environmental impact scale. It ranged from 1 to 5. He assigned a value between 0 and 100 to each point on the scale to reflect its relative importance to him.

Original Scale	1	2	3	4	5
Value	0	40	60	100	100

Table A2.20: Immediate Environmental Impacts Scale

The original scale reflected the environmental impacts from building the facilities. Going from 3 to 4 reflected the increased environmental impact from building the super structure. In terms of SF's scale this was worth 40 points. He thought about how much extra money he would be willing to pay to hide the super structure and judged that he would be willing to pay £100 million. Therefore, comparing this scale to the one for the construction costs, £100 million on this scale is worth 40 points, while on the construction cost's scale it is worth 25 points. The ratio is therefore 1 construction point to 0.625 environment points. Hence, the relative weight of the environmental impacts attribute was set at 62.5.

Next SF considered the health issues. The original scale for worker deaths goes from 1.5 to 5 a difference of 3.5 lives. Since this difference is not extreme, SF thought that the value scale would be linear. He estimated the cost of a life to be £1 million, therefore the total change in monetary terms would be £3.5 million. This is approximately 1/100th of the construction scale and would therefore give the construction deaths' attribute a weight of 1.

Worker dose was converted to monetary terms by using the NRPB value of £50 per man milliSievert for worker doses. The original scale went from 2.5 to 5 manSieverts, so in monetary terms this would be £125,000, which is 0.0003 of the construction cost scale. The public dose ranges from 0.7 to 2 manSieverts. Using the NRPB value of £20 per man milliSievert for public doses this is a monetary range of £26,000, which would give a weight of 0.00006 relative to the construction costs scale. Since the range of the scales for public and worker doses are small SF decided that they should have linear value functions. SF viewed all the health weights to be far too low and therefore decided to increase them. He gave the worker deaths a value of 5, the worker dose a value of 2 and the public dose a value of 1, as he thought they were more important than their monetary equivalents had made them.

When looking at public acceptance, SF thought about how much he would be willing to pay in order to buy local support when the facility was initially being built. He decided that he would be willing to pay £40 million, which is 1/10 of the construction costs and therefore gives local public acceptance a weight of 10. He did not think that the value scale would be linear and so converted it as shown below.

Original Scale	1	2	3	4	5	6
Value	0	10	20	30	50	100

Table A2.21: Local Public Acceptance Pre-Closure

He decided that national public acceptance was less important, and therefore gave it a weight of 5, as he felt he would only be willing to pay £20 million for it. Once again a non-linear value scale was assigned as shown in Table A2.22.

Original Scale	1	2	3	4	5	6
Value	0	10	20	60	80	100

Table A2.22: National Public Acceptance Pre-Closure

A2.6.2 Weights for 0 to 100 Years

The operating costs over the 100 years have a range of £150 million, which is about 1/4 of the range of the construction costs, and therefore received a weight of 25. SF thought that the value scale would be linear.

To assign a weight to the environmental impacts SF considered the cost of the cleanup after Chernobyl. The environmental impacts were measured on a scale that ranged from 0 to 6. This was first converted into a 0 to 100 value scale and then assigned an attribute weight.

Original Scale	0	1	2	3	4	5	6
Value	0	20	25	30	70	80	100

Table A2.23: Environmental Impacts Scale for 0 - 100 Years

The values given reflect the fact that the difference in environmental impacts was not linear and that there is a big jump from 3 to 4 on the original scale. SF thought that the range of impacts would be about half that of the construction costs and therefore assigned a weight of 50 to the attribute.

The accident costs attribute reflected the cost of cleanup after an accident and the cost of relocating people if that was necessary. SF assigned values from 0 to 100 to the original scale as shown below.

Original Scale	0	1	2	3	4	5	6
Value	10	0	10	12	15	20	100

Table A2.24: Accident Cost Scale for 0 - 100 Years

The reason the innovation option was given a value of 10 was due to the idea of decommissioning costs. The values given reflect the fact that the original scale was not linear. SF thought that the differences at the top end of the scale were much larger and therefore should be given very different values. SF used his knowledge of the costs of relocation after the Chernobyl disaster and assigned a weight of 1000 to the accident cost's attribute. This is because the cost of relocation and cleanup is far larger than the £400 million range of the construction costs.

When considering health, SF looked at the stress factor involved in the radiation leaks. This would be especially important for the people living close to the site. Again, values were assigned to reflect the non-linear nature of the doses.

Individual Doses	0	3	66	180
Value	0	10	70	100

Table A2.25: Individual Dose Scale for 0 - 100 Years

SF judged that he would be willing to pay £400 million to avoid the worst doses and so assigned a weight of 100 to the individual dose attribute.

For collective dose SF considered the number of lives that would be lost if no countermeasures were taken. In the 0 to 100 years era this would be 1500 lives. Assuming that countermeasures would be implemented he estimated that 100 lives would be lost. Using a cost of £1 million per life lost, SF judged that the range would be £100 million. This is 1/4 of the range of the construction costs and so the collective dose attribute was assigned a weight of 25. SF decided that the value scale would be linear.

SF decided to assign the same values and weights for public acceptance that he had used in the pre-closure era, as he thought the risks would be similar and that the people who had made the original decision would still be alive.

A2.6.3 Weights for 101 to 500 Years

For this era SF decided to double the weight assigned to the public acceptance because he believed that the risks to human life were bigger. This gave the local public acceptance attribute a weight of 20 and 10 for national public acceptance. He adjudged that the value scales would be the same as in the previous era.

The individual dose rates were transformed to a new value scale.

Individual Dose	0	6	100	300
Value	0	15	40	100

Table A2.26: Individual Dose Scale for 101 - 500 Years

As the range of doses received is about double that in the era 0 to 100 years SF doubled the attribute weight to 200.

The national dose's range was also double that in the era 0 to 100 years and so the attribute weight was likewise doubled to 50. The value scale remained linear.

The weight and value scale assigned to the environmental impacts and accident costs were the same as those in the 0 to 100 year era.

A2.6.4 Weights for 501 to 10000 years

In this era there is an attribute called accident impacts which is supposed to reflect the accident costs and the environmental impacts. SF assigned it a weight of 1050, which was the sum of the weights he had given to the two separate attributes in the previous eras. He assigned values between 0 and 100 to the original scale as shown below.

Original Scale	0	1	2	3	4	5	6
Value	0	5	20	40	45	50	100

Table A2.27: Accident Impact Scale for 501 - 10,000 Years

For individual doses he assigned values to the original scale.

Individual Dose	0	3	9	150	480
Value	0	10	20	90	100

Table A2.28: Individual Dose Scale for 501 - 10,000 Years

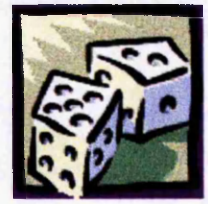
The impact range is about 1/3 bigger than in the previous era and so he assigned a weight of 300 to the attribute to reflect this.

For collective dose the range was about 2/3 bigger than the previous era and so he assigned a weight of 80. He decided that the value scale would be linear.

Appendix A3 The First World Wide Web Experiment

This appendix contains the pages from the first World Wide Web experiment. In the course of a session subjects were not allowed to move onto the next page until they had completed all the sections on the current page. However, they could go back to previous pages that they had filled in and modify their answers. Subjects could also call up a previous session and return to the page as many times as they wanted to. Although the author designed the experiment, the Web page implementation was by Dave Small.

Analytica Decision Analysis



Thank you for taking the time to visit this site. If you are visiting for the first time, please select 'Fresh Start' below.

Fresh Start

If you have visited before, and already completed a model, please enter your email address and select 'Retrieve Old Session'. The system will attempt to recover your previous model.

Your email address

Retrieve Old Session

Step 1 of 10

The Problem

The following pages outline 6 hypothetical nuclear waste facilities from which one has to be chosen. The site for all of the facilities is the same and is in low permeability rock, in this way any release of radiation will be slow. The site has been accepted by the authorities and public and the only decision left to make is which facility to build. The facility is to be built on a greenbelt site. 500 people live within a 2 mile radius of the site and 150,000 people live within a 12.5 mile radius of the site. First of all you are asked to rank the facilities based on your first impressions and the descriptions of them. You are then asked to enter the importance values that you think should be given to the different attributes that the facilities have been modelled on. Your values will be entered into an Analytica model (see web site for details) which will be solved and the results of your opinions will be sent to you.

To help you to think about the relative weights that should be given to the different attributes the Construction Costs have been given a weight of 100. This means that a change of £400 million (the difference between the highest and lowest value [*range*])is worth 100 points, this should help you to give weights to the other attributes. Some suggestions have been made to help you to think about the attributes, these are there to help you, and you can ignore them if you disagree with them or if they confuse you.

Step 2 of 10

Description of Facility Options

The following describe the different facility options available:

On Site Storage

This would involve placing the radioactive waste in sealed concrete containers and placing them in a secured building. The building would be sealed to prevent radioactive release and would be protected by security systems. This is the cheapest facility and gives the chance of developing technology before building an underground facility; however it is the most dangerous and gives the biggest risk to life in the short term.

Burial with Reburial

This involves placing the waste in a buried pit which would be reopened every 50 years to check the conditions and the safety of the waste inside it. It would involve the construction of a chamber to allow re-access into the pit. This option would allow the government to monitor the waste, but this increases the chance of a radiation leakage through structural problems.

Permanent Burial with no Drainage

An underground pit would be created which would be used to store the radioactive waste. However no complex structure would be created for drainage. Also no cut-off walls would be used. This is the most basic underground facility, so it is relatively cheap and does not result in major environmental upheaval; however, it could be made safer by spending more money and adding some of the safety systems below.

Permanent Burial with Drainage

This would be as above but with drainage included, the drainage is expected to function for the first 200 years. Drainage helps to prevent radiation leakage via water. After 200 years this facility would function in the same way as the one above with no drainage. This facility is safer than the one above for 200 years, so the extra cost buys extra safety for 200 years, however after that time the extra cost gains no extra safety.

Permanent Burial with Drainage and Cut-Off Walls

As above but with cut-off walls included to help prevent radiation leakage. This facility has increased safety, but costs more.

High Tech option

As above, but also including a more complex drainage system and a high technology closure system. This is the safest option, but the systems will not last for ever. This options costs more money and involves more environmental disturbance.

In light of the brief descriptions given above please rank the facilities. Give a value of 1 to the facility you think is the 'best', 2 to the second 'best' and so on giving a value of 6 to the facility you think is the worst.

On Site Storage	
Burial with Reburial	
Permanent Burial with no Drainage	
Permanent Burial with Drainage	
Permanent Burial with Drainage and Cut-Off Walls	
High Tech option	

Step 3 of 10

Scenarios of the future

Several scenarios were created to reflect what could happen once the facility had been built. The probability of these scenarios occurring depends on the facility being considered and changes with time. The scenarios are described below.

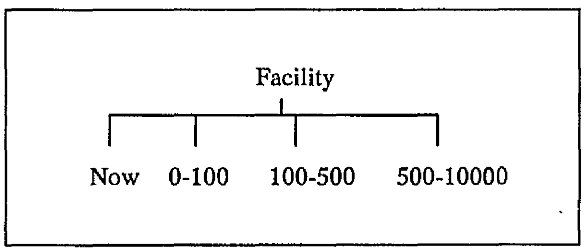
- Expected conditions occur, based on scientific information.
- Containers become unstable resulting in radiation leakage. With on site storage this would cause radiation leakage into the environment with the other systems it would result in radiation leakage into the storage facility. Therefore the consequences of this scenario are more severe for the On Site and Bury-Rebury facilities. No damage to facility structure otherwise.
- Ground water contamination occurs, small subsequent chance of corrosion of the containers holding the waste.
- The facility structure becomes damaged, small subsequent chance of ground water contamination.
- Incomplete sealing of shafts and the facility or for the On Site facility, problems with the housing structure. This would give radiation leaks in all the facilities.
- Intrusion into the facility, including accidental damage and terrorist damage.
- The radioactive material is no longer a problem. For example medical advances find cures for cancer and other radiological health risks, a use is found for the fuel, the waste is blasted to the sun, the waste is transformed into a safe material, or some other reason.

Step 4 of 10

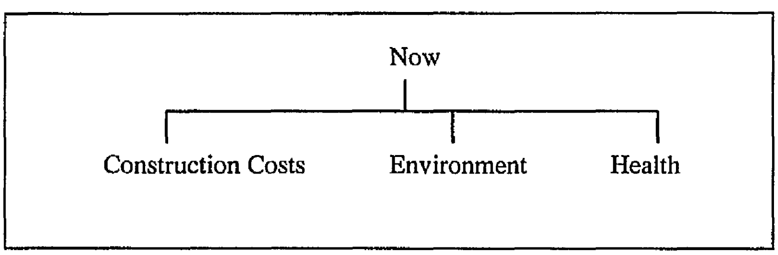
Attributes

The facilities were analysed with respect to several attributes, these depend on time. The attributes would naturally change with time as for example construction costs are incurred now, while operating costs are only incurred after the facility is closed. The attribute values depend on which facility is built, many of the values also depend on the scenario which occurs. To reflect the fact that the attributes change over time the attribute tree is divided into distinct time eras.

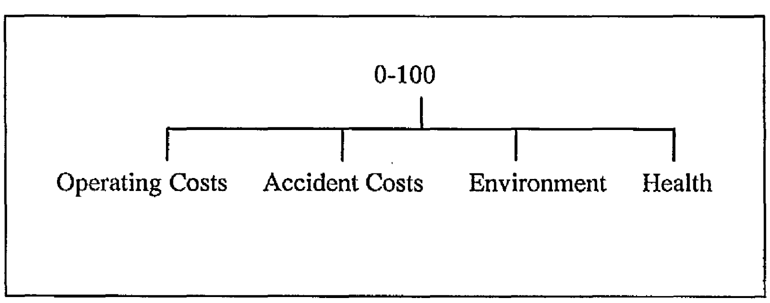
The attributes which are important in each time period differ, the diagrams below show the attribute trees for each of the time periods.



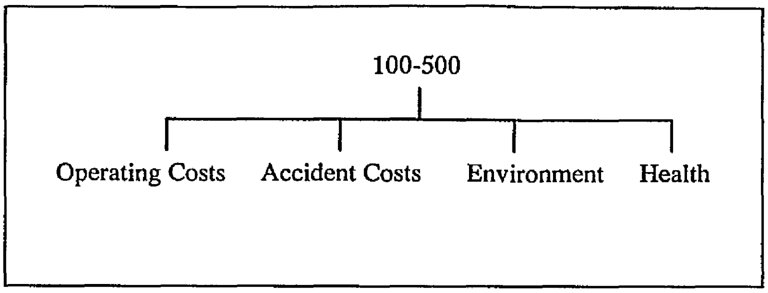
The Top Level Time Eras



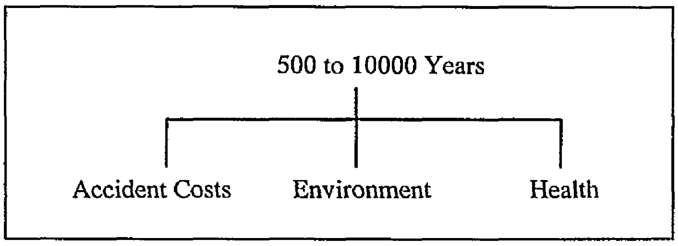
Pre-Closure Attribute Tree



Attribute Tree for 0 - 100 Years



Attribute Tree for 100 - 500 Years



Attribute Tree for 500 - 10,000 Years

Now please take a few seconds out to enter your personal details below.

Your answers will be used to attempt to group responses to this survey. Please answer as truthfully as possible.

Job title/course	
Name	
Age	
Sex (M/F)	
Country	

Step 5 of 10

Attributes Which Occur Now

Construction Costs

This is the cost of building the facility for the waste storage, the cost is measured in millions of pounds. The range of the cost is £400 million (largest minus smallest value). This has been give a value of **100** which means that £400 million is worth 100 points.

Facility	Construction Costs (mill £)
On Site	100
Bury & Rebury	400
Bury no Drainage	350
Bury & Drainage	400
Bury, Drainage & Cut-Off Walls	470
High Tech	500

Each attribute should be given a positive value, you may think that an attribute is not important and can therefore give it a value of 0. If you gave an attribute a value of 100 you would be saying that the difference between its highest and lowest value was worth £400 million and that it is as important as the construction costs.

Health Now

This is measured as the expected number of lives lost due to the construction of the facility. It includes deaths due to radiation and building accidents.

Facility	Lives Lost
On Site	1.85
Bury & Rebury	2.77
Bury no Drainage	2.77
Bury & Drainage	3.24
Bury, Drainage & Cut-Off Walls	5.16
High Tech	5.16

Currently in planning a value of about £1 million is attached to the 'value of a life', which would mean that this attribute has a range of £3.31 million (the difference between the smallest and largest value). Using this value and the value given to the Construction Costs the attribute could receive a weight of 3.31/400 which is about 1/100th of the value given to the construction costs and so is 1. You may think that this is too low a value to give to human lives and want to increase the value; however, you may think that it is too high a value because the workers will have chosen their jobs and so you may want to decrease the value. This gives you an idea of how to think about the values.

Please enter the value you think should be given to the Immediate Health Effects	

Environmental Impacts Now

This relates to the initial impact the facility will have on the area. A scale was devised for the impacts, the scale ranks the outcomes and gives a description of the impacts involved with each level.

Level	Description
1	Minimum environmental disturbance and construction, though some aesthetic impacts, due to surface storage.
2	Major construction of a facility.
3	Major construction plus excavation to create drainage.
4	As 3 but also more aesthetic impacts due to superstructure.
5	As 2 but with disturbance every 50 years involving excavation and reconstruction.

The facility is to be built on a greenbelt site. The site does not have any unique wildlife or rare species of animal living on it, so no species will be lost by building the site. You need to think how much you would be willing to pay to hide the structure from public view, the structure will be visible from miles around. Think about how much the environment is worth to you and how much you would like the government to pay to preserve it. Remember that the public will have to pay via taxes and the money could be spent on other things e.g. health.

Please enter the value you think should be given to the Immediate Environmental Effects	

Step 6 of 10

Attributes in the 0 - 100 Year Era

These attributes will occur in your life time, if there is an accident in this period it will affect you, your friends, your family and your children if you have any. Your close descendants will be alive during this era and although as you know technology is increasing at a fast rate you can still imagine what the world will be like in the early part of this era. When thinking about the attributes weights keep in mind that these attributes will affect you.

Operating Costs

This is the yearly cost of operating the facility in normal conditions once it has been constructed, this is measured in millions of pounds and varies for each facility. The costs shown below are the total costs for the whole of the period.

Facility	Operating Costs (millions £)
On Site	600
Bury & Rebury	600
Bury no Drainage	550
Bury & Drainage	500
Bury, Drainage & Cut-Off Walls	470
High Tech	450

The range of the Operating Costs is £150 million, this is 0.375 times the size of the range of the Construction Costs and so the Operating Costs could be given a value of 37.5 so that it is in line with the Construction costs, you may feel this is too high or low and so can use another value.

Please enter the value you think should be given to the Operating Costs in the 0 - 100 year era	

Accident Costs

These are the costs incurred due to adverse circumstances, for example an intrusion into the structure, these depend on which scenario occurs and the facility built. The costs include the cost of rebuilding and re-location and any intervention strategies applied to protect people.

	Cost in (millions £)
Lowest	0
Highest	4000

Relating this to the value given to the Construction Costs you could give it a value of 1000. You may think that this is too high because the people will have chosen to live in the area and will have been compensated; or you may think that it should be given a bigger value to reflect the inconvenience of moving people and the distress the accident will cause.

Please enter the value you think should be given to the Accident Costs in the 0 - 100 year era	

Environmental Impacts 0 - 100 Years

The long term impacts depend on the scenarios which may occur after the facility has been built. A scale was used to describe the impacts and to rank the outcomes. The impacts were to reflect loss of land, either agricultural or wild, and animals and their habitats because of an accidental release.

Level	Description
0	Radiation is no longer a problem so the facility can be dismantled.
1	No environmental disturbance.
2	Minimum environmental disturbance no radiation leakage, but new construction work is needed to rectify the problem.
3	Radiation reaches the environment and results in contamination of the local environment, but with minimum clean-up necessary. Construction is necessary to rectify the problem.
4	As 3 but a major clean-up operation is needed.
5	As 4 but long term environmental impacts occur and major re-building is necessary.
6	Relocate people and radioactive waste, the site is then unsafe for habitation.

You need to think about how important the environment is to you, think about how much you would be willing to pay to avoid the worst environmental impact. You could then relate this back to the Construction Costs to determine the weight you would like to give to this attribute.

Please enter the value you think should be given to the Environmental Effects in the 0 - 100 year era	

Health 0 - 100 Years

This attribute looks at the number of lives that will be lost due to radiation leakage in this era under the different scenarios.

	No. of Lives	Cost in (millions £)
Lowest	0	0
Highest	100	100

Comparing this to the Construction Costs could give the attribute a value of 25. You may think that this adequately covers the stress that will be incurred by the people who suffer because of the accident or you may think that the value needs to be increased to take this into account; or you may think that it is too high because the people will have chosen to live in the area.

Please enter the value you think should be given to the Health Effects in the 0-100 year era	

Step 7 of 10

Attributes in the 100 - 500 Year Era

These attributes will occur after your life time, if there is an accident in this period it will affect your very distant descendants. It is not possible to think about how the world will have changed by this time. After all who a 100 years ago would have thought that space travel would be possible in the way that it is, or that many then killer diseases e.g. whooping cough would now not be such a big problem; however, radiation may still be a problem in this era and you may think that cancer will still not have a cure. When thinking about the attributes in this era remember that the world will be very different to the one we know now and technology may be very advanced. You may think that the environment and quality of life in this era will be far worse than it is now and so we should give more weight to events that will happen in the future because of actions we take today.

Operating Costs

This is the yearly cost of operating the facility in normal conditions once it has been constructed this is measured in millions of pounds and varies for each facility. The costs shown below are the total costs for the whole of the period.

Facility	Operating Costs (millions £)
On Site	2400
Bury & Rebury	2400
Bury no Drainage	2200
Bury & Drainage	2000
Bury, Drainage & Cut-Off Walls	1880
High Tech	1800

The range of the Operating Costs is £600 million, this is 1.5 times the size of the range of the Construction Costs and so the Operating Costs could be given a value of 150 so that it is in line with the Construction costs. You may feel this is too high because of changes in the world which will make money worth less or too low because this generation did not benefit from the nuclear energy which caused the waste and so can use another value.

Please enter the value you think should be given to the Operating Costs in the 100 - 500 year era	

Accident Costs

These are the costs incurred due to adverse circumstances, for example an intrusion into the structure, these depend on which scenario occurs and the facility built. The costs include the cost of rebuilding and re-location and any intervention strategies applied to protect people.

	Cost in (millions £)
Lowest	0
Highest	4000

Relating this to the value given to the Construction Costs you could give it a value of 1000, however you may think that it should be given a bigger value to reflect the inconvenience of moving people and the distress the accident will cause; or you may think it is too high as technology may have advanced and so radiation will be less of a problem.

Please enter the value you think should be given to the Accident Costs in the 100 - 500 year era	

Environmental Impacts 100 - 500 Years

The long term impacts depend on the scenarios which may occur after the facility has been built. A scale was used to describe the impacts and to rank the outcomes. The impacts were to reflect loss of land, either agricultural or wild, and animals and their habitats because of an accidental release.

Level	Description
0	Radiation is no longer a problem so the facility can be dismantled.
1	No environmental disturbance.
2	Minimum environmental disturbance no radiation leakage, but new construction work is needed to rectify the problem.
3	Radiation reaches the environment and results in contamination of the local environment, but with minimum clean-up necessary. Construction is necessary to rectify the problem.
4	As 3 but a major clean-up operation is needed.
5	As 4 but long term environmental impacts occur and major re-building is necessary.
6	Relocate people and radioactive waste, the site is then unsafe for habitation.

You need to think about how important the environment is to you, think about how much you would be willing to pay to avoid the worst environmental impact. You could then relate this back to the Construction Costs to determine the weight you would like to give to this attribute. You may think that an accident in this time is not as severe because technology may have advanced so that cleaning up after an accident is less difficult, however you may think that it is more severe because the people living in this era did not benefit from the fuel which is now causing the problems.

Please enter the value you think should be given to the Environmental Effects in the 100 - 500 year era	

Health 100 - 500 Years

This attribute looks at the number of lives that will be lost due to radiation leakage in this era under the different scenarios.

	No. of Lives	Cost in (millions £)
Lowest	0	0
Highest	200	200

Comparing this to the Construction Costs could give the attribute a value of 50, you may think that this adequately covers the stress that will be incurred by the people who suffer because of the accident or you may think that the value needs to be increased to take this into account, you may want to compensate these people more because it is not their waste which is causing the problems; or you may think that medicine will have progressed sufficiently so that the number of deaths will be far less and so the value should be lower.

Please enter the value you think should be given to the Health Effects in the 100 - 500 year era	

Step 8 of 10

Attributes in the 500 - 10,000 Year Era

There is no way of predicting what the world will be like at this time, will man still exist? Even though we cannot answer the uncertainties we can predict what could happen because of the facility being built and because the facility will have an effect on this era we need to take this into account. There are no operating costs in this era as it is unrealistic to try to estimate what they will be.

Accident Costs

These are the costs incurred due to adverse circumstances, for example an intrusion into the structure, these depend on which scenario occurs and the facility built. The costs include the cost of rebuilding and re-location and any intervention strategies applied to protect people.

	Cost in (millions £)
Lowest	0
Highest	4000

Relating this to the value given to the Construction Costs you could give it a value of 1000. You may think that it should be lower because of technological advances which would make radiation less of a problem; or you may think that it should be given a bigger value to reflect the inconvenience of moving people and the distress the accident will cause.

Please enter the value you think should be given to the Accident Costs in the 500 - 10,000 year era	

Environmental Impacts 500 - 10,000 Years

The long term impacts depend on the scenarios which may occur after the facility has been built. A scale was used to describe the impacts and to rank the outcomes. The impacts were to reflect loss of land, either agricultural or wild, and animals and their habitats because of an accidental release.

Level	Description
0	Radiation is no longer a problem so the facility can be dismantled.
1	No environmental disturbance.
2	Minimum environmental disturbance no radiation leakage, but new construction work is needed to rectify the problem.
3	Radiation reaches the environment and results in contamination of the local environment, but with minimum clean-up necessary. Construction is necessary to rectify the problem.
4	As 3 but a major clean-up operation is needed.
5	As 4 but long term environmental impacts occur and major re-building is necessary.
6	Relocate people and radioactive waste, the site is then unsafe for habitation.

You need to think about how important the environment is to you, think about how much you would be willing to pay to avoid the worst environmental impact. You could then relate this back to the Construction Costs to determine the weight you would like to give to this attribute. You may think that the environment in this time will be worse than it is today and so environmental impacts should be given a high value; or you may think that technology will have advanced and so an accident would not cause an environmental problem and so want to give it a lower value.

Please enter the value you think should be given to the Environmental Effects in the 500 - 10,000 year era	

Health 500 - 10,000 Years

This attribute looks at the number of lives that will be lost due to radiation leakage in this era under the different scenarios.

	No. of Lives	Cost in (millions £)
Lowest	0	0
Highest	333	333

Comparing this to the Construction Costs could give the attribute a value of 83. You may think that the value should be decreased because medicine will have progressed sufficiently so that the number of deaths will be far less and so the value should be lower, or you may think that technology will have progressed and so radiation will not be a problem; or you may think that the value should be increased to take into account the stress that will be incurred by the people who suffer because of the accident, or you may want to compensate these people more because it is not their waste which is causing the problems.

Please enter the value you think should be given to the Health Effects in the 500 - 10,000 year era	

Step 9 of 10

Time Era Weights

You need to think about how important each era is in relation to the other eras, give the most important era a value of 1 and then relate the other eras to that, so your values should be between 0 and 1. If you think all the eras are equally important then you can give them all a value of 1. You may think that the 500 - 10,000 year era is not very important because it happens in the very distant future and you do not know what the world will be like then, so you may want to give it a smaller value or you may think that the future is more important as the people living then will not have benefited from the waste and so should be given more value as a compensation. It might help you if you think about which of your descendants will be around in each of the eras as this may help you to think about how important they are to you or the compensation you may want to give to future generations for the problems we will leave them. Maybe you would like your weights to reflect the way you think that the world will be for example you may think the planet will be in a much worse condition than it is today and so future generations should be given more weight because of this; or you may think that technology will be far better and so the people in the future will be better off and therefore do not need to be given as much consideration. You may want your weights to reflect the fact that the people who live in the future did not choose to have the waste facility and did not benefit from the energy produced or that they will benefit from the technology we have developed and so should be given less weight.

Please enter the value you think should be given to the different time eras your values should range between 0 and 1.

Immediate Era	
0 - 100 Years Era	
100 - 500 Years Era	
500 - 10,000 Years Era	

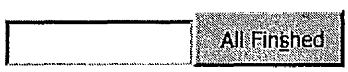
Step 10 of 10

Thank you for your time.

You are now ready to submit your model to the Analytica system. If you wish to check your entries, you may backtrack through any of the steps using the 'Previous' button.

The server will run your model and send the results via email.

Please enter your email address below and click the 'All Finished' button to begin the analysis.



Appendix 4 The Results of the First World Wide Web Experiment

This appendix contains the subjects' responses during the first World Wide Web experiment. Each subject is given a number, for ease of identification in each of the tables.

					Initial Facility Rankings					
Subject	**Job Title**	**Age**	**Sex**	**Country**	**OnSite**	**BuryRebury**	**Bury**	**Drains**	**Walls**	**HighTech**
1a	Student	23	M	UK	6	5	4	3	2	1
2a	Professor	38	M	Netherlands	3	1	6	5	4	2
3a	Committee Assistant	31	M	UK	5	6	1	2	3	4
4a	MSc Student	22	M	UK	6	5	4	3	1	2
5a	MSc Student	46	M	UK	6	3	5	4	2	1
6a	PhD Student	26	M	UK	5	1	6	4	3	2
7a	Lecturer	40	M	UK	5	4	3	2	1	6
8a	Msc Student	25	M	UK	6	5	4	1	2	3
9a	Student	25	M	UK	6	5	4	3	2	1
10a	Professor	50	M	USA	3	1	6	4	2	5
11a	MRes Student	23	F	UK	6	4	2	1	3	5
12a	Researcher	28	M	Belgium	4	5	6	3	2	1

Table A4.1

					Initial Facility Rankings					
Subject	Job Title	Age	Sex	Country	OnSite	BuryRebury	Bury	Drains	Walls	HighTech
13a	Student	21	F	UK	2	6	5	4	1	3
14a	Student	25	M	UK	6	4	5	2	1	3
15a	Student	21	F	UK	6	5	4	1	2	3
16a	Student	20	F	UK	6	5	4	3	1	2
17a	Student	20	M	UK	6	5	3	2	1	4
18a	Student	21	M	UK	6	5	4	2	1	3
19a	Student	23	M	UK	3	4	6	2	1	5
20a	MSc Student	31	F	UK	5	4	1	2	3	6
21a	MSc Student	21	M	UK	6	5	3	2	1	4
22a	MSc Student	22	M	UK	6	5	4	3	1	2
23a	Student	21	M	UK	4	6	3	1	5	2
24a	Student	20	M	UK	6	5	4	3	2	1

Table A4.2

					Initial Facility Rankings					
Subject	Job Title	Age	Sex	Country	OnSite	BuryRebury	Bury	Drains	Walls	HighTech
25a	MSc Student	29	M	P.R.China	6	5	3	4	1	2
26a	PhD Student	42	M	UK	1	2	3	4	5	6
27a	MSc Student	24	F	UK	6	4	3	2	1	5
28a	PhD Student	32	M	UK	1	2	3	4	5	6
29a	Professor	35	M	USA	3	1	6	5	4	2
30a	Assistant Director	45	M	Australia	5	3	2	1	4	6
31a	PhD Student	26	F	UK	6	5	2	1	3	4
32a	PhD Student	24	F	U.K.	6	5	4	3	2	1
33a	Policy Analyst	30	F	Netherlands	6	4	1	2	3	5
34a	Student	21	M	UK	5	6	3	1	2	4
35a	Behavioural Scientist	47	M	UK	2	1	6	5	3	4
36a	Research Assistant	25	M	Sweden	5	6	3	1	2	4

Table A4.3

					Initial Facility Rankings					
Subject	Job Title	Age	Sex	Country	OnSite	BuryRebury	Bury	Drains	Walls	HighTech
37a	MSc Student	42	M	Iran	3	2	1	5	4	6
38a	MSc Student	33	M	UK	6	5	3	4	2	1
39a	MSc Student	22	M	France	6	4	3	2	1	5
40a	MRes Student	29	M	Germany	4	5	6	3	2	1
41a	Research Fellow	32	M	UK	4	1	3	2	6	5
42a	Research Officer	28	M	UK	6	5	4	2	1	3
43a	Post Doctoral	28	M	Norway	5	4	6	3	2	1
44a	Research Fellow	28	M	UK	6	5	4	3	2	1
45a	Scientist	45	M	Germany	6	5	4	3	1	2
46a	MRes Student	21	M	UK	1	2	3	4	5	6

Table A4.4

	Immediate Attributes			0-100 Years				101-500 Years			
Subject	Construction	Health	Env	Operating	Accident	Env	Health	Operating	Accident	Env	Health
1a	100	1	1	37.5	1000	5000	25	400	10000	100000	500
2a	100	1	1	50	500	50	50	200	2000	200	400
3a	100	10	50	20	2000	1000	50	200	2000	1000	50
4a	100	1.5	30	37.5	1500	500	50	50	100	250	250
5a	100	1	1	450	1001	1	100	100	1000	2	10
6a	100	1	1	37.5	2000	3	25	150	800	3	50
7a	100	2	1	25	100	80	10	50	80	50	10
8a	100	25	15	60	2000	250	200	60	1500	200	200
9a	100	0.05	3	50	0.1	3	25	1000	500	3	100
10a	100	2	0.01	37.5	1000	10	50	1.5	500	5	100
11a	100	1.5	80	60	600	150	25	300	800	500	75
12a	100	100	10	37.5	1000	10	1000	150	1000	10	500

Table A4.5

	Immediate Attributes			0-100 Years				101-500 Years			
Subject	**Construction**	**Health**	**Env**	**Operating**	**Accident**	**Env**	**Health**	**Operating**	**Accident**	**Env**	**Health**
13a	100	1.5	1	25	1500	100	25	100	500	50	45
14a	100	2	10	40	500	50	35	75	300	20	40
15a	100	5	3	40	2500	3	15	200	2500	3	4
16a	100	4	5	6	7	3	1	8	9	10	5
17a	100	1	1	6	500	2	30	25	600	150	100
18a	100	1	3	40	1200	2	30	150	700	2	60
19a	100	0.5	3	40	1500	2	15	100	1200	2	75
20a	100	3	0.5	40	300	50	100	50	1	50	100
21a	100	5	5	450	850	5	35	2000	650	4	100
22a	100	3	4	50	1000	6	50	150	1000	6	50
23a	100	0.9	4	37	1000	2	25	800	900	2	50
24a	100	50	20	37.5	1000	1000	100	90	500	500	100

Table A4.6

	Immediate Attributes			0-100 Years				101-500 Years			
Subject	Construction	Health	Env	Operating	Accident	Env	Health	Operating	Accident	Env	Health
25a	100	15	50	30	1500	1000	50	50	800	100	80
26a	100	4	8	80	90	76	99	400	400	400	300
27a	100	2	3	15	1000	225	25	150	1000	2	35
28a	100	4	8	80	90	76	99	400	90	400	200
29a	100	2	15	7	166	150	50	7	25	25	50
30a	100	3.24	2	500	2000	25	25	2000	1000	50	50
31a	100	1	0.5	30	900	10000	300	110	800	5000	40
32a	100	3	50	37.5	1000	50	200	150	1000	50	300
33a	100	1	0.5	30	400	500	50	80	150	200	100
34a	100	5	1	60	1000	2	100	100	500	4	25
35a	100	1	1	60	600	100	50	200	600	200	80
36a	100	0.9	30	40	1100	70	30	150	900	60	50

Table A4.7

	Immediate Attributes			0-100 Years				101-500 Years			
Subject	Construction	Health	Env	Operating	Accident	Env	Health	Operating	Accident	Env	Health
37a	100	58	5	71	55	46	38	66	37	66	38
38a	100	1.5	1.5	38	500	50	50	80	500	200	80
39a	100	2	3	20	1000	2	25	150	1000	2	40
40a	100	0.5	1	40	2000	2	20	200	1200	2	100
41a	100	3	1	40	10	3	3	50	50	3	3
42a	100	10	10	50	1100	50	30	200	1100	50	75
43a	100	2	0.01	26.9	2000	2000	50	24.8	2000	8000	100
44a	100	1	5	40	1000	5	20	100	500	100	60
45a	100	10	5	38	1000	1000	1000	200	2000	2000	500
46a	100	50	80	80	89	69	81.678	11	12	13	14

Table A4.8

	501-10,000 Years			Time Era Weights				Facility Rankings After MCDA					
Subject	Accident	Env	Health	Now	0-100	101-500	501-10000	OnSite	BuryRebury	Bury	Drain	Wall	HighTech
1a	10000	50000	830	0.1	0.1	0.4	1	6487784	5705653.61	4504087	4471058	3953030	3874816
2a	2000	100	200	0.1	0.25	1	0.5	231977	209099.08	151993	142647	103802	95736.05
3a	2000	1000	50	0.5	0.8	1	1	441765	410541.62	303899	293231	240353	230541.3
4a	500	250	250	1	0.98	0.6	0.4	79082.8	86290.7	57363.9	55213.6	48426.8	47302.45
5a	1000	3	50	1	1	0.75	0.5	144997	148230.42	101605	83291.2	59792.6	51509.41
6a	800	4	80	1	1	1	0.5	122559	130507.52	84398.3	76508.6	56926.8	52573.05
7a	40	50	20	0.9	0.7	0.4	0.1	10086.3	16950.29	12463.2	12214.8	12333.6	12370.92
8a	500	200	100	1	1	1	1	199210	200027.63	135643	129776	100962	95346.89
9a	2000	2	100	0	0.1	0.3	0.6	122595	105725.15	83007.5	72486.7	57467.6	53125.68
10a	200	2	166	1	1	1	1	67071.5	71358.94	47116.3	45559.5	35335.5	33986.74
11a	500	100	100	0.8	1	0.5	0.1	698868	617433.59	499766	494010	457274	453496
12a	500	10	200	1	1	0.5	0.5	84329.5	86182.7	58566.8	56130.1	49317.5	47011.07

Table A4.9

	501-10,000 Years			Time Era Weights				Facility Rankings After MCDA					
Subject	Accident	Env	Health	Now	0-100	101-500	501-10000	OnSite	BuryRebury	Bury	Drain	Wall	HighTech
13a	400	50	50	1	1	0.75	0.25	66484.1	77439.25	48206.7	44147.8	34380.5	32310.75
14a	200	10	10	1	1	0.6	0.05	29426.7	38421.44	25218.6	23140.5	19957.6	18954.99
15a	5	1	1	1	1	0	0	39580	57343.1	28770.8	26304	21430	20834.27
16a	8	78	8	0	0.3	0.6	1	7023.7	6045.17	4819	4583.09	4015.39	3905.24
17a	1500	150	60	1	0.75	0.75	0.5	98194.4	94251.21	71588.9	71196	60425.4	59437.61
18a	600	2	90	1	1	1	1	120556	122029.61	84228.7	77205.2	59516.4	55645.92
19a	750	3	50	0.75	1	0.66	0.3	94191.4	100932.42	64674.9	59775.7	43877.6	40583.94
20a	25	10	100	1	1	1	1	24882.9	29912.49	20693.1	18578.1	16301.7	15684.13
21a	3500	6	180	0.8	1	0.9	0.8	466403	435876.54	317917	241133	171931	141530.3
22a	1000	6	160	0.75	1	0.5	0	56468.1	64995.58	40405.6	35694.2	25856.1	23206.83
23a	1000	2	83	1	0.8	0.6	0.4	122028	125993.63	86499.7	69194.1	49718.9	42227.39
24a	100	50	83	1	1	1	1	127925	135457.45	93839.9	89584.4	77561.7	73998.1

Table A4.10

	501-10,000 Years			Time Era Weights				Facility Rankings After MCDA					
Subject	Accident	Env	Health	Now	0-100	101-500	501-10000	OnSite	BuryRebury	Bury	Drain	Wall	HighTech
25a	500	100	83	0.8	1	0.8	0.5	120157	128846.65	86732.6	83753.9	70697.7	67910.01
26a	800	8000	6000	0.5	0.7	0.9	0.8	639864	503029.84	403701	389646	326831	320267
27a	500	2	50	1	1	0	0	22037.7	34049.04	20143.7	19856.2	18740.9	18909.59
28a	1000	100	300	0.99	0.99	0.3	0.3	58029.5	59031.87	44433.1	38921.5	33272.7	31111.2
29a	1	25	100	1	1	1	1	16011	22170.37	16200	17084.2	17426.4	17797.79
30a	0.1	0.1	0.1	1	1	0.8	0.2	288311	302061.52	195492	122600	67131.3	37848.61
31a	300	1000	40	1	0.9	0.7	0.4	550584	554396.95	405024	394144	347127	336832.2
32a	1000	50	500	1	1	0.5	0.3	85776.5	88895.38	60552.4	57725	47554.2	45206.34
33a	30	40	50	0.25	0.25	0.25	0.25	14815.9	16290.72	11411.6	10556.6	8973.98	8563.22
34a	100	4	20	0.8	1	0.7	0.4	51308.7	59688.19	37249.3	32552.2	24312.6	22012.2
35a	600	250	120	0.8	1	1	0.6	121064	119600.12	84699.9	75516.8	58145.8	53311.96
36a	400	30	50	1	0.9	0.75	0.5	88037.8	95549.82	63947.7	59183.5	46751.2	43466.05

Table A4.11

	501-10,000 Years			Time Era Weights				Facility Rankings After MCDA					
Subject	Accident	Env	Health	Now	0-100	101-500	501-10000	OnSite	BuryRebury	Bury	Drain	Wall	HighTech
37a	200	17	22	0.9	0.8	0.3	0.3	16061.3	23339.98	17872.2	17148.1	19558.8	19153.71
38a	50	50	80	1	0.7	0.5	0.3	36479.4	43328.48	29620.3	27985.9	23387.5	22357.04
39a	800	2	50	1	0.9	0.7	0.5	93777	98052.79	67419.3	62988.3	49060.4	46161.38
40a	2500	10	500	0.8	0.6	0.5	0.4	137511	131036.25	94052.1	89060.3	70735.3	67824.81
41a	50	3	3	0.4	0.2	0.2	0.2	3199.15	6081.94	4684.87	4586.97	4818.9	4858.09
42a	1100	50	83	1	0.9	0.8	0.8	153707	150835.01	108021	100772	80110.6	75591.05
43a	2000	190000	166	1	1	1	1	1.3E+07	10913496.2	8977970	8967690	8333203	8313920
44a	1000	100	100	1	0.8	0.2	0.01	24687.8	34958.35	21437.3	20144.3	17643	17168.84
45a	2000	2000	170	1	1	1	0.5	448711	416371.77	305177	293856	237763	226533.2
46a	1	2	3	1	0.85	0.2	0.00001	10407.6	21405.29	16487.2	17936.7	24805.1	24592.52

Table A4.12

Appendix A5 The Second World Wide Web Experiment

This appendix contains the World Wide Web pages used in the second experiment. Subjects were allowed to go back and modify their entries during a session and could return to the page as often as they wanted to. Although the author designed the experiment, the Web page implementation was by Dave Small.

VALUING THE FUTURE

Thank you for taking the time to visit this site.

The aim of these web pages is to obtain people's opinions about how the future should be valued. It will take about 20 minutes to complete the page. Your opinions will be used in research to determine how people view the future.

If you would like to receive a copy of the results of this research then please email liz@scs.leeds.ac.uk

Step 1 of 4

The Problem

Many projects with long term outcomes currently use a constant discount rate to (de)value the future. The UK treasury has used a rate of about 6%. However, when projects span thousands of years this means that the long term future is disregarded. Another possibility would be to give a weight to time eras in the future. This would involve dividing time into distinct periods and giving each period a weight to reflect how important it is in comparison to the other eras. Time could be divided up for several reasons:

- Because technology is changing;
- Because new legislation will come into effect;
- Because the uncertainty surrounding outcomes changes over time;
- Because people are less concerned about what happens after a certain point in time.

Time eras could be used to group together years which are equally important or which have some common feature. The value assigned to the eras would be used to reflect their relative importance and the trade-off between different time eras.

To try to investigate this idea we would like you to divide a thousand years into separate time eras and then give a weight to the eras to show how important they are to you, and the relative importance between them.

You may want to think about your affinity to the years, or how you imagine things may be changing, for example, technology or the World in general.

Thank you for your help with this research.

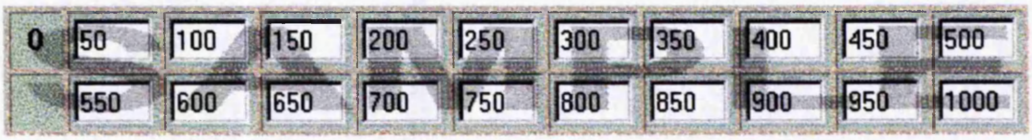
Please enter your personal details	
Name	
Age	*
Sex	Male Female
Nationality	
Job Title	
Email Address	

* We ask for your age (above) to determine if there are any differences in the way people of different ages view the future. Please respond as truthfully as you feel able.

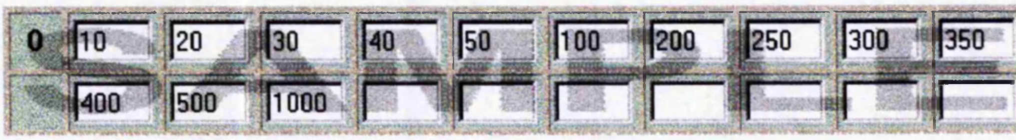
Step 2 of 4

The Time Eras

Please separate 1000 years into time eras, each era can be any length that you desire. On the next page you will be asked to give an importance weight to each era. For example, you might want to divide time in twenty 50-year intervals, in this case your boxes would look like this.



Alternatively, you may divide the 1000 years into different sized intervals. There is no need to fill all boxes, but please ensure you fill in consecutive boxes, and place **1000** as the final measure. An example follows:



Please divide the 1000 years into eras; enter the years in the box where you would like the time eras to end.

0	100	200	300	400	500	600	700	800	900	1000

Step 3 of 4

The Weights

Please enter the importance you think should be given to each of the time eras. For example, you might want to give all the eras the same weight; in this case you would type 1 in each of the boxes. This would mean that each time era was equally important to you. If you gave less weight to the latter time eras you would be saying that these eras were less important to you. Giving them more weight would mean that they were more important.

Please enter your values to reflect the importance of the eras.

The weights you give can be integers or decimals.

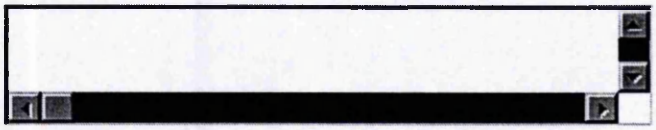
Time Era 0-100 years	
Time Era 100-200 years	
Time Era 200-300 years	
Time Era 300-400 years	
Time Era 400-500 years	
Time Era 500-600 years	
Time Era 600-700 years	
Time Era 700-800 years	
Time Era 800-900 years	
Time Era 900-1000 years	

Step 4 of 4

Final Comments

The following questions are designed to obtain your thinking about the weights and how they might change if the length of the project changed.

What was motivating you to give the weights that you did? Please enter your thoughts.



Please check-mark the box that reflects your opinions in the following questions.

If the project had outcomes which impacted people for only 100 years would the weight given to year 100 have changed?

I would have given year 100	
Less weight	○
The same weight	○
More weight	○

If the project had outcomes which impacted people for 2000 years would the weight you gave to year 100 have changed?

I would have given year 100	
Less weight	○
The same weight	○
More weight	○

If the outcomes of the project would adversely affect people living in the future would you change the weight that you gave to the future?

I would give the future	
Less weight	○
The same weight	○
More weight	○

If the outcomes of the project would benefit people living in the future would you change the weight that you gave to the future?

I would give the future	
Less weight	○
The same weight	○
More weight	○

If the outcomes of the project would benefit people living now, but adversely affect people living in the future how would you value the future in comparison to now?

I would give the future	
Less weight than the present	○
The same weight as the present	○
More weight than the present	○

Would the outcome of a project affect the weights that you gave to the future? For example, if it involved people becoming ill or dying?

Yes ○	No ○

Would the context of the project affect the weights you gave to the future? For example, would you change your weights if the project was concerned with nuclear waste?

Yes ○	No ○

If you answered yes, how would you change the weights you gave to the future?

I would give the future	
Less weight	○
The same weight	○
More weight	○

All Finished

The Results of the Second World Wide Web Experiment

This appendix contains the subjects' responses during the second World Wide Web experiment. Each subject is given a number, for ease of identification in each of the tables. At the end of the appendix the data is sectioned into age groups and the results of exact p value tests on the age group data is shown. There were no statistical differences between the subjects of different ages who took part in the experiment.

					Questions							
Subject	**Age**	**Sex**	**Nationality**	**Occupation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1b	25	F	British	PhD Student								
2b	29	M	British	Research Fellow								
3b	43	M	French	Researcher								
4b	27	M	British	Research Fellow	S	S	S	S	L	N	Y	M
5b	38	M	British	Research Scientist	S	S	S	S	S	N	N	
6b	33	M	USA	Economist	S	S	M	S	L	Y	Y	M
7b	30	M	Canadian	Defence Scientist	M	L				Y	Y	M
8b	23	F	British	Research Student	L	S	M	S	S	Y	Y	M
9b	29	M	German	Student	L	M	M	M	M	Y	Y	M
10b	43	M	USA	Technical Staff	M	S	S	S	S	N	Y	M
11b	36	M	Maltese	University Lecturer	M	S	M	S	L	Y	N	
12b	41	F	Australian	Senior Lecturer	S	L	S	S	S	Y	Y	M
13b	46	M	British	Project Nurse	M	S	S	S	M	N	Y	L

Table A6.1

L = Less; S = Same; M = More, Y = Yes; N = No.

					Questions							
Subject	Age	Sex	Nationality	Occupation	1	2	3	4	5	6	7	8
14b	18	M	Portuguese	Student	S	L	S	M	L	Y	Y	M
15b	29	M	British	Higher Research Officer	S	M	M	M	M	Y	N	
16b	30	M	British	Senior Lecturer in Geology	S	S	S	S	S	N	N	
17b	27	F	British	Production Manager	M	S	M	S	S	Y	Y	M
18b	37	M	Irish	Epidemiologist	S	S	M	S	M	Y	N	
19b	30	M	British	University Lecturer	S	S	S	S	S	N	Y	M
20b	23	F	British	Student	S	M	S	M	S	Y	Y	L
21b	53	M	Brazilian	University Professor	S	S	M	S	M	Y	Y	M
22b	29	M	British	Lecturer	S	L	M	M	M	Y	N	
23b	29	F	British	Lecturer	S	L	M	M	S	Y	N	
24b	24	M	USA	Maths Teacher	M	L	S	S	L	N	N	
25b	35	M	Swiss	Senior Lecturer	S	S	S	S	L	N	N	
26b	25	F	French	PhD Student	M	S	S	S	L	N	Y	M

Table A6.2

L = Less; S = Same; M = More, Y = Yes; N = No.

					Questions							
Subject	**Age**	**Sex**	**Nationality**	**Occupation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
27b	25	M	Swiss	Engineer	L	S	M	M	M	N	N	
28b	32	M	British	Director	S	S	S	S	S	N	N	S
29b	36	M	British	Photographer	M	S	M	M	S	Y	Y	M
30b	39	F	British	Project Manager	S	S	S	S	S	N	N	
31b	30	F	British	Environmental Project Officer	S	S	S	S	M	Y	N	
32b	26	F	British	Project Officer	M	S	M	M	M	Y	Y	M
33b	29	F	British	Research Assistant								
34b	24	M	Welsh	EHO Pollution Control	L	M	M	S	M	Y	N	L
35b	48	M	USA	Policy Specialist	L	M	S	S	S	Y	Y	M
36b	32	M	British	Research Fellow	M	S	M	S	S	Y	N	
37b	31	M	German	Research Assistant	S	S	S	S	S	N	N	
38b	25	M	Belgian	Programmer	S	S	S	S	S	N	N	
39b	45	F	Belgian	Technician/Biochemistry	S	S	S	S	S			S

Table A6.3

L = Less; S = Same; M = More, Y = Yes; N = No.

					Questions							
Subject	**Age**	**Sex**	**Nationality**	**Occupation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
40b	32	M	Belgian	Scientist	L	S	S	S	S	N	N	
41b	22	M	British	MSc Student	S	M	S	S	S	N	N	
42b	30	M	Belgian	Project Engineer	L	M	S	S	S	Y	N	
43b	42	M	Belgian	Project Engineer	S	S	S	S	S	N	N	
44b	22	M	French	Student	M	S	M	S	M	Y	Y	M
45b	25	M	British	Research Student	S	S	M	S	S	Y	Y	M
46b	50	M	Belgian	Y2K Co-ordinator	S	S	S	S	S	N	N	
47b	40	M	Belgian	Researcher	L	L	S	S	S	Y	N	
48b	52	M	Belgian	Project Leader	L	M	S	S	L	Y	N	
49b	40	M	Belgian	Project Manager	S							
50b	52	M	Belgian	Department manager	S	S	M	S	S	Y	N	
51b	53	M	Belgian	Marketing Director	S	S	S	S	L	Y	N	
52b	27	M	Belgian	Sustainable Development	S	S	S	S	L	Y	N	

Table A6.4

L = Less; S = Same; M = More, Y = Yes; N = No.

					Questions							
Subject	**Age**	**Sex**	**Nationality**	**Occupation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
53b	37	M	Belgian	Sustainable Development	L	S	S	L	M	Y	Y	M
54b	61	M	Belgian	Manager CO2-Mitigation	S	S	S	S	L		N	
55b	45	M	German	Scientist	S	S	M	S	M	Y	N	
56b	29	F	Belgian	Scientific Researcher	S	S	M	S	S	Y	N	
57b	32	F	Belgian	Economist	S	S	M	S	M	Y	Y	M
58b	38	M	British	Lecturer	M	S	M	M	S	Y	Y	M
59b	43	M	Colombian	Senior Lecturer	M	S	S	L	S	Y	N	
60b	25	M	Belgian	Scientific Collaborator	S	S	M	S	S	Y	N	
61b	25	F	British	Research Assistant	L	S	M	L	L	Y	Y	M
62b	54	M	USA	Director	M	M	M	M	L	Y	N	
63b	49	M	German	Director MUT	L	S	S	S	S	N	N	
64b	28	F	Greek	Research Associate	S	S	M	S	S	Y	N	
65b	34	F	Belgian	Psychologist	M	S	S	S	L	Y	Y	M

Table A6.5

L = Less; S = Same; M = More, Y = Yes; N = No.

					Questions							
Subject	**Age**	**Sex**	**Nationality**	**Occupation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
66b	31	F	British	PhD student	S	S	M	S	M	Y	Y	M
67b	26	F	British	Research Engineer	S	S	M	L	M	Y	Y	M
68b	26	M	Austrian	Junior Fellow/Student	S	S	M	L	S	Y	Y	M
69b	43	M	Portuguese	Professor	S	S	S	S	S	N	N	
70b	30	M	Belgian	Research Assistant	M	L	S	S	S	N	N	
71b	41	F	Portuguese	Professor	M	S	S	M	M	Y	Y	M
72b	32	M	Portuguese	Engineer	S	S	L	M	L	Y	Y	M
73b	32	M	British	Researcher	L	M	M	L	M	Y	N	
74b	29	M	Portuguese	Researcher	S	S	S	S	S	N	N	
75b	22	M	Portuguese	Student	M	L	M	M	S	Y	Y	M
76b	27	M	British	Investment Banker	L	M	S	S	L	N	N	

Table A6.6

L = Less; S = Same; M = More, Y = Yes; N = No.

Subject	Time Eras And Weights																			
1b	50	100	200	400	650	1000														
	1	1	0.8	0.7	0.5	0.4														
2b	10	20	30	40	50	100	200	300	400	500	1000									
	1	1	1	0.8	0.7	0.6	0.2	0.1	0.1	0	0									
3b	100	1000																		
	1	1																		
4b	5	10	20	30	50	75	100	150	200	300	400	500	1000							
	1	0.9	0.75	0.6	0.5	0.4	0.4	0.3	0.3	0.2	0.2	0.2	0.2							
5b	1	2	5	10	20	50	100	200	500	1000										
	1	1	1	1	1	1	0.5	0.5	0.5	0.5										
6b	1	2	4	8	16	32	64	128	256	512	1000									
	1	0.99	0.97	0.94	0.88	0.82	0.75	0.65	0.5	0.5	0.5									
7b	50	100	150	250	500	1000														
	1	0.8	0.6	0.4	0.2	0.2														

Table A6.7

Subject	Time Eras And Weights																			
8b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	0.89	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.89	0.89	0.89	0.78	0.89	0.89	0.89	0.89	1
9b	100	200	300	400	500	600	700	800	900	1000										
	1	0.5	0.4	0.3	0.3	0.1	0.1	0.1	0.1	0.1										
10b	1	10	50	100	500	1000														
	0.33	0.33	0.33	1	1	1														
11b	200	400	600	800	1000															
	0.5	0.25	0.25	0.5	1															
12b	50	70	100	120	180	250	300	350	400	500	600	700	800	900	1000					
	1	0.9	0.9	0.8	0.8	0.7	0.6	0.6	0.6	0.5	0.5	0.4	0.3	0.3	1					
13b	5	10	20	30	40	50	100	150	200	300	400	500	1000							
	0.33	0.33	0.33	0.33	0.33	0.33	0.67	0.67	0.67	1	1	1	1							
14b	100	200	300	400	500	600	700	800	900	1000										
	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1										

Table A6.8

Subject	Time Eras And Weights																		
15b	1	2	3	5	8	13	21	34	55	89	144	233	377	610	1000				
	1	0.8	0.6	0.4	0.4	0.4	0.4	0.2	0.2	0.2	0.2	0.1	0.1	0.1	0.08				
16b	100	200	300	400	500	600	700	800	900	1000									
	1	1	1	1	1	1	1	1	1	1									
17b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
18b	10	20	40	60	100	250	500	750	1000										
	1	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5										
19b	5	20	50	100	150	200	300	400	500	1000									
	1	0.9	0.7	0.6	0.5	0.3	0.3	0.3	0.3	0.3									
20b	5	10	15	25	50	100	200	300	400	500	600	700	800	900	1000				
	0.2	0.2	0.2	0.4	0.4	0.6	0.6	0.8	0.8	0.8	0.8	1	1	1	1				
21b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	1	0.65	0.53	0.41	0.29	0.18	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06

Table A6.9

Subject	Time Eras And Weights																	
22b	25	50	75	100	125	150	200	250	300	350	400	500	600	700	800	900	1000			
	1	1	1	1	0.75	0.75	0.75	0.5	0.5	0.5	0.5	0.5	0.4	0.3	0.2	0.2	0.2			
23b	20	40	100	150	250	350	450	550	650	750	850	950	1000							
	1	1	1	1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8							
24b	200	375	525	650	760	850	930	970	990	1000										
	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1										
25b	1	5	10	15	20	50	100	250	500	1000										
	1	1	1	1	1	1	0.83	0.83	0.33	0.33										
26b	25	50	100	150	200	300	500	750	1000											
	1	0.94	0.89	0.78	0.67	0.56	0.56	0.56	0.56											
27b	10	25	50	100	200	500	1000													
	0.67	0.67	0.67	0.33	0.33	0.67	1													
28b	50	100	150	200	300	400	500	600	700	800	900	1000								
	1	1	1	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9								

Table A6.10

Subject	Time Eras And Weights																			
29b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
30b	100	200	300	400	500	600	700	800	900	1000										
	1	1	1	1	1	1	1	1	1	1										
31b	10	20	50	100	200	500	1000													
	1	1	1	1	1	1	1													
32b	5	10	20	30	50	100	250	500	1000											
	1	1	0.7	0.5	0.5	0.5	0.3	0.2	0.2											
33b	250	500	1000																	
	1	0.9	0.8																	
34b	500	600	700	800	900	950	1000													
	0.1	0.2	0.3	0.4	0.6	0.8	1													
35b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table A6.11

Subject	Time Eras And Weights																			
36b	5	10	20	50	100	200	500	1000												
	1	0.8	1	1	1	0.5	0.5	0.5												
37b	50	150	1000																	
	1	0.1	0.01																	
38b	5	10	20	50	100	200	500	1000												
	1	1	1	1	1	1	0.75	0.5												
39b	25	50	75	100	150	200	250	300	400	500	750	1000								
	1	1	1	1	0.8	0.8	0.8	0.5	0.5	0.5	0.5	0.5								
40b	20	50	100	300	1000															
	1	0.8	0.6	0.4	0.2															
41b	10	20	30	40	50	100	200	300	400	500	600	700	800	900	1000					
	1	0.86	0.71	0.57	0.57	0.43	0.29	0.29	0.29	0.14	0.14	0.14	0.14	0.14	0.14					
42b	5	10	20	40	60	100	150	200	500	1000										
	0.5	0.5	1	1	1	1	0.5	0.5	0.5	0.5										

Table A6.12

Subject	Time Eras And Weights																			
43b	5	10	20	30	50	100	200	500	1000											
	1	1	1	1	1	1	1	1	1											
44b	100	200	300	400	500	550	600	650	700	750	800	850	900	950	1000					
	1	0.5	0.6	0.8	0.9	1	0.9	0.8	0.8	0.9	1	0.9	0.8	0.8	0.9					
45b	60	160	260	460	660	960	1000													
	1	0.67	0.33	0	0	0	0.25													
46b	10	20	30	40	50	100	200	300	400	500	1000									
	1	0.9	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1									
47b	5	10	20	40	80	160	320	640	1000											
	1	1	1	1	1	1	1	1	1											
48b	10	20	50	100	200	500	1000													
	1	0.9	0.7	0.6	0.4	0.3	0.2													
49b	25	50	100	300	500	1000														
	1	1	0.67	0.67	0.33	0.33														

Table A6.13

Subject	Time Eras And Weights																			
50b	30	80	150	300	500	1000														
	1	1	0.5	0.2	0.1	0.1														
51b	100	300	500	600	700	750	800	850	900	950	975	1000								
	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5								
52b	10	30	50	100	200	300	400	500	600	700	800	900	1000							
	1	1	0.75	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4							
53b	10	20	40	60	100	150	200	300	400	500	650	800	1000							
	0.5	0.75	1	1	1	0.75	0.75	0.75	0.75	0.75										
54b	10	30	100	1000																
	1	1	0.1	0.01																
55b	5	15	50	150	500	1000														
	1	1	0.8	0.5	0.3	0.3														
56b	20	40	60	80	110	150	200	250	300	400	500	600	700	800	900	1000				
	1	1	1	1	1	1	1	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75				

Table A6.14

Subject	Time Eras And Weights																			
57b	5	10	20	30	40	50	100	200	300	400	500	750	1000							
	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5	0.5							
58b	5	10	20	30	40	50	100	250	500	750	1000									
	0.14	0.29	0.43	0.57	0.71	0.86	1	1	1	1	1									
59b	5	15	65	165	500	1000														
	1	1	0.8	0.5	0.3	0.1														
60b	30	50	100	150	250	300	500	700	1000											
	1	1	1	0.5	0.5	0.5	0.2	0.2	0.1											
61b	5	10	20	30	40	50	75	100	150	200	300	500	1000							
	1	1	0.75	0.75	0.5	0.5	0.4	0.3	0.25	0.1	0.1	0.08	0.05							
62b	10	20	50	100	150	300	400	500	1000											
	1	0.5	0.3	0.2	0.1	0.1	0.1	0.1	0.1											
63b	50	100	1000																	
	1	0.5	0.17																	

Table A6.15

Subject	Time Eras And Weights																			
64b	5	10	20	50	100	500	1000													
	1	0.98	0.96	0.92	0.9	0.7	0.1													
65b	5	10	20	30	40	50	60	70	80	100	150	200	300	400	500	750	1000			
	1	0.75	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5			
66b	1	5	10	20	30	40	50	75	100	150	200	300	400	500	600	700	800	900	1000	
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	1	1	1	1	1	1	1	1	
67b	10	25	50	100	200	300	400	500	750	1000										
	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1										
68b	1	5	20	60	150	1000														
	0.5	1	0.5	0.5	0.25	0.13														
69b	1	5	25	75	375	1000														
	1	0.9	0.5	0.2	0.1	0														
70b	10	30	50	75	100	200	300	400	500	750	1000									
	1	0.6	0.6	0.4	0.4	0.2	0.08	0.08	0.08	0.04	0.04									
	1	0.95	0.9	0.85	0.8	0.75	0.7	0.65	0.6	0.55	0.5	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05

Table A6.16

Subject	Time Eras And Weights																		
71b	50	100	200	500	750	1000													
	1	0.67	0.67	0.33	0.33	0													
72b	20	50	100	500	1000														
	1	0.8	0.6	0	0														
73b	1	2	5	10	30	100	300	1000											
	1	0.67	0.67	1	0.67	1	0.33	0.67											
74b	10	25	50	100	200	300	400	500	600	700	800	900	1000						
	1	1	1	0.67	0.67	0.67	0.67	0.67	0.33	0.33	0.33	0.33	0.33						
75b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.2	0.4	0.6	0.8	0.8	1
76b	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000

Table A6.17

Subject	Reasons for Time Eras and Weights
4b	Mostly uncertainty about the state of knowledge in the future with regards to technological advances, and I must admit there was an element of selfishness involved.
5b	The question is quite ambiguous: are we weighing time-points or durations? So for example I gave a weight of 2 to year 1, 2, 5, 10 etc. and a weight of 1 to 50, 100, 200 etc. What does this (i.e. your use of 'importance' MEAN?) My interpretation was that I was weighting each block; i.e. I gave the same weight to the whole periods (time-blocks) 0-1 year, 1-2 year, 2-5 years, and half these weights to the entire periods 50-100 100-200, 200-500, 500-1000. There is a large literature on discounting in health economics (contact Prof. John Cairns at Aberdeen): is it clear that a social discount rate should be an aggregate of individual time-preference rates. Time Preference Rates are not the only factor in the rationale for discounting Discount rates may depend on the quantity addressed (health or money..), gain or losses, your own or others, sequence effects (what happens before and after).
7b	The nearest future is the most important.
9b	The time I am living and the time of the children.
10b	I gave equal weight to my remaining life-span, the life-span of my children, the life-span of their children and grandchildren, and the life-span of all future generations.
11b	The beginnings always assume a certain greater importance than a mid-way through period... The later stages gain importance cognisant of the fact that as something starts to end one asks what has been done... which is a motivation to get things done at a faster rate.
12b	I think people are concerned about the future 50 to 100 years, then they would not think much about the rest of the time until it comes to a 1000 years point, as a kind of milestone.

Table A6.18

Subject	Reasons for Time Eras and Weights
13b	My lifetime feels most important to me, may be as I've got older I realise that I am the sum of all the parts and not just the more recent ones. Beyond recent centuries, it is now to knowingly feel any resonance from 'eras' - I know of the '30s' but can remember the sixties.
19b	Greater weights for the very near and medium terms because reflecting little scope for technological developments (e.g. thinking about environmental protection. Relatively high weights for the next 150 years or so, selfishly reflecting the period of my life and that of my (possible!) children/grandchildren. But lower than near term, due to greater development and substitution possibilities. Significant weight still attached to very long term, as I don't believe we have the right to impose full costs of our actions onto future generations - but technological and other developments will certainly reduce the costs of cleanup etc in the future.
20b	Own personal stage in life, career and relationships perception of the possible human and technological developments.
21b	I would value the present and immediate future generations simply because: (i) I think I understand their values in a better way; (ii) their would be my own as well as my child's and the children of my child's generations.
22b	Environmental effects and human lifetimes.
23b	What may happen in my lifetime, what may happen in the lifetime of my children and the next succeeding generations. Thereafter, I feel more detached but still feel a high concern for the future, it is still important to me what the future will be like and what legacies we are making but perhaps not as important as right now.
24b	As technology improves, change moves at a greater speed with more impact.

Table A6.19

Subject	Reasons for Time Eras and Weights
25b	It is very difficult to estimate correctly the consequences of a project in 100, 500 or 1000 years. It does not mean that we should not take this information into account, but it seems to me that it is more relevant to give more weight to the information we know with a better precision. Another thinking is that the context will not change a lot in 1, 5 or 10 years. But what do we know about the state of the planet in 100, 500 or 1000 years ?
26b	I value the present higher than the future. It's equivalent for me to consider 500-750 or 750-1000 : it seems too far to make a difference.
27b	Either thinking short way, or very long way. You have to work for the next years and for a sustainable development.
28b	I found this task totally arbitrary, as there was no guidance on the nature of the time period or the purpose of the weights. I assumed the task to be referring to the NEXT 1,000 years, i.e. 1999 to 2098, and I assumed importance to be referring to quality of human life and environment. This latter assumption was an arbitrary one, chosen because it happens to be important to me (and because it was partially implied by some of the examples on your first page). I do not think that my weights would ever decrease no matter how much further into the future you projected. The whole point of sustainability is that it has to be permanent. The only variation in my weights would ever be that the next century or two would get a very slightly higher weighting than later periods, in recognition of the selfish (self interest) element of human nature - i.e. this is the period when I and my offspring who I will know personally (children, grand-children) will be alive. However, the weights might change if you were to more clearly define what they were meant to reflect, e.g. importance of the ability of the planet to support a variety of flora and fauna vs. importance of the ability of humans to live long healthy lives, vs. importance in terms of likely impact on the future of these aspects, etc.
30b	All eras should be treated with equal importance. Decisions taken at any stage might preclude options at later stages. It is important to try and assess the implications of decisions made on future options and goals/targets.

Table A6.20

Subject	Reasons for Time Eras and Weights
31b	The value we place on the current time and any time in the future should not be based on our own life-spans or even that of our children. Each and everyone of us has a duty to preserve the planet and, if possible, improve it for all life ahead of us. This should apply to all decisions we consider whether they be social, environmental of economical. A short-term decision that benefits us immediately is unlikely to be sustainable. Consideration for the future should not mean that we deprive people today but that we think about the consequences of our actions before endeavouring on any project, whether it be to do with nuclear power, education, the NHS, genetically modified soya or simply the air that we breath.
32b	That we are able to "predict" more accurately the shorter term future but longer term projects can not be foreseen as well. By placing more influence on the shorter term it should be possible in the future to make more reasoned justification.
33b	I'm sorry but without knowing what you mean by 'the project' I cannot comment. Do you mean a dam project, a research project, your study even? I can't see how your results can be meaningful without at least a little context...
42b	The reason why I consider the period 0-10 years less important than, say, 10-100 years, is that on short term, one may choose sub-optimal solutions to e.g. storage of nuclear waste. However, on a time scale of 50-100 years, one should study the solutions to this problem a lot better, to come up with something that is much more durable, that does not compromise the quality of life of future generations.
43b	The weights are equal because, if the long term cannot be sacrificed for the short term, the reverse proposition is also true.
44b	My weights are defined based on my current knowledge of a future on our current basis. I consider that what is done today can last but it will always be more difficult to maintain as the techniques used at this time would not be available or at a very high cost it might not worth. However I expect the future to provide us with better techniques and tools giving an opportunity to have something better for a better cost than today.

Table A6.21

Subject	Reasons for Time Eras and Weights
45b	Well first 60 years is about my lifetime so is of most concern to me, I have a stake in what happens in the next few generations possibly so hence some interest in next couple of centuries. Rest of time is beyond my conception as to what will happen and thus of no importance.
46b	How far in the future, how meaningless whatever we can think about it.
47b	Uncertainty increases with time, therefore the far future is less important than the near future. On the other hand future generations should be accorded a level of protection consistent with that provided today.
48b	The farther in the future, the longer the periods are in which the scores do not change. A gradual change in the weights are then given with some discontinuities after the time period corresponding to one generation (20 y) and after the average lifetime of an individual (at 100 year).
51b	The periods in the near future have a relatively greater importance given the fact they are more perceived as real. Of course, this is rather subjective as a motivation. On the other hand, I am convinced the evolution of technology will in a way continue in an exponential way. This has as a consequence that any consequence of any long term event will be submitted to a proper exponential evolution or submitted to an environment that has its own exponential evolution. Therefore, we could say that: -If the consequences are foreseeable and fixed, its influence will in the far future be lower than foreseen now. -If the project has its own evolution, this evolution could be greater than now to be foreseen and a far away period could have a greater impact. I considered more the second possibility, where it could be said that shorter periods in the future will have a greater impact.

Table A6.22

Subject	Reasons for Time Eras and Weights
52b	The higher weights in the first 50 years reflect my personal statistical life-span. The first couple of 100 years, I can still imagine my grandchildren having grandchildren of their own. After some 200 years or so, it becomes hard to change my time preference, which in any case should be lower than the one for the near future. However, I see no reason to reduce my time preference after between 200 and 1000 or longer.
53b	The first period is already determined by the past? The second less determined, but still. The green gas effect is very important in the following period. After this period, this problem in less important, but nuclear is important.
54b	1. Short term (10 and 30 years; Kyoto and the near future): the decisions are already taken and decided investments should be depreciated as planned. If not you destroy wealth. 2. Medium term (100 years, the residence time of GHG Greenhouse Gasses in the atmosphere): Cf. on this topic Ari Rabl's "Discounting of long term costs: What would future generations prefer us to do?" Ecological Economics 17 (1996) 137-145 3. Long term (1000 years, the ozone problem): I suppose that the difference between the growth rate of the GNP and the escalation rate (inflation) will be about 1%. That's why I choose 0.01 for intergenerational discounting. Your example concerning the risks of long-living radio-active waste is not relevant on the point of view of risk. It represents an extremely low risk (cf. Bernard Cohen: ISBN 0-306-43567-5).
56b	I believe I cannot even imagine what society would be like in two hundred years and beyond; I can imagine wanting to be responsible for my 'offspring' for a few generations, but further than 200 years seems pointless. The reason for not weighting 0 beyond 200 years is that I wish for humanity to prosper, but I don't think my life will bear any influence on society or the world past +/-200 years.
57b	Weight 1 for the first 100 years because we can do something about it, after that nobody has an idea of what's going to happen (new technologies...).
58b	Whether or not I will be alive to experience the eras. The increasing difficulty of predicting how the world will change in total as the time from present increases.

Table A6.23

Subject	Reasons for Time Eras and Weights
59b	The direct effect on my own working life has more weight since I can react to it. Second come the days of my retirement. The direct effect on the life of my children, comes third. The life time of two generations after me have less weight than the above. After two generations and before 500 years, I won't personally be affected, but what ever we do in the current generation is likely to have an impact there. After 500 years the world will be completely different from what we know today, and the influence of our generation will be nil.
60b	I give the bigger weight to the period concerning human life or human civilisation. Speaking about time interval of 1000 don't seem to be very realistic if we look to the human life time and the human evolution.
61b	I imagined the 1000 years starting from now and thought about my expected life span and weighted accordingly. When considering eras of over a hundred years I thought of historical events that occurred that length of time ago and their relative importance to me. This is how I value my future, this is not necessarily how I would like society to value the future.
62b	The closer in time the greater the personal impact. The more distant the less the ability to forecast.
63b	Degree of uncertainty.
64b	I valued the present more than the future. I care for the future generations but I believe that future technology will be so advanced that any major disasters could be prevented.
65b	The possibility of me being still alive in that particular era. The distance between now (= 0) and the particular era. The possibility that certain events, decisions might influence that era. Or the people living in it.

Table A6.24

Subject	Reasons for Time Eras and Weights
66b	I tried to work out how many generations there would be in 200 years. I've also been thinking that due to nuclear weapons etc. there probably won't be anyone around in the next 100-200 years anyway. Sorry to sound so pessimistic!
73b	Concerned about short, medium and long term damage, avoiding concern merely over the life of one parliament. Kinetic and thermodynamic constraints can mean excessive long term concern translates into overspending over the short term, but concern remains. 100-300 could take care of itself so long as shortish and longish concerns are considered.
74b	The first eras are most important because the next eras are influenced by the previous eras.
76b	The theory of causality infers an inverse pyramid methodology, with the start of the period of time at its base. The earlier years are more important because they can determine the later years. At the end of the 1000yr period, the very last 1/xth second (where x is infinity) of the very last day of the very last year should have a zero weighting - i.e. because weighting in this case implies the degree of influence, at this extreme, the period of time in question would have no weighting because it would have zero influence.

Table A6.25

The following tables show the data divided into age groups and the results of the exact p value tests performed on the data.

	Motivations			
Age Group	Affinity	Obligations	Technology	Uncertainty
< 30	13	7	4	2
30 +	16	6	1	7

Table A6.26: Motives of the Different Age Groups

	Time Era Sizes			
Age Group	Decreasing	Equal	Increasing	Increasing/ Decreasing
< 30	0	8	28	1
30 +	1	4	33	0

Table A6.27: Time Eras of the Different Age Groups

	Time Era Weights			
Age Group	Decreasing	Equal	Increasing	Increasing/ Decreasing
< 30	26	3	1	7
30 +	24	5	4	5

Table A6.28: Time Era Weights of the Different Age Groups

	Best Fit of Time Era Weights	
Age Group	Hyperbolic	Exponential
< 30	7	10
30 +	10	2

Table A6.29: Shape of the Time Era Weights of the Different Age Groups

Statistic	Exact p Value
Motives (Table A6.26)	0.22
Time Eras (Table A6.27)	0.218
Time Era Weights (Table A6.28)	0.478
Discount Models (Table A6.29)	0.23

Table A6.30: Exact p Values Between the Age Groups