Readings in Decision Analysis

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A collection of edited readings, with accompanying notes, taken from publications of the Operational Research Society of Great Britain.

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This collection of readings and notes was developed originally for a tutorial day on Decision Analysis, which I gave in the Spring of 1986 at the behest of the Operational Research Society. It is a feature of the Society's tutorial days that participants are provided with substantial handouts. I have an aversion to writing what has already been written. Thus I developed much of the handout from material previously published in the Journal of the Operational Research Society, formerly known as the Operational Research Quarterly. The Resulting collection of readings and accompanying notes received favourable comments both from the participants at the event and from several colleagues. I also used the notes with several groups of MSc students taking management options, and again received favourable comment. These comments, and my own ambition,

forms a constent whole: a picture of decision analysis as it is practised

have led me to seek publication in a more permanent form.

I believe that this collection can help satisfy various needs. Firstly, it can serve as a primary text for students on undergraduate and postgraduate management courses. Although decision analysis is fundamentally a quantitative technique, the presentation here involves little beyond basic arithmetic and the ability to read the occasional symbol, perhaps complicated by a subscript or two. Secondly, for students meeting decision analysis on more quantitative courses, e.g. operational research, statistics or mathematics, the collection provides supplementary reading to support more mathematical texts such as my Decision Theory: An introduction to the mathematics of rationality (Ellis Horwood, 1986) or Jim Smith's companion volume to this (Decision Analysis: A Bayesian approach, Chapman and Hall, 1988). Such supplementary reading is essential if students are not to be left with a 'recipe book' view of decision analysis. They need to see case studies so that they may appreciate how quantitative results are interpreted qualitatively in practice. Thirdly, portable, powerful, interactive computing means that decision analysis is finding more and more applications in industry, commerce and government. Operational research practitioners and management consultants need texts to refresh and update their memories of techniques once only encountered in academic courses.

I hope that what follows is not merely a collection of reprints with a few accompanying notes and comments. I have tried to edit and weave the

several extracts and papers together with material of my own so that it forms a coherent whole: a picture of decision analysis as it is practised today. One point that I should make is that, although I have drawn heavily on the writings of others, I do not claim necessarily to have reflected their views fairly. My aim has been to describe decision analysis as I see it. In selecting material to include, in quoting from some papers and in referring to others, I have emphasized the issues that I see as central. I have often discarded or discounted material that I see as peripheral; doubtless, the original authors did not see it as such. If I have offended anyone by doing so, I apologize.

Naturally, I am grateful to many people for assistance:

- 1. The Operational Research Society for inviting me to give the tutorial day. Indeed, they were foolish enough to ask me to repeat the exercise in February 1988, thus giving me the opportunity of refining my notes again as I was preparing this book.
- 2. Ray Showell, who has handled the Society's interests in producing this collection in a manner that could not been more helpful.
- 3. Elizabeth Johnston of Chapman and Hall, who could have found more cooperative, punctual authors elsewhere, but put up with me nevertheless.
- 4. Peter Hall, Roger Hartley, Patrick Humphreys, Dennis Lindley, Larry Phillips, Jim Smith, Lyn Thomas, Marilena Vassiloglou, Doug White and many others with whom I have discussed the role and purpose of decision analysis.
- 5. Those authors whose work I have remorselessly pillaged to serve my

And last, but certainly not least:

6. My family, who nodded knowingly a few years ago when I promised never to write another book, yet supported me wholeheartedly when I did. mil to face boowsoff siles released or line solumentan

To all, thank you. A sandank nor read and a smuloy remanding. Chapman and Hail, 1988). Such supplementary read

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Foreword

This book sprang from a Tutorial Event on Decision Analysis conducted by Simon French, which was organized by the Operational Research Society in 1986 during my term of office as President of the Society. Indeed, it was the first such event in a series which is now a well-established feature of the British Operational Research scene.

It is certainly extremely satisfactory that Professor French's pathbreaking tutorial has also given us this permanent contribution to the literature on decision analysis. The unusual format, in which case studies and other previous papers illuminate and complement the original text, is one which other authors might well emulate. Indeed, the republication in readily accessible form of so many excellent practical studies would itself be an event to celebrate in any field.

This book, of course, does far more than that. It provides and admirably simple and lucid introduction to the subject of decision analysis, and takes the reader with the minimum of mathematical apparatus through the main concepts and types of application. The reader will reach the boundaries of the subject, where issues are still being hotly debated and new territory staked out. The emphasis of the book, on generating understanding rather than optimal solutions, is one I wholeheartedly support.

Decision analysis is a topic of growing practical importance. It deserves to be taken seriously; so I will take this opportunity to touch briefly on a few questions, some explicitly raised in the book and some not, which readers might profitably mull over as they digest the contents. Are probabilities the most appropriate way of representing the uncertainties which plague decision-making? What is the appropriate role of analysis to replace judgement, to support judgement, or to model judgement? What are the credits and debits when decision analysis is compared with cost benefit analysis, or with the *soft* problem structuring methods of OR, as a means of making *messes* tractable?

There are other issues aplenty. The subject is alive and kicking. This book provides an excellent way in.

Jonathan Rosenhead

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Thursday and sharing perceptions

by K. D. Loquer, K. M. Adolson, S. Hrench, R. Hartley

1.1 PREAMBLE

If I had to pick the technique or methodology that had been most misunderstood by the operational research profession, then I think that decision analysis would be my choice. Certainly it would be if I confined my attention to the operational research profession in the UK. How often have I heard decision analysis berated because it supposedly applies simplistic ideas to complex problems, usurping decision makers and prescribing choice!

References are cited in these notes and readings in two distinct ways.

Yet I believe that it does nothing of the sort. I believe that decision analysis is a very delicate, subtle tool that helps decision makers explore and come to understand their beliefs and preferences in the context of the particular problem that faces them. Moreover, the language and formalism of decision analysis facilitates communication between the decision makers. Through their greater understanding of the problem and of each other's view of the problem, the decision makers are able to make a better informed choice. There is no prescription: only the provision of a framework in which to think and communicate. Decision makers are not usurped. Far from it: their position is strengthened; they are supported in their task.

It is this view of decision analysis that I wish to convey in the following pages; but, of course, before I can do that I must give you some idea of what concepts it uses and of what techniques lie at its heart. Only when these are before you, can I begin to show you how they combine to help and support decision makers. So let me introduce you to decision analysis - or, rather, let me call upon P. G. Moore and H. Thomas to perform the introduction. Their 1973 paper, The Rev Counter Decision, is quite simply the best introduction to decision analysis that I know. However, perhaps they will forgive me if I emphasize that it is an introduction. You will see a little, but only a little of the subtle, delicate exploration of beliefs and preferences that I alluded to above. In order to present the central ideas in an easily digestible form Moore and Thomas simplify, and thereby risk portraying decision analysis as precisely the naive and simplistic methodolgy that I, and they, deny it to be. When reading their paper remember that you are only seeing an initial outline sketch: there are plenty of hues and tints to be applied before the picture of decision analysis will be complete.

References are cited in these notes and readings in two distinct ways. Those occurring in the text that I have written are indicated by author and year of publication. They are listed in alphabetic order in the references section at the end of the book. Those occurring in the papers reprinted here are indicated by a superscript and listed at the end of each paper.

1.2 The Rev Counter Decision

P. G. MOORE and H. THOMAS London Business School

This case-based article arose out of a decision tree analysis carried out by the authors in an industrial firm. The company's identity and the actual product manufactured have both been altered for reasons of confidentiality. The various discussions outlined in the case are reported in the same order as they occurred within the firm whilst the problem was originally under study. The work reported was first carried out in 1971 and has been the subject of regular "follow-up" analyses since that date. A much simplified and restricted version of Parts I and II of this case was originally published in two articles appearing in the *Financial Times* during January 1972.

PART I

It is 10.30 a.m. and a meeting is in progress in a Midlands factory office. The Pethow car component company believes there is going to be increased demand for one of its products, a revolution counter for cars. The managing director and four of his executives are considering ways of coping with this new level of demand. Existing plant in the company is working at full capacity on normal shifts, and the firm is considering two alternative options to meet the demand. The first is to expand capacity by putting all its employees on overtime, whilst the second is to purchase an additional revolution counter assembly machine. The managing director has ruled out subcontracting the work to another supplier, because this might result in the subcontractor marketing his own competitive instrument with similar technical features. Furthermore, a price change, except one linked directly to inflation, is ruled out by the marketing manager because of various undertakings that have been given to customers.

Once the options have been outlined, the meeting gets down to a discussion of what might happen under each of them. First of all, they decide that they ought to base their decision upon the gains to Pethow over a 1-year planning period. The marketing manager feels that the projected rise in demand in this period will probably be 15 per cent (if present trends continue), but he adds that there is some possibility of a fall of 5 per cent if the market turns sour. Other possibilities are, he feels, so unlikely that they can be excluded from further consideration. Pressed by the others, the marketing manager admits that he and his staff have accumulated a considerable body of information of future levels of demand and, as a synthesis of

3

this information, he puts the relative likelihoods of the two possible outcomes at something a little different from evens, say 3:2 in favour of increased sales.

Next, the accountant is asked to cost the various options according to the possible outcomes. This he does, after discussions with the production manager on material and equipment costs, and with the personnel manager on wage rates. The new equipment option is costed to include a fair market rent for the use of equipment in the year concerned. The managing director now puts all the data together into a payoff table given below, giving the net cash flows for each possible action and outcome combination, converting the likelihoods to probabilities that sum to unity over all possible outcomes. After a few moments thought he includes a further alternative, namely that they do not accept any order beyond a level that could be met with their present capacity, working no overtime.

	Demand (probabilities in parentheses)		
Action	5 per cent fall (0.4)	15 per cent rise (0·6)	
New equipment (S ₁)	130	220	
Overtime (S ₂)	150	210	
Existing level (S ₃)	150	170	

Figures in £000

The managing director asks how they should best handle the information contained in this table, whereupon the production manager suggests that it should be put out in the form of a "decision tree" (Figure 1). In explaining to the others the relevance of the decision tree, he points out that each path along the tree represents a route along which the decision-maker could drive. Along each route he may have to pay a toll, such as the cost of some capital investment, and will attain different outcomes or rewards through following each route. Obviously the tree simplifies even this particular problem but "we can always", the production manager states. "add these complexities later".

The marketing manager next takes up the story, pointing out that the current decision is but one of a whole range of decisions about various products that the company makes, and that their company philosophy is to achieve the highest expected overall gain. This would be satisfied through using Expected Monetary Value (EMV) as a choice criterion at every stage in a project, always choosing that action for which the EMV was highest. To implement the EMV approach they need to look at each possible option in turn. Thus for S_1 (which is to install new equipment) there is a payoff of 220 with probability 0.6, or an alternative payoff of

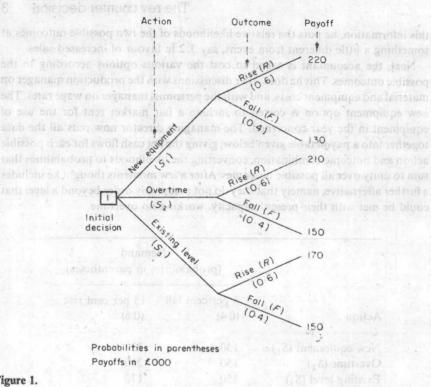


Figure 1.

130 with probability 0.4. The EMV would accordingly be:

$$0.6 \times 220 + 0.4 \times 130 = 184$$
.

A similar calculation shows that the EMV for the decision S₂ (to have overtime working) is 186. Finally, S₃ (to do nothing, but continue with present production level and no overtime working) has an EMV of 162. The Pethow company ought. under the EMV approach, to choose the action which gives the highest expectation, namely to work overtime. In this instance, of course, the EMVs for overtime and new equipment are so close that the results are virtually indistinguishable. On seeing this result, the personnel manager points out that overtime would be popular with the men, whilst the accountant states that the overtime option would make his life easier as no fresh capital has to be obtained. Hence there seems to be no reason to reverse the strict order to the options produced by the analysis.

The accountant now suggests they should examine the effect that the precise values of the likelihoods assumed have had on the decision reached. To do this, he suggests that the decision should be approached the other way round, calculating

the EMV for each of the three options against a range of values of p, the probability assigned to having high demand (the probability of reduced demand would then be 1-p). The EMV for the three options would then be:

$$S_1$$
 90 p + 130,
 S_2 60 p + 150,
 S_3 20 p + 150.

Thus option S_2 always dominates S_3 ; whilst S_1 is the best provided that:

$$90p + 130 > 60p + 150$$

or

$p > \frac{2}{3}$.

If $p < \frac{2}{3}$, option S_2 is best. The differences in EMV are very small, around $p = \frac{2}{3}$, and hence the suggested decision seems to be relatively insensitive to small changes in the likelihoods assigned to the two possible levels of demand. Accordingly, the meeting is about to break up at 12.45 p.m., having decided to proceed on an overtime basis.

At this stage the managing director intervenes. "Surely", he says, "we have simplified rather too much and glossed over too many of the realities and difficulties. Whilst I can accept that the payoff values calculated are probably correct to within 1 or 2 per cent, and that the decision is not particularly sensitive to the probabilities, I feel that we haven't explored some of the other issues fully enough. For example, shouldn't we have looked at a somewhat longer horizon than one year only; or again, shouldn't we have examined a little more critically whether or not EMV is the appropriate criterion for decision?" The others agree that further examination is necessary and decide to hold the decision over and resume discussion after lunch.

PART II

When the meeting resumes after lunch, the accountant and marketing manager are already hard at work on an extended tree diagram. They explain that they are trying to extend the analysis to a more realistic 2-year planning period, considering only initial options S_1 (new equipment) and S_2 (overtime), arguing that the earlier analysis effectively ruled out option S_3 (do nothing). The marketing manager feels that, in the second year, he needs three levels of possible sales, rather than two levels, to describe accurately the possible situations that could arise. The tree structure that they reach, without any numbers inserted on it, is shown in Figure 2.

The meeting now discusses the structure of the tree. At decision point [1] the choice is between options S_1 and S_2 . If S_1 is chosen and sales rise, decision point [2a] is reached, when options S_4 (more new equipment) and S_5 (retain existing

equipment but work overtime) are open for choice, similarly along other branches. The general feeling is that, although this tree clearly involves some degree of simplification of the basic problem, and of the options available, the structure provides a reasonable basis for further analysis and lays bare the essential elements of the problem.

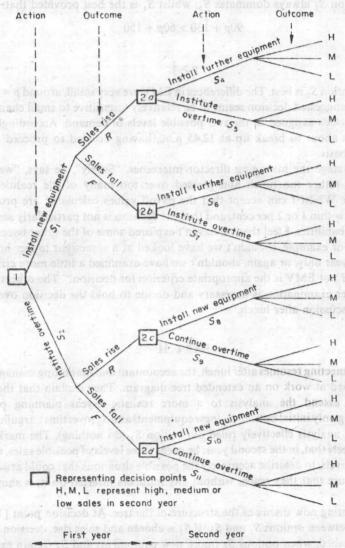


Figure 2.

The group now turns to assessing the numerical quantities required. First, they consider the difficult task of probability assessments. Both the marketing manager and the accountant feel that the rev counter has a good long-term sales future. They argue that, if the sales fell over the first year, the probabilities of high, medium and low sales in the second year are 0.4, 0.4 and 0.2 respectively. If the sales rise in the first year, the corresponding probabilities are 0.5, 0.4 and 0.1 respectively. These probability assessments are "educated guesses" based on the best information currently available, but nevertheless the managers concerned feel that they provide the best summary they can give of their present views.

The next step is to estimate the various payoffs, or net cash flows that will accrue, if the company "drives" along the many possible routes in the tree. Altogether there are 24 possible payoffs to be estimated, each corresponding to an end position on the right-hand side of the tree, the payoff relating to the whole 2-year period from the start point, marked [1] on Figure 2.

At this stage the managing director comments that the analysis is going to be rather more difficult than for the 1-year problem considered that morning. However, the production manager suggests that the principles used earlier could be extended to the 2-year problem. He argues that if EMV can be used for the single-stage problem, it can equally well be used for the two-stage problem. The essence of his argument is that, when one of the decision points [2a]-[2d] is reached the decision criterion will still be EMV. Hence the tree should merely be analysed backwards, from right to left using the EMV criterion for choice, looking at [2a]-[2d] first. The production manager says he believes that this backwards analysis procedure is colloquially called "rollback". Decision point [2a] is then considered. The EMV for option S_4 (install further equipment) is:

$$0.5 \times 410 + 0.4 \times 395 + 0.1 \times 380 = 401$$

whilst the EMV for option S_5 (institute overtime) is:

$$0.5 \times 425 + 0.4 \times 408 + 0.1 \times 395 = 415.2$$
.

Hence the better decision is to choose option S_5 ; accordingly a bar is placed on route S_4 and the value of 415·2 placed against decision point [2a], as shown in Figure 3 which reproduces only the upper part of the original tree.

A similar calculation for decision point [2b] shows that option S_7 has a higher EMV (330) than option S_6 (316), and hence that S_7 should be preferred. S_6 is accordingly blocked off and the value of 330 placed against decision point [2b]. The two branches leading to the decision points [2a] and [2b] can now be combined. Since the probabilities of a rise or fall in demand in the first year are 0-6 and 0-4 respectively, the overall EMV for the initial option S_1 at decision [1] is:

$$0.6 \times 415.2 + 0.4 \times 330 = 381.1.$$

At this point the managing director asks the other to excuse him whilst he makes a couple of telephone-calls, suggesting that meanwhile they deal with the lower

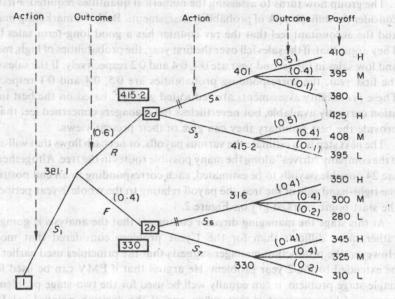


Figure 3.

part of the tree. On his return about fifteen minutes later, they tell him that the EMV for the initial option S_2 (work overtime) is now 340-4 and that Figure 4 gives the outline of the completed tree.

The analysis appears to suggest that the best initial decision now is to install new equipment, a reversal of the morning's decision, and the meeting turns to a discussion as to why this should be so. The reason rapidly emerges, namely that on a 1-year basis overtime is better because the investment cost may not be fully matched with immediate sales increase. In a 2-year period, the growth in sales volume can well make up for any sales shortfall experienced in the first year.

The personnel manager is showing signs of unease at this point. He is unhappy because the meeting seems to be committing the company to massive overtime in one year's time. What if wage rates have soared ahead by then and overtime could only be obtained at a crippling rate? The accountant thinks about this for a moment and replies that at this moment they are only deciding the initial decision, using the best information available to them. If, in 1 year's time, fresh information is to hand concerning the second year's prospects, then they would at that time have to take it into account when making their decision at either point [2a] or [2b]. They are not, he emphasizes, rigidly fixing the later decision now.

The managing director now raises his earlier point of the validity of EMV as a means of deciding between alternatives; "Things always seem to go wrong and I don't fancy working on probabilities" he said, "let's work on the basis that the worst happens." They all peer at the decision tree and, after a moment's pause, the