STRUCTURING THE BIG DECISION : A PRACTICAL REVIEW OF MULTI-CRITERION DECISION MAKING

Dr Glen D'Este
Senior Transport Planner
Economic Planning & Research Division
Transport Tasmania
TASMANIA

ABSTRACT: *Over the past 20 years, there has been a growing recognition that major decisions involve a trade-off between many competing and perhaps conflicting objectives and that decision-making structures and techniques should reflect this complexity. The aim of this paper is to review recent advances in the management and resolution of multi-criterion (multi-objective) decision problems. Various decision structures and resolution techniques will be discussed; with particular attention to their practicality and relevance to the real-life decision maker. In particular, their use in large-scale investment decisions in the transport industry will be assessed through an examination of several case studies. It is concluded that multi-criterion decision analysis can play an important role in management and decision-making as a means of clarifying objectives and priorities, structuring the analysis and ultimately helping to make the big decision.*

STRUCTURING THE BIG DECISION

- A Practical Review of Multi-Criterion Decision Making -

Glen D'Este, Senior Transport Planner
Economic Planning & Research Division
Transport Tasmania

INTRODUCTION

It is undeniable that the world is a complex place full of conflicting objectives and multiple criteria for success. This makes it difficult to compare alternative courses of action and decide upon a "best" course to follow. In many cases, the best that can be reasonably expected is a timely and effective solution that produces a successful result. Often this means selecting an alternative that is not optimal with respect to any criterion but provides the most successful compromise between the competing interests and objectives.

Many decision models do not recognise this complexity. Their aim is define a single all-powerful and objective decision criterion and to distance the decision-maker from the decision process. The decision process is then automated in the sense that the individuality of the decision-maker is eliminated and given the same information, every decision-maker should come to the same conclusion.

On the other hand, multi-criterion decision making (MCDM) techniques accept that conflicting objectives and multiple criteria are a natural part of decision-making. In recognising these conflicts they return the essential human element to the decision process. Personal preference, discretion and value judgements are not seen as undesireable elements that should be eliminated but are seen as natural processes that should be incorporated into systematic decision-making techniques. The essential elements of MCDM have been summed up by Cowley (1987) ;

> ...(MCDM) is seen as an aid to the decision maker, rather than as a device to reduce the decision-maker's involvement. Its emphasis is on clarification, and on helping the decision-maker to better understand the available options; the final choice is based on the decision-maker's own priorities, which reflects the way most decisions are made in practice.

Most of the development of MCDM has appeared in journals such as *Operations Research*, *Management Science* and *Decision Sciences* or in the proceedings of conferences and seminars [Carlsson & Kochetkov (1983), Cochrane & Zeleny (1973), Fandel & Spronk (1985), Morse (1980), Zeleny (1976), Zionts (1978)]. Several books have appeared that summarise the theory and application of MCDM [Easton(1973), Goicoechea et al (1982), Keeney & Raiffa (1976), Zeleny (1982)] but for the most part, the results are not readily accessible to the majority of managers involved with day-to-day decision-making.

The aim of this paper is to provide a practical introduction to the major elements of MCDM and to relate the techniques to decision-making in transport. It concentrates on decisions involving a choice from several alternative courses of action. The objective may be to select a single "best" option, as in the selection of a solution to a given problem, or to select the "best" combination of options, as in a budgetary situation. Both types of decision are common in transport planning in either a Government or commercial environment. Since the emphasis is on choice from discrete alternatives, there is no discussion of multi-objective optimisation techniques such as multiple linear programming, goal or compromise programming. For an introduction to these techniques, see Zeleny (1982) or Goicoechea et al (1982). Further, discussion is limited to decisions made under conditions of certainty at a particular point in time. Most of the techniques discussed below can be generalised to conditions of risk or uncertainty and to decisions involving variations in the timing of impacts, but these extensions are beyond the scope of the current paper. For an introduction to some of these techniques, see Wilhelm (1975) or Roy (1977).

STAGES IN THE DECISION PROCESS

In many respects each problem or decision situation is unique but it appears that most share 5 stages of development. Adair (1985) lists these stages as :

1. Define Objective	Specify the aim or objectives, having identified the need for a decision.
2. Collect Information	Collect and organise data; check facts and opinions; identify possible causes; establish time constraints and other criteria.
3. Develop Options	List possible courses of action; generate ideas.
4. Evaluate and Decide	List pros and cons; examine the consequences; measure against criteria; trial ; test against objectives; select the best.
5. Implement	Act to carry out the decision; monitor the results; review.

This list should not be regarded as a recipe for 'good' decision-making but it does provide a convenient structure for managing and reviewing the progress of the decision process. Representing the decision process in this form suggests that decision-making is a linear process that flows through the 5 stages to a natural conclusion. Unfortunately this is rarely the case; it is much more common to have a convoluted network of loops and feedbacks. The following discussion of MCDM is largely concerned with the evaluation and decision phase but any results will inevitably have implications for other stages of the process.

STAGES IN SELECTING AN ALTERNATIVE

The essence of MCDM is the search for a single "best" solution or set of acceptable alternatives in an environment that is complicated by the existence of multiple performance criteria and multiple and often conflicting objectives. Hence the task is very different to classical optimisation and to the sort of single-criterion decision-making problems that can be handled by standard operations research techniques. Von Neumann and Morgenstern (1953) observed that ;

> ..... this multiple objective situation is certainly no maximum problem, but a peculiar and disconcerting mixture of several conflicting maximum problems ..... This kind of problem is nowhere dealt with in classical mathematics ..... It arises in full clarity even in the most "elementary" situations

The failure of classical mathematics to cater adequately for this situation has lead to the development of a number of techniques for resolving the decision problem. These techniques take a variety of approaches but most share a common structure. The major steps in evaluating alternatives and selecting an appropriate course of action, are :

1. Determine Selection Criteria	List all relevant criteria; define quantitative or qualitative measures of effectiveness; clarify preferences.
2. Evaluate Alternatives	Evaluate the performance of each alternative against each criterion.
3. Eliminate Inferior Alternatives	Cull all infeasible alternatives; cull all non-dominant alternatives; set a minimum standard of performance; cull all alternatives not reaching the required level; adjust and revise standards as required.
4. Resolve Conflicts	Identify trade-offs; select an appropriate method for resolving the conflicts; implement the method.
5. Review Results	Examine recommended option(s); revise criteria; develop new options.

SELECTION CRITERIA

The first step in the decision process is to identify the criteria that will influence the overall assessment of each alternative course of action. For the purposes of this discussion, the term "criterion" is being used to indicate a conceptual measure of performance, as opposed to the way that it is actually measured. For example the criterion "freight volume" may be assessed in terms of tonnage, cubic volume or number of articles.

The set of criteria can be very large but should not be excessive. Barron (1987) has shown that ;

> if evaluation is based on an incomplete set of factors, and if the purpose of the evaluation is to select a single best alternative, inferior alternatives may be selected with surprising frequency and/or severe negative impact.

This is not an excuse to include an excessively large number of criteria but it is a warning that effective results cannot be expected if relevant criteria are ignored.

The set of criteria will depend on the situation and on the time and resources available, but may include some of the measures of performance listed in Table 1. In the initial stages it is advisable to include as many criteria as can be practically accommodated. It is not necessary that the relevant criteria can all be measured in common units or even that they can be measured numerically. As far as possible, the criteria should each be assessed in "natural" units, such as dollars for financial matters, minutes for time savings or numbers of movements, accidents, persons etc. Criteria can alternatively be assessed in "fuzzy" qualitative terms such as "high", "low", "good", "bad", "average" etc. The only limiting factors is the existence of a clear preference structure. For each criterion it must be clear what represents a "good" result and what results would be considerable better (preferred) and worse. Without a clear scale of preferences for each criterion, decision-making would be impossible.

Unfortunately, the scale of preferences does not always mirror the scale of "natural" units used to assess the performance of alternatives. For instance, there may be an optimum level of performance which is preferred to either a higher or lower value on the "natural" scale. The profit of a Government or semi-Government enterprise engaged in providing a transport service is an example of this phenomenon. A small profit is typically the preferred result while losses or large profits are both undesireable. Under these circumstances, it will be necessary to map the "natural" scale onto a scale of preferences.

Another problem arises when the decision is to be made by a group or committee instead of an individual. Since preferences are inherently subjective and dependent on the individual and current circumstances, it is likely that there will be some measure of disagreement over the ranking of performance. Various procedures exist for resolving the differences or at least eliciting the dominant view. Most of these procedures depend on real or simulated voting, or use some technique (such as the Delphi method) to guide the group towards consensus. See Goicoechea et al (1982) for a summary of group decision-making techniques.

A common mistake is to limit the criteria to those of immediate interest to a particular decision-maker or group. In the transport environment, there tends to be a large number of stake-holders in any major decision; for example Government, unions, community, business and trade groups. The influence of these concerned groups can be expected to be brought to bear at some stage of the decision process so it can simplify decision-making to anticipate their behaviour and include criteria that will be relevant to these groups. It is then possible to simulate the priorities and decision-making behaviour of different groups and thereby anticipate likely problems. Any future privatisation or corporatisation of transport operations will do little to diminish the power of these groups or their influence on decision-making.

After establishing the decision criteria, the next step is to evaluate the relevant attributes of each alternative using the agreed units and scales of preferences. It is usually convenient to summarise these results in a Table with the alternative courses of action listed on one axis, the attributes listed on the other and a matrix of results making up the body of the Table. Such a table is analogous to the payoff table used in single-criterion decision analysis.

Operational Measures	Passenger/vehicle movements Congestion/delays Accident rate Accessibility Time savings
Financial Measures	Cost/revenue Profit/loss Loans/equity Riskiness/sensitivity Net present worth Internal rate of return
Cost-benefit Analysis	
Budgetary Implications	Opportunities foregone Flexibility Staffing
Environmental Impact	Exposure to risk/discomfort Environmental damage Energy savings
Regional Impact	Local economy Landuse Human displacement Community disruption
National Impact	Development priorities Global borrowings Balance of trade International relations
Distributional Effects	Winners/losers
Political Impact	Electoral implications

TABLE 1 : EVALUATION CRITERIA

Elimination of Inferior Alternatives

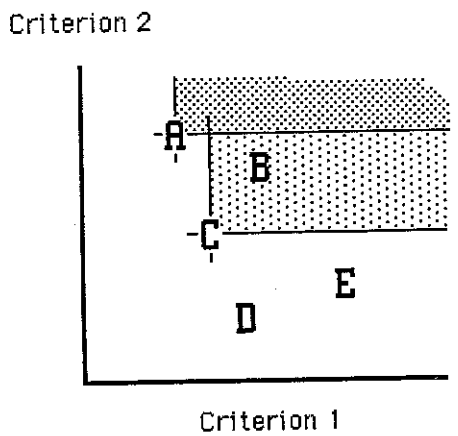
Before applying some technique to resolve the conflict between objectives, several types of inferior alternatives can be eliminated. In a situation involving a large number of alternative courses of action, this step can help to reduce the choice to more manageable proportions. It is convenient to eliminate all those alternatives that are infeasible, dominated by other options or do not reach a prescribed level of performance.

During the evaluation phase, it may become clear that an option is not practical or feasible within some set of constraints (such as technological or financial). Any such options can be culled at this early stage.

Another useful preliminary step is to identify the dominant alternatives. In the literature of MCDM, these alternatives are called the **non-dominated set**. Rather than define the non-dominated set directly, it is simpler to consider its complement, the dominated set. This set consists of all those alternatives that are clearly dominated by some other project, that is, there exists a feasible alternative that is at least equal with respect to every criterion and better in at least one. Therefore the dominated set is a set of clearly inferior projects that can be eliminated from further consideration. On the other hand, any element of the non-dominated set is potentially the "best" choice since each is an optimal solution in the Pareto sense, that is, moving to an alternative involves being worse-off with respect to at least one criterion. Therefore there is no clear ranking of elements of the non-dominated set and the choice between alternatives will inevitably require trade-offs. The outcome of these trade-offs will depend on the priorities of the decision-maker.

The process of dividing the alternatives into dominated and non-dominated sets is illustrated in Figure 1. This Figure describes a decision situation having two decision criteria and a five alternative courses of action, denoted A to E.

FIGURE 1

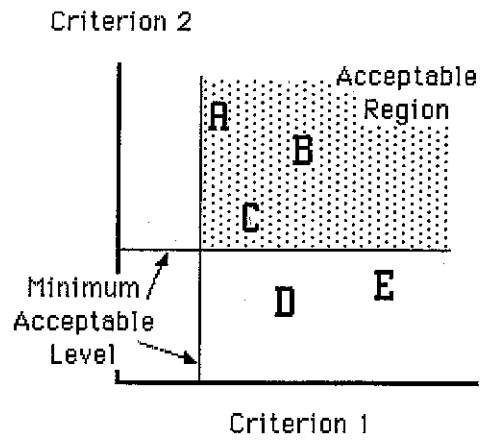


The axes represent performance in the decision criteria and are scaled so that greater distance along the axis indicates increasingly preferred performance. Any given Option can then be plotted on the plane according to its performance with respect to each criterion and the other alternatives. For example, the performance of Option C with respect to Criterion 1 is shown as being better than (in the sense of being preferred to) that of Option A and worse than B, D and E. With respect to Criterion 2, Option C performs better than Options D and E and worse than A and B. In graphical terms, the test for membership of the non-dominated set for a given Option involves identifying the region that represents equal or preferred performance in both criteria. For Option C this region is shown lightly shaded and for Option A the region is indicated by heavier shading. All locations in this region represent a dominant standard of performance so an Option is a member of the non-dominated set if and only if the region is empty of other Options

It is clear from Figure 1 that Option C is dominated by Option B and that Option A is a non-dominated alternative. For this example, the non-dominated set consists of Options A, B and E. In general, Options in the non-dominated set form the outer boundary of the region of space occupied by set of all Options. In practice, when confronted by a large number of alternatives and criteria, it is more convenient to use a computerised sorting algorithm to sort alternatives into the dominated and non-dominated sets.

The set of alternative courses of action can be further reduced by setting a minimum standard of performance. This is known as **satisficing**. All those alternatives that exceed the standard deliver an acceptable level of performance and are potential solutions to the decision problem. Those alternatives that fail the test can be eliminated from further consideration. The situation is illustrated in Figure 2. Options that lie in the shaded region are satisfactory while those outside can be culled

FIGURE 2



If both the Dominance and Satisficing Principles were applied to the example then only Options A and B would remain for further consideration. Options D and E do not have a satisfactory level of performance in Criterion 2 and Option C is dominated by Option B.

CONFLICT RESOLUTION

The alternative courses of action that remain are all acceptable options in the sense that they are feasible, meet a prescribed minimum level of performance and are not equal or inferior in every respect to some other alternative. If more than one option remains after this preliminary filter, then a conflict exists. There is no clearly superior alternative and the choice of a single "best" option will depend on trade-offs between decision criteria.

Many ways have been proposed for resolving this conflict. These techniques can be broadly classified into categories depending on whether or not the decision-maker can effectively quantify the set of preferences both within each criterion and between criteria. In economic terms, this corresponds to the perennial debate between ordinal and cardinal utility. In an ordinal approach, preferences are ordered but this ordering is not placed on a numeric scale. For example a profit of $10m may be preferred to a profit of $5m but the degree of preference is not quantified. In a cardinal approach, a numeric scale of preferences is established. For example the preference for a $10m profit may be rated as being twice as great as for a $5m profit. When a numeric scale of preferences is established within a criterion, the ratings are usually referred to as **utilities** and when the scale is between criteria, the ratings are called **weights**.

If preferences within and between criteria are treated separately then there are 4 distinct categories of techniques. There are no commonly used techniques that use a utility approach within criteria but revert to strict preferences between criteria, so the number of categories reduces to three :

1. Preferential Techniques	Take a purely ordinal approach. Includes screening and outranking techniques.
2. Weighted Preferences	Assume that cardinal weights can be ascribed to criteria but that preferences within criteria cannot necessarily be quantified. Includes various weighting techniques and the theory of the displaced ideal.
3. Weighted Utilities	Take a purely cardinal approach. Includes utility maximising techniques.

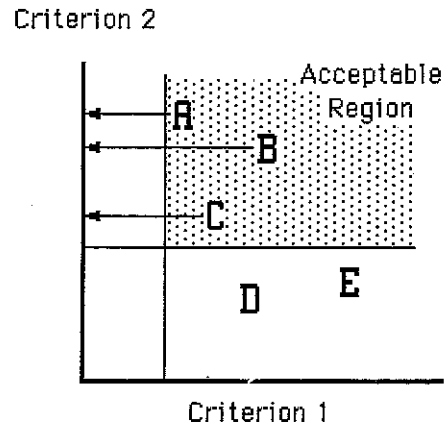
Screening and Outranking Approaches

These approaches are based on the premiss that a decision-maker can satisfactorily articulate the preference for one alternative over another but cannot accurately quantify this preference. There is also an emphasis on the belief that a decision-maker normally satisfices rather than optimises, partly because the concept of a maximum (or minimum) has no valid definition in many real-world situations [see Dorfman (1960)].

Screening approaches involve progressively raising the minimum acceptable standards of performance and successively eliminating alternatives until a decision is reached. When setting progressively more stringent acceptance standards, it is advisable to consider the relative priorities attached to the criteria The criteria considered most important should be subject to the highest standards. An extension of this technique involves setting acceptance levels and then selecting the alternative that has the most preferred performance in the most important criterion.

This approach is illustrated in Figure 3. The shaded region represents acceptable alternatives and if Criterion 2 is considered to be the most important factor, then Option A is the favoured course of action.

FIGURE 3



Outranking approaches involve successive comparison of alternatives. All alternatives are compared to all other alternatives. The "winner" of each comparison is the alternative that is preferred in the greater number of criteria, and the overall "winner" is the alternative that is preferred in the greatest number of comparisons. It should be noted that, in this approach, there is an implicit assumption that all criteria are valued equally.

Maximum Expected Utility

At the other extreme is multi-attribute utility (MAU) theory and decision-making on the basis of maximum expected utility. For this approach it is necessary to quantify the preference structure of all criteria in a common unit and to also to provide numeric rating for the relative importance of each criterion.

The first step is to evaluate the performance of each alternative in each criterion on a common numeric scale. The common unit of measurement of performance is **utility**. Utility is a rather elusive concept that is difficult to satisfactorily define. It has been defined by the Penguin Dictionary of Economics as, "the satisfaction, pleasure or fulfilment of needs derived from consuming some quantity of a good ... essentially a psychological concept that is incapable of measurement in absolute units". The measurement of utility involves mapping the preference structure of the decision-maker onto an arbitrary numeric scale. This can be accomplished by direct rating, by lotteries that trade-off performance against the "best" and "worst" cases or by a variety of other techniques. For a review of utility estimation techniques, particularly lottery techniques, see Keeney and Raifa (1976).

When using utility as a measure of performance it must be recognised that it is a subjective measure. The personal preferences and circumstances of the decision-maker will heavily influence the degree of satisfaction afforded by different levels of performance. For example, the level of profit generated by an enterprise may be valued differently by an entrepreneur, a conservative businessman, an employee, a government official and a politician. Further, the utility of profit will be different for public and for private enterprises. The differences in utility perception of decision-makers has important implications for the privatisation-corporatisation debate. As the role of the enterprise changes, there is an obligation for the decision-making styles of its managers to change with it. The decision-maker needs to be aware of his/her utility perceptions and their relevance to the current decision.

The next step is to evaluate the **weight** associated with each decision criterion. These weights reflect the subjective priorities of the decision-maker and are a measure of the relative importance attached to each criterion in the overall multi-criterion decision. The values of the weights can be determined directly by rating, preference or trade-off techniques, or indirectly through an analysis of revealed preferences. For details of techniques for estimating criterion weights see Zeleny (1982).

The utilities attached to the individual criteria are then combined with the weights to form a single measure of the overall utility of the alternative. If the utility estimates for the individual criteria are denoted u_1, u_2, ... and the MAU is denoted U, then the process can be expressed mathematically as

$$U = f(u_1, u_2, \ldots ; \lambda_1, \lambda_2, \ldots)$$

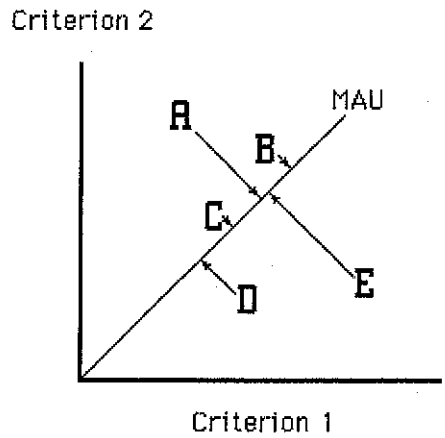
where $\lambda_1, \lambda_2, \ldots$ are the weights attached to the criteria. The function, f() , can take a variety of forms; the most commonly used being the additive form

$$U = u_1\lambda_1 + u_2\lambda_2 + \ldots$$

The MAU estimates for the various alternatives are then ranked in descending order with the recommended option or options being those with the greatest overall utility.

The use of MAU as the final decision criterion is illustrated in Figure 4. The effect of combining the attributes to form a single MAU measure of performance is geometrically equivalent to projecting the alternatives onto a line through the origin and whose slope reflects the weight attached to each attribute. The alternative whose projection is furthest from the origin has the greatest MAU and hence is the recommended option. In Figure 4, equal weight is attached to the two attributes and Option B emerges as the preferred course of action.

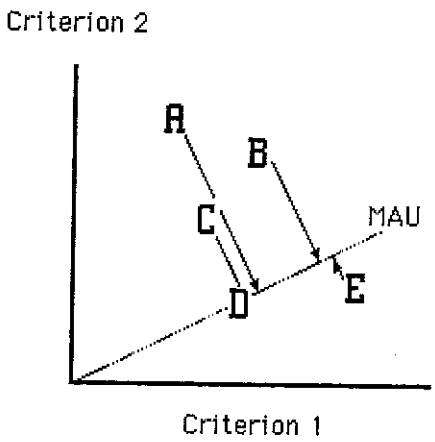
FIGURE 4



Now if the weights were changed to give greater emphasis to Criterion 1, the MAU line moves closer to the axis representing Criterion 1 and the recommended option becomes Option E. This situation is shown in Figure 5.

From its definition and use, it is clear that the underlying philosophy of the MAU approach to decision-making is very similar to cost-benefit analysis (CBA). In CBA, the common unit of measurement is the dollar and the assessments for the criteria are then simply added having assumed that the dollar value is the same for all criteria. MAU extends and generalises this approach by using utility instead of dollars and by allowing different weights to be applied to the various criteria. While MAU avoids some of the problems of CBA, many of the criticisms of CBA can also be applied to the MAU approach to decision-making. In particular, the need to evaluate all criteria in a common unit of measurement, the difficulty of constructing utility scales, the tendency to omit criteria that are hard to quantify and the difficulty in agreeing criterion weights, especially in a group decision-making environment. There is also an implicit assumption that the axioms of utility and the empirical laws of rational decision-making in a single-criterion situation extend to multi-criteria situations. A growing body of evidence suggests that this may not be the case.

FIGURE 5



The Displaced Ideal

The theory of the displaced ideal was developed by Zeleny (1975,1982) as a response to problems associated with the utility maximising approach when applied in a multi-attribute environment. In particular, it addresses the peculiarities associated with choice and preference when multiple criteria are present. These peculiarities include intransitivity of preferences, anchoring of preferences to an arbitrary point of reference, dependence on supposedly "irrelevant" alternatives and the interdependence of means and ends. The criterion of maximum expected utility is intuitively and mathematically appealing but it has been demonstrated to disagree with certain aspects of the psychology of human choice and decision-making.

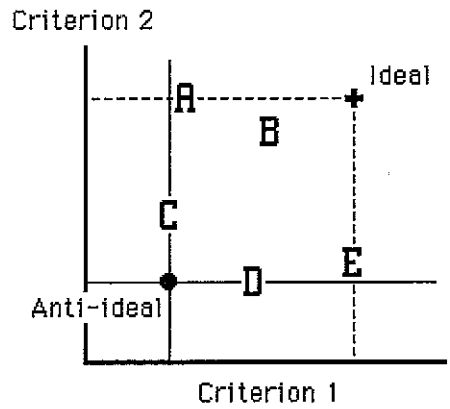
As the basis of this approach, Zeleny (1982) declared the axiom of choice :

> Alternatives that are closer to the ideal are preferred to those that are farther away. To be as close as possible to the perceived ideal is the rationale of human choice.

The **ideal** is a synthetic course of action which is constructed from the decision alternatives. In the theory of the displaced ideal, it is assumed that performance is measured on a relative scale which does not have any absolute zero point or arbitrary upper bound. Consequently, the ideal is taken to have a level of performance in each criterion, which matches the highest level achieved by any of the decision alternatives. This approach ensures that the ideal level is both feasible and achievable. The converse of the ideal is the **anti-ideal** which has a performance which matches the lowest performance level achieved in each criterion.

The construction of the ideal and anti-ideal is illustrated in Figure 6. Ideal levels of performance for the two criteria are determined by Options E and A while the anti-ideal is defined by Options C and D.

FIGURE 6



The resolution paradigm is to select the course of action that is closest to the ideal (or conversely is furthest from the anti-ideal). The concept of **"closeness"** is defined in a manner akin to the concept of "fuzzy" set membership developed by Zadeh (1975). For each alternative, the degree of closeness of each criterion to the ideal for that criterion is rated as a number between 0 and 1. A rating of 1 would represent a level of performance equal to that of the ideal and lower ratings represent performance that is progressively inferior to the ideal. Therefore each criterion can be measured in "natural" units and compared to the ideal performance in the same units but the "degree of closeness" ratings are measured on a scale common to all criteria. Hence this method avoids the need to convert all measures of performance to a common scale such as utility or dollars and can be classified as a weighted preference technique. By defining the closeness rating, the common scale is one step removed from the measurement of individual criteria.

The closeness ratings for individual criteria are then weighted and combined to form a single measure of the "distance" of the alternative from the ideal. This distance measure has been defined by Zeleny as

$$D = [\ \Sigma_i \lambda_i^p\ (1 - d_i)^p\ ]^{1/p}$$

where d_i is the degree of "closeness" for the ith criterion, λ_i is the weight applied to the ith criterion and p is a parameter. This formula may appear complex but it is basically just a generalisation of the familiar Euclidean distance formula. The smaller the distance, the closer the alternative is to the ideal. The theory of the displaced ideal recommends that the appropriate decision is to select the option that is closest to the ideal (or furthest from the anti-ideal). In Figure 6, the option "closest" to the **ideal** is Option B. Therefore Option B is the recommended course of action.

This is a very sophisticated approach to decision-making but it is rather technically demanding and it requires the decision-maker to provide commensurable estimates of "closeness" to the ideal. This may prove to be an unfamiliar and difficult task.

Other Weighted Preference Techniques

These techniques are basically extensions of the outranking procedure described above. Previously, the "winner" of a pairwise comparison was taken to be the alternative that was preferred in the greater number of criteria. If weights are introduced, instead of simply counting the number of criteria in which a particular alternative is preferred, the weights of these criteria are summed. The alternative in the pairwise comparison with the greater sum of weights is then the "winner". As before, the overall "winner" is the alternative that is preferred in the greatest number of pairwise comparisons.

Outranking has been developed in a slightly different direction by Roy (1971) in a technique known as ELECTRE. This technique constructs a partial ordering of the non-dominated set and hence allows further alternatives to be eliminated from consideration. Essentially the technique consists of defining an outranking relationship based on the degree of concordance and discordance between paired alternatives. The concord index is a measure the satisfaction gained from choosing a particular alternative while the discord index measures the corresponding level of dissatisfaction. The outranking relationship is then used to extract a kernel of preferred alternatives from the non-dominated set. The construction of the outranking relationship and subsequent ordering is quite complex and beyond the scope of this paper, for more details see Roy (1971) or Goicoechea et al (1982). The technique has been subsequently extended to provide a complete ordering of alternatives by defining strong and weak outranking relationships.

CASE STUDIES

The operation of the techniques of MCDM is illustrated by the following Case Studies :

Case Study 1 : Mexico City Airport

The decision involved selection of a strategy for developing the airport facilites of Mexico City. The decision-making process has been reported by de Neufville and Keeney (1972) who participated as consultants to the Study team.

Six objectives were identified:

1. Minimise total construction and maintenance costs
2. Provide adequate future capacity
3. Minimise access time to the airport
4. Maximise safety of the system
5. Minimise social disruption
6. Minimise the effects of noise pollution

and to measure the effectiveness of each alternative development proposal in meeting the stated objectives, the following criteria were considered:

1. Total cost (with suitable discounting)
2. Practical capacity in terms of aircraft movements
3. Access time weighted by number of passengers from each zone
4. Number of persons that would be killed or injured in the event of an aircraft accident
5. Number of persons displaced by airport development
6. Number of persons subjected to high noise levels.

The technique used to evaluate and rank the alternatives was an extension of MAU theory. Lotteries were used to assess the single-attribute utility functions and the relative weight attached to each criterion. The effect of each proposal was then assessed in terms of the prescribed criteria and a probability distribution was constructed for the likely outcomes. Using these probabilities and the utility and weight attached to each measure of effectiveness, an expected total utility was calculated for each alternative. The development proposals were then ranked in order of expected utility.

It is interesting to note that the recommended strategy was for a flexible approach involving a staged transfer of international and domestic flights to a new site outside the urban area.

Case Study 2 : EEC Road Funding

The decision involved the apportionment of transport infrastructure development funds by the EEC. The decision-making process has been described by Cowley (1987).

The major decision criteria were:

1. Capital costs
2. Internal rate of return
3. Cost-benefit ratio
4. Net present worth
5. First year benefit
6. Accident savings
7. Environmental impact
8. Regional development
9. Energy savings
10. Community traffic impact

No attempt was made to determine criterion weights or to calculate overall scores for the alternatives. The proposals were simply sorted using screening and outranking procedures. According to Cowley (1987), the main effect of applying MCDM techniques has been to remove all but the direct economic effects from the economic appraisal and to present these as separate criteria. The EEC has not yet developed sophisticated procedures for project appraisal using true multi-criteria pricipals but it is at the stage of recognising that :

(a) Transport investment policy involves multiple objectives
(b) CBA does not adequately handle these objectives
(c) In the complex decision-making environment of the EEC, problems remain in the agreement of weights and priorities for criteria

CONCLUSIONS

The example of EEC project appraisal highlights an important conclusion. The lesson is that it is not necessary to employ sophisticated conflict resolution procedures to benefit from adopting a multi-criteria approach to decision-making. Many of the advantages are realised in the additional clarity that is brought to the decision-making process and will be realised irrespective of the final decision paradigm.

Some of the advantages of adopting a multi-criteria approach to decision-making are:

- MCDM reflects the way that decisions are actually made.
- MCDM provides a convenient structure for summarising relevant information.
- MCDM helps to clarify the aims and objectives of the decision-maker. The very act of defining all relevant performance crieria and setting acceptance standards can help the decision-maker to understand the goals of the organisation and improve management. Corporate objectives can be written into decision-making or conversely the decision process can help to define or refine these objectives.
- MCDM provides a convenient structure for explaining the rationale behind decisions. Relevant factors and the weight given to each are clearly shown and decisions can be defended on their merits. In an environment of open decision-making, a decision should not only be defensible but should be defensible on the basis of its documentation.
- MCDM stimulates the invention of new options. One of the most important steps in any decision process is the generation of feasible options. MCDM highlights the strengths and weaknesses of each option and can stimulate the synthesis of new options at all stages of the decision process. When past decisions are analysed it is often found that the course of action that was eventually adopted was not one of the original alternatives.
- MCDM enables decisions (or at least interim decisions) to be made on the basis of incomplete information. Several decision techniques only rely on preferences and an ordering of the performance levels for each criterion. It is often possible to define this ordering without final or even accurate figures for the performance level. For example it may be possible to determine that a given option will produce a greater profit than an alternative before the magnitude of the difference is accurately known. This type of pre-emptive (or "intuitive") decision-making has an important role in refining the set of alternatives and in hastening the decision process. The potential danger in prolonging the decision process in a competitive commercial environment has been highlighted by Bourgeois and Eisenhardt (1987).
- MCDM can be used to simulate the responses of other interested parties. The priorities of other stakeholders may be different to those of the decision-maker. MCDM can help to anticipate and understand their responses and to suggest appropriate action.
- MCDM avoids much of the artificiality of assigning cash values to intangibles. This is often the most contentious component of project appraisal since many people are suspicious of attaching "values" to factors such as time or human life.

REFERENCES

ADAIR, J. (1985) *Effective Decision-making* Pan Books, London.

BARRON, F. (1987) Influence of missing attributes on selecting best multi-attributed alternatives. *Decision Sciences* 18(2) , 194-205.

BOURGEOIS, L.J. and EISENHARDT, K.M. (1987) Strategic decision processes in Silicon Valley : the anatomy of a "living dead". *California Management Review* 30(1) , 143-159.

BELL, D.E. , KEENEY, R.L. & RAIFFA, H. (1977) *Conflicting Objectives in Decisions* Wiley, New York.

CARLSSON, C. & KOCHETKOV, Y. (1983) *Theory and Practice of Multiple Criteria Decision Making* proceedings of a workshop on Multiple Criteria Decision Making held in Moscow, May 1981. North-Holland, Amsterdam.

COCHRANE, J.L. & ZELENY, M. (1973) *Multiple Criteria Decision Making* University of South Carolina Press, Columbia.

CROWLEY, J.A. (1987) Use of multi-criteria decision analysis in infrastructure investment appraisal. *Australian Road Research* 17(3), 169-174.

de NEUFVILLE, R. & KEENEY, R.L. (1972) Use of decision analysis in airport development in Mexico City. In *Analysis of Public Systems* by R.L. Keeney & P.M. Morse, MIT Press, Cambridge.

DORFMAN, R. (1960) Operations research. *American Economic Review* 50(4), 575-623.

EASTON, A. (1973) *Complex Managerial Decisions Involving Multiple Objectives* John Wiley & Sons, New York.

GOICOECHEA, A. , HANSEN, D.R. & DUCKSTEIN, L. (1982) *Multiobjective Decision Analysis with Engineering and Business Applications* Wiley, New York.

KEENEY, R.L. & RAIFFA, H. (1976) *Decisions with Multiple Objectives : Preferences and Value Trade-offs* Wiley, New York.

MORSE, J.L. (1980) *Organisations : Multiple Agents with Multiple Criteria* proceedings of the 4th International Conference on Multiple Criteria Decision Making, University of Delaware, Newark.

ROY, B. (1971) Problems and methods with multiple objective functions. *Mathematical Programming* 1(2) , 239-266.

ROY, B. (1977) Partial preference analysis and decision-aid : the fuzzy outranking relation concept. In Bell et al, *Conflicting Objectives in Decisions* Wiley, New York.

von NEUMANN, J. and MORGENSTERN, O. (1953) *Theory of Games and Economic Behaviour* Princeton Univ. Press, Princeton.

WILHELM, J. (1975) *Objectives and Multi-objective Decision Analysis Under Uncertainty* Springer-Verlag, Berlin.

ZADEH, L (1975) *Fuzzy Sets and Their Applications to Cognitive and Decision Processes* Academic Press, New York.

ZELENY, M. (1975) The theory of the displaced ideal. In *Multiple Criteria Decision Making - Kyoto 1975* , M. Zeleny (ed.). Springer-Verlag, Berlin. (1976) 153-206.

ZELENY, M. (1976) *Multiple Criteria Decision Making - Kyoto 1975* Springer-Verlag, Berlin.

ZELENY, M. (1982) *Multiple Criteria Decision Making* , McGraw-Hill , New York.

ZIONTS, S. (1978) *Multiple Criterion Problem Solving* proceedings of a conference held at Buffalo, New York. Springer-Verlag, Berlin.