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Multi-objective decision support for transport proposals: getting it right

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Abstract:

This paper considers fundamental elements of multi-objective decision support (MODS) for transport proposals, with a view to "getting it right".

Consideration is given to identification of objectives, measurement of outcomes and value transformations, weighting of objectives and attributes, and characterisation of uncertainty and sensitivity testing.

Further, it is suggested that although relatively sophisticated MODS technologies have been developed in recent years, MODS based on additive weighting has potential to complement more traditional cost-benefit techniques in a broader assessment of transport proposals that includes not only efficiency criteria but also non-monetary and intangible impacts. Additive weighting has the advantage of transparency and has shown to be readily understood by decision-makers and stakeholders.

Some recent developments and variants of additive weighting are considered (including stochastic and fuzzy versions which more adequately acknowledge the uncertainty pervasive in decision-making). It is believed that these developments have potential to enhance the effectiveness of transport decisions

It is concluded that although some limitations of MODS are apparent, MODS technology has significant potential in comprehending the diverse range of impacts associated with transport proposals and affords substantial opportunities for more rational and comprehensive assessment and more effective and accountable decision-making.

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Introduction

This paper advocates the merits of *multi-objective decision support* (MODS), in particular *additive weighting*, as a tool for transport planners in context of grappling with the complexities of multiple conflicting objectives, multiple stakeholders, and considerable uncertainty. It is well known that major transport investment proposals frequently engender widespread community concern and opposition. Commonly significant benefits accrue to some sections of the community whilst other sections of the community (and the wider environment) suffer significant disbenefits. Rarely are the disbenefits of transport proposals fully accounted for since it is common for economic criteria, in particular, travel-time savings, construction cost, and operating cost to predominate in the assessment of transport proposals. However, it is increasingly recognised that this traditional approach towards the assessment of proposals is deficient, and that broader, more encompassing assessment is required taking account of non-efficiency criteria and non-monetary impacts (eg. Harris, 1994; McFall et al, 1994). MODS technology and MODSSs *(multi-objective decision support systems*) facilitate this.

MODSS

A *decision support system* (DSS) implies a computer program that will assist individuals and groups in their decision processes, supports rather than replaces judgements of individuals, and improves the effectiveness of the decision process (Janssen, 1992). The focus of a DSS is on *procedural rationality* (quality of decision process) rather than *substantive rationality* (quality of decision). MODSS is a DSS which explicitly acknowledges the existence of multiple objectives pervasive in decision-making. Substantial development of MODS in recent years has resulted in an overwhelming variety of technologies. Currently, however, MODSSs are rather pragmatic and not based on any firm theory. In addition, their quality is demonstrated by their usefulness in practical situations

It is believed that MODS should form the basis of a broader assessment of transport proposals under consideration by transport authorities to facilitate the synthesis of complex and conflicting information towards more effective and accountable decisions. Houghton (1998) has also recently advocated the use of MODS in the context of transport infrastructure decisions within the framework of ecologically sustainable development (ESD).

In MODS, P_i ($i = 1,\ldots,I$) is a set of *proposals* (*projects*, *alternatives*, *options*) identified for a decision problem, O_j ($j=1,\ldots,J$) is a set of *objectives*, X_j is a measure (*attribute*) indicating the degree to which O_j is met. x_j indicates a specific amount (level) of X_j. For example 'maximise savings in travel time' is an objective, 'savings in travel time' is an attribute, and '200 hours' is a level. A basic component of a MODS system is an *outcome matrix* which arrays the proposals (rows) against the attributes (columns) and is represented as $\mathbf{X} = [x_{ij}]$, where x_{ij} is the outcome of proposal P_i ($i = 1,\ldots,I$) on attribute X_j ($j = 1,\ldots,J$).

The rationale for MODS is based on the finding that decision-making with respect to complex proposals characterised in terms of multiple objectives/attributes presents formidable difficulties for unaided intuition or judgement. It is well documented, for example, that the information processing ability of individuals is severely limited in terms of the complexity of many real world tasks (Miller, 1956). That is, individuals have finite limits to their ability to absorb and process information in any given unit of time. If individuals are provided with 'too much' information such that it exceeds their information processing limits, then overload occurs leading to dysfunctional performance. It has been suggested that about seven (in fact, the range 5-9) 'chunks' (packages) of information is the upper limit of the processing capacity of short-term memory (Miller, 1956). The cognitive overload in discriminating between multi-dimensional proposals implies that the decision-maker will focus on one or two attributes and ignore the significant contributions of the other attributes or, worse, flit inconsistently between different subsets of the attributes characterising proposals. The simplifying strategy most commonly adopted is sequential consideration of the attributes; decision-makers screen proposals for their adequacy (or discriminability) on a set of attributes at each stage dropping those that do not meet the requirements (Einhorn and McCoach, 1977).

Identification of objectives

Values provide the foundation for any decision situation and are made explicit by the identification of objectives. Thus, a clear statement of fundamental objectives, based on the values of decision-makers and stakeholders, should attempt to identify 'what matters' in developing transport proposals. The literature is limited regarding selection of objectives or regarding which set of objectives adequately characterises a decision problem. The process of generating objectives is the most creative, least systematically explored aspect of MODS. It is not possible to be certain that the set of objectives designed, created, invented, or selected is the single best set. The consequences of missing important bjectives/attributes can frequently result in the selection of inferior proposals (Barron, 987). In the context of multi-modal transport proposals, a review of objectives and tributes used in current U.S. practice has been given (NCHRP, 1994).

any applications of MODS technology recognise a hierarchical structure of objectives,
ten called a *value tree* (Keeney et al, 1990) which reduces the cognitive load resulting
m an individual's need to assimilate large quantities of information. Structuring a
rarchy can have a profound effect on the outcome of a MODS process (Weber et al,
38) Hierarchical structures, of course, cannot be validated by reference to some external
lity (Brownlow and Watson, 1987). However, Phillips (1984) has proposed the concept
requisite decision model (a model whose form and contents are sufficient to solve a
icular problem) which is useful in determining the adequacy of a value tree.

Objectives should be *complete* (all important dimensions of proposals should be covered), *operational* (attributes should be meaningful to both decision-makers and stakeholders involved in the decision process); *non-redundant* (objectives should not contain redundancies in the form of conceptualising or measuring essentially the same thing in different ways); *decomposable* (such that performance along different objectives can be assessed independently); and, *minimal* (the number of objectives should be as few as possible) (Keeney and Raiffa, 1976). In this latter respect, however, the number of objectives should be sufficient to adequately characterise the proposals. A rule of thumb based on the cognitive limitations of information processing is that the number of attributes should not exceed 10 or so and perhaps be of the order of 7 (Belton and Vickers, 1990).

Stakeholder input into the process of structuring values in terms of objectives and operationalising objectives in terms of attributes (in addition to the expression of trade-offs between attributes) is essential and may be implemented through workshops, focus groups, or surveys (Keeney et al, 1990) Increasingly, computer networks or the Internet may assist in this task

Measurement of outcomes and value transformation

A basic element of MODS is the outcome matrix Fundamental to the outcome matrix is the level of measurement of outcomes achievable and this is an important determinant of the possibilities for MODS technology. Outcomes may be measured on an *ordinal* scale or on a *cardinal* scale (ie. *interval* or *ratio* scale). Differences between ordinal, interval and ratio scales are not always well understood In the context of MODS for transport proposals, arithmetic is sometimes performed on numbers that is not justified by their level of measurement, for example, Schlager (1965). Though cardinal scales are more precise and convey more information than ordinal scales, it should be noted that cardinal scales are more difficult to construct and are more sensitive to 'noise' (and therefore more error prone) Most frequently in MODSS, attributes will be measured along a mixture of both ordinal and cardinal scales and such mixed outcomes must be manipulated in particular ways in order to achieve some degree of comparability (Voogd, 1983). For additive weighting, at least an interval scale of measurement for attributes is desirable.

For cardinal outcomes, a transformation of outcomes is often necessary to yield values. Value transformation of outcome scores may take many different forms. The simplest is a *linear* transformation which maps outcome scores (along a given attribute) into the unit interval so that the worst performing proposal attains a score of zero and the best performing proposal attains a score of one (Voogd, 1983). *Local* scales are completely defined by the proposals under consideration whereas *global* scales involve some globally worst and best performing proposals The latter scales are more flexible but demand more information (Belton and Vickers, 1990).

More realistic, though more difficult to specify, are *non-linear* transformations or *value functions* (Keeney and Raiffa, 1976) which imply unequal changes in value for equal changes in outcome scores. Most commonly a unit change at the 'lower performance' end of the attribute scale is valued more than a unit change at the 'higher performance' end of the scale, consistent with the concept of diminishing marginal utility or value (that is, individuals commonly attach less and less value to each additional unit of a benefit they might receive). Parallel forms of non-linearity is characteristic of an individual's response to uncertainty (*risk aversion*) (Keeney and Raiffa, 1976) and perception of the magnitudes of physical stimuli where differences in stimulus levels are perceived proportionally rather than absolutely (Stevens, 1951). Logistic (S-shaped) non-linear value transformations of outcome scores have also been advocated in the context of assessing transit system designs (Janarthanan and Schneider, 1986). This includes a linear range of value between acceptable and ideal outcomes with diminishing marginal value towards the minimum and maximum outcomes for a given attribute. Where quantitative natural scales are unavailable, value functions may be constructed through direct rating or midvalue splitting (Keeney and Raiffa, 1976). Explicit specification of value functions associated with attributes is uncommon in the assessment of transport proposals characterised in terms of multiple objectives/attributes.

Visualisation is an important component of MODS and may take various forms. Simple methods to visualise the performance profiles of proposals include *bar charts* (where the bar for attribute X_j is at height x_{ij}), *polygonal line plots* (connecting points for attributes where attribute X_j is at height x_{ij}) and *star plots* (connecting points for each attribute X_j at x_{ij} wrapped around a circle) have all been proposed. All provide a cogent visual impact of the relative performance of proposals and facilitate discrimination them.

Weighting of objectives and attributes

Associated with objectives/attributes is a set of positive *weights* or *priorities*. In the case of multiple decision-makers and stakeholders, multiple sets of weights will exist. Weights, in contrast to outcomes are values and represent the importance, significance or salience of an attribute. Weights are postulated value statements rather than empirically derived facts and MODS is conditional on the weight set(s) selected (Voogd, 1983). The conditional nature of aggregate performance of proposals (involving outcomes and weights) should not be seen as a weakness of MODS if weights accurately reflect the judgements of decision-makers and stakeholders.

The concept of attribute weight is relatively unexplored in psychological terms and there is much confusion and considerable debate about the theoretical interpretation and operational definition of weight. In addition there is little definite evidence about the validity of various methods for eliciting weights from decision-makers and stakeholders.

No obvious criterion is available to test the validity of any elicitation method (Rowe and Pierce, 1982). Searches for *convergent validity* (that is, for similar estimates generated by different methods) have produced negative results in that different methods lead to inconsistent estimates (Rowe and Pierce, 1982; Schoemaker and Waid, 1982; Jaccard et al, 1986). Examination of the theoretical soundness of weight elicitation methods is another possible approach, particularly for additive weighting, where the meaning of attribute weight is clearly defined (Hobbs, 1980).

Often, prioritisation or weighting of attributes is made in terms of abstractions (such as travel-time saved or social dislocation as, for example, travel-time saved for commuters is more important than social dislocation) rather than in terms of specific amounts (such as x minutes of travel-time saved for commuters is more important than displacing y households). It arguable whether the former type of statements have any real meaning though many decision-makers and stakeholders are usually quite able to respond to such questions concerning importance, and the majority of practical applications of MODS technology adopt weighting procedures that are independent of outcomes (eg. Schimpeler and Grecco, 1968; Jessiman et al, 1967; Saaty, 1980; Edwards, 1977; Edwards and Newman, 1982). However, the hypothesis has been advanced that individuals have some plausible set of proposals and ranges in mind when judging importance and therefore judgement of the relative importance of attributes should only change when the environment radically changes for the plausible set of proposals (Gabrielli and von Winterfeldt, 1978). More recently, GRaphical Point Allocation (GRAPA) has been proposed which implicitly assumes this view (Leon, 1997).

Often, a weight matrix might be represented as $\mathbf{W} = [w_j^k]$, where is the weight assigned to attribute X_j by stakeholder S_k, $0 \leq w_j^k \leq 1$ and $\sum_{j=1,J} w_j^k = 1$, $\forall k$. In some situations weights or priorities may be aggregated over stakeholders yielding a single set of weights (that is, $w_j = f(w_j^1, w_j^2, \ldots, w_j^K)$, where $f(\bullet)$ is some aggregation function, for example, an average). Sometimes, 'political' weights $\{\alpha_1, \alpha_2, \ldots, \alpha_K\}$, $0 \leq \alpha_k \leq 1$ and $\sum_{k=1,K} \alpha_k = 1$, are included to represent the relative 'power', 'influence', or 'importance' of stakeholders groups. Again, it is unclear as to how best to determine these weights, thought in a democratic society, the relative number of members in each group might approximate relative power.

Uncertainty and sensitivity testing

Uncertainty can arise in many aspects of MODS, for example, regarding the outcomes of proposals with respect to the attributes, with respect to the weighting of attributes, and with respect to the values to be associated with outcomes at any given point in time. There are other sources of uncertainty, for example, uncertainty concerning the completeness of the set of attributes. Recognition of uncertainty is often not an explicit component of MODS. Estimation of maximum, minimum (and possibly modal) outcomes with respect to attributes is more in the spirit of limitations of current estimation/forecasting methods. Such limitations are recognised by MODS technologies involving statistical uncertainty (Kahne, 1975) or deterministic uncertainty (Smith, 1994).

Uncertainty or imprecision surrounding attribute weights is also common and also can be incorporated using statistical or deterministic uncertainty. Voogd (1983) suggests that where only an importance order of attributes is given (for example, $w_1 \geq w_2 \geq w_3$ and $\sum_{j=1,J} w_j = 1$ for $J = 3$) underlying (cardinal) weights may be approximated by exploring the implications of extreme weight sets (for J=3 attributes: (1,0,0), (1/2,1/2,0), (1/3,1/3,1/3)). For example, the preference orders of proposals based on random weight sets within the polyhedron (here, triangle) defined by the extreme weight sets might be generated. Though there are several other possibilities, a 'best' proposal might be considered to be that which is ranked first with greatest frequency. Given an importance order such as $w_1 \geq w_2 \geq \ldots \geq w_J$ and $\sum_{j=1,J} w_j = 1$, *rank-order centroid* (ROC) weights defined as averages of extreme points also reflect weight uncertainty. Thus, $w_j = (1/J)\sum_{i=j,J}(1/i)$ and for $J = 3$, $w_1 = 11/18$, $w_2 = 5/18$, $w_3 = 2/18$.

However, if weights do not inherently acknowledge uncertainty, then it is a simple matter to test the sensitivity of the resulting preference order of proposals to variations in an attribute weight. For example, the change (if any) in the weight of a given attribute that will result in the second 'best' proposal becoming equal 'best' or perhaps 'best' overall may be informative to decision-makers (Smith, 1992a).

MODS technology

A wide range of relatively sophisticated MODS technologies has been developed in recent years, for example, *multi-attribute utility theory* (Keeney and Raiffa, 1976), the *analytical hierarchy process* ('AHP') (Saaty, 1980), and *outranking* methods such as 'ELECTRE' (Elimination Et Choix Tradiusant la REalité) (Roy, 1991) and 'PROMETHEE' (Brans and Vincke, 1985). The AHP is an increasingly well known MODS technology originally developed in the context of transport scenarios and priorities (Saaty, 1977). Though theoretical questions have been raised about its validity, the implementation of the AHP in the 'EC Pro' advanced decision support software (Expert Choice Inc) has enhanced its popularity and application. 'REMBRANDT' is a software package that has been developed to adjust for the contended flaws in the AHP (Lootsma, 1992).

However, despite these developments, additive weighting remains one of the simpler and more transparent technologies and is consistent with a predominant view of 'simplicity' in decision-making (Behn and Vaupel, 1982; Edwards et al, 1988; Belton, 1985). This view is that MODS should assist decision-makers with their problems, and that complicated, hard-to-understand, hard-to-communicate models and elicitation methods, should be avoided Additive weighting is both well tried and minimally demanding on decision-makers and stakeholders in terms of eliciting responses concerning values It facilitates separate assessment of technical judgements (outcomes) and attribute weights (values) combining them in a rational and consistent manner. Further, there are a number of recent developments of additive weighting which *prima facie* enhance its use as a MODS technology. Formally, additive weighting is expressed as follows

$$V(x_1, x_2, \ldots, x_J) = \sum_{j=1}^{J} w_j v_j(x_j)$$

where $v_j(x_j)$ is a uni-dimensional (attribute) value function and w_j is a weight associated with attribute X_j. Value functions are scaled such that $v_j(x_j^*) = 1$ and $v_j(x_{j0}) = 0$ where x_j^*, x_{j0} denotes the best level and worst level of attribute X_j, respectively. Again value functions may be defined locally or globally.

Substantial support for linear models such as additive weighting as a robust approximation to more complex models is well known in the context of behavioural decision-making. Dawes and Corrigan (1974), for example, cite a number of studies of individual decision-making processes in which linear models perform well. In each study, the common characteristic was that independent variables (attributes) each had a monotonic relationship to the dependent variable (aggregate value). Dyer and Larsen (1985) document further empirical and theoretical studies supporting this conclusion.

Additive weighting has been used in the context of transport related decisions (for example, Jessiman et al, 1967; Schimpeler and Grecco, 1968; Bor and Hoel, 1977; Cerwenka, 1982; Scott, 1987; Pearman and Hopkinson, 1989; Kulkarni et al, 1993). Schwartz and Eichhorn (1997) document the use of additive weighting involving stakeholders in a collaborative process to resolve controversial transport issues.

Additive weighting appears in various forms as 'SMAUP' (Einhorn and McCoach, 1977), 'SMART' (Edwards, 1977), 'SMARTS' and 'SMARTER' (Edwards and Barron, 1994), 'GRAPA' (Leon, 1997), and (along with the AHP) forms the basis of recent MODSSs such as 'Logical Decisions' decision support software (Logical Decisions), and 'Criterium' (InfoHarvest) Additive weighting forms the basis of 'VISA' (Belton and Vickers, 1990) and is a component of the 'DEFINITE' DSS (Janssen, 1992; Janssen and van Herwijnen, 1994) as both the weighted summation and the expected value method. It has been endorsed by the U.S. National Academy of Science as an approach to selecting nuclear waste disposal sites (Merkhofer and Keeney, 1987).

It is important to recognise that some critics have considered additive weighting as naïve and too simple as a MODS technology. In addition, the 'linearity trap', which suggests that for convex sets of efficient (non-dominated) solutions additive weighting is indeterminate to the extent that different combinations of weights may equally identify the best proposal, has been discussed (Zeleny, 1982). This may also account for the robustness of additive weighting. Also if the set of efficient solutions is non-convex, then some proposals may never be selected. Additive weighting implies that indifference surfaces among levels of attributes are hyperplanes and do not admit changes in preference under extreme conditions.

In additive weighting, independence or dependence between attributes must be considered. In particular, attributes should be *value independent*. This means that the preferences between alternate levels of a given attribute are independent of the levels attained by the other attributes. Often no testing of this independence condition is undertaken. However, the assumption of value independence is considered to be an adequate approximation in that it is claimed that quite substantial amounts of deviation from it make little difference to the aggregate value of proposals (Edwards, 1977). When *conditional monotonicity* is present (that is, more is preferred to less of an attribute), failure to meet this requirement is contended not to cause inaccurate results.

In additive weighting, the weight of an attribute should be interpreted as the change in the aggregate value for a proposal resulting from a unit of change in the value function for a given attribute (Hobbs, 1980). Decision-makers and stakeholders should thus be asked to make judgements concerning the relative importance of increments on each attribute and not the attribute in abstract. Elicitation of weights should therefore be based on one of the methods that yield theoretically valid weights, for example, the *trade-off* method. However, though the trade-off method guarantees theoretically valid weights it is based on an assumption that stakeholders are able to make valid trade-offs. Zhu and Anderson (1991) identify some systematic inconsistencies in an attempt to validate the trade-off method (in addition to attempting to validate the rating and allocation methods). *Swing* weights have also been proposed which involve asking stakeholders to compare a change (or swing) from the least preferred to the most-preferred value on one attribute to similar changes in another attribute (Edwards and Barron, 1994).

ROC weights are the basis of SMARTER (Edwards and Barron, 1994) justified by recent research by Barron and Barrett (1996) though in this case, outcome ranges on attributes are ranked rather than the attributes themselves. The requirement that no more than a rank order of importance of attributes or attribute ranges be elicited from decision-makers and stakeholders is consistent with a view of simplicity in decision-making and, in particular, with a view that procedures for eliciting responses from individuals be minimally demanding (Hajkowicz, 1997). Schwartz and Eichhorn (1998) recommend weighting attributes by point allocation, again for reasons of simplicity and ease of response from stakeholders.

With respect to additive weighting, sensitivity analysis is straightforward. Usually it is assumed that the weights are normalised such that $\sum_{j=1,J} w_j = 1$ and that component value functions are in the range [0,1]. Then for a given attribute, the weight may be varied from 0 to 1 on the horizontal axis of a graph (with compensating changes in the remaining attribute weights to ensure that $\sum_{j=1,J} w_j = 1$) and the associated aggregate value for each proposal (also in the range [0,1]) may be plotted on the vertical axis The aggregate value of proposals will be a linear function of the variable weight for the given attribute If the aggregate value scores for proposal P_i lie above those of proposal P_k for all possible weights in the range [0,1], then proposal P_i is a 'robust' or 'dominant' proposal relative to P_k with respect to that attribute More frequently, lines for each proposal will intersect at a particular point (weight) thus reversing aggregate preference for the proposals represented by the lines. Such crossover points give some perspective on how the aggregate preference (value) for proposals is dependent on the weight assigned by decision-makers or stakeholders and to what extent variation in a weight will reverse preference.

Yakowitz et al (1993) use an importance order of attributes ($w_1 \geq w_2 \geq \ldots \geq w_J$) in additive weighting which has found expression in a MODSS under development for the Queensland Department of Natural Resources (Robinson, 1998) This approach is conceptually simple and provides the decision-maker with evidence if one proposal is dominant over another. Proposal P_i dominates proposal P_k (with respect to additive weighting) if and only if for every set of weights $\{w_1, w_2 \ldots w_J\}$, consistent with the importance order of attributes, $\sum_{j=1,J} w_j v_j(x_{ij}) \geq \sum_{j=1,J} w_j v_j(x_{kj})$ with at least one weight set satisfying this as a strict inequality. Given an importance order of attributes, the best and worst overall value for each proposal can be identified by a linear program, which amount to finding the minimum and maximum value of the partial sums for each proposal P_i ($i = 1, \ldots, I$)

$$s_{ij} = (1/j) \sum_{k=1,j} v_j(x_{ik}) \qquad j = 1, \ldots, J$$

When outcomes are not known with certainty, *utility* functions may be used to capture decision-maker and stakeholder attitudes towards risk (Keeney and Raiffa, 1976), though the need to elicit gambles for lotteries involving hypothetical consequences can be onerous for both Less demanding is *stochastic* additive weighting (Kahne, 1975) which allows for the incorporation of uncertainty using outcomes and weights expressed as *uniform* probability density functions (*triangular* or *trapezoidal* probability density functions may also be used). The method involves generating uniform random variates ($h = 1,2, \ldots$) for weights ($\omega_j^{(h)}$) and outcomes ($\rho_{ij}^{(h)}$), and aggregating as follows

$$V_i^{(h)} = \sum_{j=1,J} \omega_j^{(h)} \rho_{ij}^{(h)}$$

A frequency distribution showing how many times each proposal is ranked first, second, etc may be analysed to identify a 'best' proposal

Where only *soft* data regarding outcomes (or a mixture of hard and soft outcomes), *fuzzy additive weighting* has been advocated in the context of transport proposals (Smith, 1992b, 1994; Teng and Tzeng, 1996) which facilitates the additive aggregation of *fuzzy numbers* representing linguistic ratings of the performance of proposal P_i with respect to attribute X_j,

r_{ij} (eg 'superior', 'poor', 'low', 'medium', 'high', 'very high', etc) and importance of attribute X_j, w_j (eg 'important', 'critical', 'rather important') This takes the form

$$V_i \quad = \quad (1/J) \oplus_{j=1,J}\{w_j \otimes r_{ij}\}$$

V_i is a fuzzy number representing the aggregate performance of proposal P_i, $\oplus$ denotes fuzzy addition and $\otimes$ denotes fuzzy multiplication For example, in the case of J=2 attributes, V_i, might be expressed as

$$V_i \quad = \quad (1/J)\{\textbf{critical} \otimes \textbf{low} \oplus \textbf{rather important} \otimes \textbf{very high}\}$$

where w_1 = **critical**, w_2 = **rather important**, r_{i1} = **low** and r_{i2} = **very high** Usually, fuzzy numbers are defined on base set [0,1] in which case the aggregate value of proposals, V_i, is a fuzzy number in [0,1]. Various strategies are available to 'defuzzify' these numbers to identify a 'best' proposal. Though fuzzy additive weighting aggregates linguistic ratings of performance and linguistic expressions of attribute importance, *crisp* (non-fuzzy) measures of performance measured in interval or ratio scale terms may also be combined with soft linguistic ratings of performance. Various methods are available to facilitate decision-maker and stakeholder input in terms of the definition of fuzzy numbers representing linguistic ratings of performance and attribute importance.

It should be noted, however, that a computationally efficient approach to fuzzy additive weighting involves defuzzifying the fuzzy numbers representing linguistic values of performance and attribute importance prior to the use of conventional additive weighting (Tseng and Kein 1992; Chen and Klein 1997)

It is important to note that the overall evaluation of proposals based on additive weighting should not be considered as the end of the analysis but must be used to further develop understanding and promote further discussion between stakeholders and decision-makers A MODSS based on additive weighting and incorporating interactive visual display of the performance of proposals, attribute weights, etc would provide a powerful tool for reflecting back to decision-makers and stakeholders the information they have provided, the judgements they have made and initial attempts to synthesise this information This output should be construed as a catalyst for learning about the values of decision-makers and stakeholders.

Conclusion

In the context of planning for transport, decision-making is ultimately the responsibility of elected representatives in the political arena Transport planners provide only supporting information to those invested with the power to make key decisions. Clearly transport planners should seek to provide more incisive as against more voluminous information and MODSS should impart to decision-makers greater insight and clarity rather than obfuscation (Wyatt, 1996). In particular, additive weighting within a visual interactive computer-based MODSS has potential to achieve this, involving complete transparency, flexibility (to facilitate the learning process through iteration), graphic presentation of all relevant information (in particular, the performance profiles of proposals), and complete sensitivity analysis (particularly regarding attribute weights as perceived by decision-makers and stakeholders and implications for the aggregate preferences of proposals).

MODS technology has significant potential in comprehending the diverse range of impacts associated with transport proposals affording substantial opportunities for more rational and broader assessment. In view of its relative simplicity, ease-of-understanding, and the minimal demands placed on decision-makers and stakeholders, additive weighting has been advocated for MODS in the context of transport proposals.

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