FUZZY MULTICRITERIA TECHNIQUES: AN APPLICATION TO TRANSPORT PLANNING

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Abstract: This paper deals with the problem of allocating a fixed budget between a set of competing investment proposals. Based on previous practical experience with problems of this type, an analysis using the fuzzy outranking approach promised to be potentially effective. A decision aid computer package has been developed and applied to a case study. It proved to be flexible and to give additional insights into the structure of the set of alternatives.

Keywords: Multicriteria Decision Making, Fuzzy Outranking Relation, Transport Planning.

1 - INTRODUCTION

In recent years, a range of mathematically based techniques, termed multicriteria methods, has been derived with the aim of helping decision makers make more effective choices from among the options available to them. In particular, a number of such techniques stress the importance of achieving a realistic balance between the power which a rigorous mathematical foundation can give and the reality that most public sector decisions involve factors which are very difficult to quantify in a numerically precise form. Fuzzy multicriteria techniques, because of their potential for representing imprecise preferences in a formal yet flexible way, represent a potentially valuable tool for the analysis of such decisions.

Within transport planning, a common administrative arrangement in many countries is for local highway planning agencies to have devolved to them responsibility for smaller-scale investments, subject to a centrally determined budget. Individually, such projects are typically quite small; the work reported here, for example, is primarily concerned with schemes costing no more than one or two million pounds and the normal range of costs is often much lower even than this. Failure to allocate the available resources in an appropriate fashion is potentially a substantial misallocation of public funds. In normal circumstances, there are many more candidate schemes than available funds will allow to be undertaken. A means of selecting preferred schemes is thus required.

Small, local highway schemes can be of many different types -junction improvements; road straightening setting up traffic signals, etc-. They are not all directly concerned with achieving faster, cheaper traffic flows through the road network. There are frequently proposals to be considered whose principal purpose is to alleviate some environmental problem or to reduce accidents or to improve access to some facility. However, all are competing against each other under the same budget constraint and for this reason must (implicitly or explicitly) be compared and ranked. Any evaluation framework must therefore incorporate all the potentially decision-relevant criteria likely to occur for any of the types of scheme which might be proposed. Both to ensure consistency of policy and to facilitate use by non-specialists, the criteria and their weights need to be established in advance, before knowing the specific set of candidate projects which are to be ranked. In this respect, the analysis reported here is more difficult than many multicriteria choice problems, both because of the difficulty of specifying measurement scales suitable to such a wide range of possible schemes and because of the size of the resulting evaluation model.

2 - PREVIOUS EXPERIENCE

During the late 1970's and early 1980's, many local authorities in Great Britain developed what came to be termed Priority Assessment Techniques (PAT's) to provide guidelines for selecting between competing highway improvement projects. Earlier work (Simon et al., 1988) examined the range of techniques that had been developed and, based on that work, formulated a PAT (Pearman et al. ,1989) with an explicit multicriteria formulation, using a straightforward additive value function. This model (COMPASS) was implemented through a linked series of spreadsheet programs.

Building on experience of PAT's already in operation, the structure chosen for COMPASS was a hierarchical one, with a value tree having four aggregate levels of impact (safety; traffic; environment; local planning and development) which in turn were sub-divided into 11 and then 32 lower-level impacts. The 32 are all measurable, some objectively and some judgementally. Examples include numbers of accidents saved and travel cost and time saving (each disaggregated by vehicle class), all of which are normally assessed on an objective scale, but also impacts such as visual intrusion and disruption to existing activity patterns, which are judgementally assessed in a 0-10 scale.

The need to admit judgemental assessment is occasioned in part by the nature of the criteria, but also by the need to keep strict control of the cost of the appraisal process itself. For relatively low cost schemes, complex and hence expensive traffic forecasts, pollution estimates, etc. cannot be justified, as their cost could easily represent a substantial proportion of any potential scheme benefits. Apart from its contribution to clarifying the set of criteria being used and convincing decision makers that the full range of relevant criteria has been taken into account, a major reason for adopting a hierarchical structure is to facilitate the evaluation of smaller schemes. Where a scheme is too small to justify the expense of evaluation using the full set of (potentially) 32 lowest-level criteria, some or all aspects of the project may be evaluated at a higher (more aggregate) level in the tree. This may be done either by replacing a group of lowest-level criteria by a single judgemental assessment or by choosing one of the relevant lowest-level criteria to stand as a proxy for all the rest. In this way, with minor local adjustment to the weighting of criteria, small projects can be evaluated directly alongside larger ones using the same basic evaluation framework and broadly equivalent scoring and criteria weights. This allows a wide range of disparate projects to be ranked against each other, a major objective for COMPASS, since concern had been expressed that existing procedures were leading to an under-evaluation of small, unspectacular but cost-effective schemes, allowing higher-profile alternatives undue precedence in the ranking process.

With the 32 criteria established and appropriate measurement scales developed, the next important step in the modeling process was to determine the relative weights to be given to unit changes in the different scores. Even exploiting the hierarchical structure of the impacts, this was not a simple task. Both the size of the problem and the difficulty in clarifying what levels of real changes correspond to what scores in the judgementally assessed impacts contribute to the problem. For the initial applications of COMPASS, the weights were established in one of two ways. One was essentially a "pricing out" procedure (Keeney & Raiffa, 1976); the other used Saaty's analytic hierarchy method, asking users to make pairwise comparisons of criteria first within each of seven related groups of lowest-level criteria and then successively up the tree between representative criteria selected from lower-level groupings.

As well as being linear in the criteria weights, the model used, in its basic form, uses linear scales for each of the individual criteria, i.e., a given level of improvement is scored equally, independently of what was the initial score on the criterion concerned. For some clearly non-linear phenomena like noise levels, this was a major simplification. It can only be justified as an approximation against the setting of an evaluation exercise where many of the scores are likely to be correct only to a broad level of magnitude and by the existence of sensitivity testing modules within the COMPASS structure that permit the consequences of doubts about the accuracy of any of the input data to be explored.

Overall project ranking within COMPASS is based on a calculation of project effectiveness: capital cost ratio. This choice is made because in all probable applications the capital cost constraint is likely to be binding. Hence, drawing a direct comparison with cost-benefit analysis and capital budgeting in general (see, e.g., Pearce & Nash, 1981), ranking by ratio provides an effective heuristic for establishing the best overall set of projects to implement. Especially in the presence of some schemes whose capital cost may be high relative to the budget available, ranking by effectiveness with capital cost simply weighted and netted out as a negative contribution to effectiveness will not in general lead to an optimal selection of schemes.

The original COMPASS program has been tested on data provided by a number of local authorities. The feedback has been positive, while at the same time identifying areas of potential improvement. In particular, one matter of concern derives from the difficulty in establishing accurate measures of project effectiveness on each of the different criteria. A second concern is the extent to which decision makers view projects in their own right as individual schemes, rather than as members of a package of schemes contributing to an overall improvement in traffic conditions in the town for which they are responsible.

This paper responds to these two issues by exploring the use of a fuzzy multicriteria model for prioritizing highway schemes (although the previous pure additive model had the advantage of being relatively straightforward to implement and to explain to non-specialist decision makers, trial applications to priority assessment exercises have suggested attempting an alternative procedure based on a fuzzy multicriteria approach). As will be explained more fully in subsequent sections, this approach firstly allows for a more flexible assessment of whether one project's criteria scores really do establish that it is preferable to another. Additionally, a method is derived for testing sets of projects against each other, where the assessment of the sets looks at their aggregate achievement in each of the 32 dimensions of impact, rather than at what is contributed by any one component project from the set in isolation. The functioning of the method is illustrated using data on a group of twelve projects supplied by a British local authority (see the APPENDIX with the original data). The projects represented are broadly typical, with the one exception that they are clearly divided into low-cost and high-cost subsets, with relatively little representation of the more common medium-scale schemes. It is clear that high-cost and low-cost schemes are particularly difficult to compare, and that the way of including capital cost in the model will be important.

3 - THE BASIC MODEL

This alternative PAT model has been derived from the method proposed by Siskos *et al.*, 1984, but the output -final information to be analyzed by the decision maker-is expanded according proposals given in Montero & Tejada, 1986; in order to get a better knowledge of projects. The initial set of data -expected scores G(i,j) under the ith criteria if project j is developed- has been given by a group of specialists, including the relative weight of each criteria and the threshold of significant difference and the veto threshold for the scores under each criterion. Based on this set of parameters, the following fuzzy relations are then defined:

a) *Partial fuzzy outranking relations:* they provide the strength of relationship between any two projects, in outranking terms, regarding only one criterion. In this way, a value PO(i,j,k) is assigned to represent the degree to which project k is outranked by the project j, taking into account only the ith criterion. It depends on the significance threshold, and as a first step it was defined as $PO(i,j,k)=1$ if $G(i,k)\leq G(i,j)$, $PO(i,j,k)=0$ if $G(i,k)\geq G(i,j)+S(i)$ and linear interpolation for intermediate values.

b) *Partial fuzzy discordance relations:* they provide information about incomparability phenomena between two projects, due to a given criterion. In relation to the outranking of a project j by the project k, a value PD(i,j,k) will show how discordant is an unfavorable difference in performance under the ith criterion, depending on the veto threshold and the significance threshold (as a first step it was taken as $PD(i,j,k)=1$ if $G(i,k)\geq G(i,j)+V(i)$, $PD(i,j,k)=0$ if $G(i,k)\leq G(i,j)+S(i)$ and also linear interpolation otherwise).

c) *Fuzzy concordance relation:* it provides the weighted aggregated outranking, obtained from all the partial outranking relations and taking into account the criteria weights W(i) ∀i, previously standardised.

$$C(j,k) = \sum_i W(i)*PO(i,j,k) \qquad \forall j,k$$

d) *Fuzzy outranking relation:* it aggregates the fuzzy concordance relation with the partial discordance relations. Final analysis will be based on its associated domination structure (see Orlovsky ,1978). Initially the following expression was proposed:

$$D(j,k) = C(j,k) * \min_i (1-PD(i,j,k))$$

4 - THE OUTPUT

The initial idea was to adapt an *outranking method* to our particular transport planning problem. Two important difficulties were found in such an implementation: the specific formulas to be used and the way of including cost (it should not be considered just as another 33rd criterion, and if included in the basic formulas, it becomes too easily either decisive or non-relevant). At its final stage, the complete treatment is provided by a set of programs; in order to get more insight, complementary fuzzy relations are also provided (*similarity, strict preference* and *incomparability*) at each level, together with other useful indices (*ratio effectiveness*, for example).

Based on the fuzzy set of nondominated alternatives

$$ND(j) = 1 - \max_k (D(k,j)-D(j,k))$$

(Orlovsky, 1978), two outputs are included in a final step (see Montero & Tejada, 1986):

a) *Hierarchical representation with δ-level choice sets*, which allows us to consider slight errors in the evaluation of such a fuzzy set of nondominated projects. Orlovsky's choice set will appear as the 1-level set, when it is non-empty.

b) *Successive discarding analysis*. Worst projects -those with the lowest degree of nondomination- are successively discarded, and then a new nondomination structure is re-evaluated without taking into account those projects.

Cost is included, as a second step, in two alternative ways, and then both previous treatments a) and b) are developed:

c) *Effectiveness as a fuzzy preference relation*, to be aggregated at the fuzzy outranking relation level, through an interactive aggregation rule.

$$D_{pe}(j,k) = D(j,k) * \min (1,Cost(k)/Cost(j))$$

d) *Effectiveness as a fuzzy set*, to be aggregated also through an interactive aggregation rule, but at the fuzzy set of nondominated alternatives level.

$$ND_{fe}(j) = ND(j) * CK/Cost(j)$$

where CK is defined in order to get an appropriate scale (for example, minimum cost of the projects under consideration).

TABLE 1

Project	Cost	RE x1000	Rank	ND	Rank	FE x100	Rank	PE x100	Rank
1	2870	0.1500	7	0.4464	6	0.3889	8	57.345	4
2	3710	0.0813	10	0.4473	5	0.3014	9	44.632	6
3	6030	0.0238	11	0.4630	4	0.1920	12	13.435	10
4	850	0.1136	9	0.0908	12	0.2673	11	9.089	12
5	3300	-0.037	12	0.3884	7	0.2943	10	46.638	5
6	1600	0.1473	8	1.0000	1=	0.6944	7	100.00	1=
7	201	0.7625	6	0.2471	9	3.0736	6	26.812	8
8	50	3.5650	2	1.0000	1=	58.000	2	100.00	1=
9	30	2.4697	3	0.1851	11	15.428	3	39.138	7
10	105	0.9041	5	0.2689	8	6.4251	4	10.948	11
11	25	7.1837	1	0.5449	3	54.496	1	86.355	3
12	87	1.5457	4	0.2124	10	6.1000	5	15.044	9

In the above TABLE 1 it is shown a small portion of the output for the complete set of our twelve *single* projects: in the RE column appear the ratio effectiveness indices, ND are the nondomination degrees without costs, FE are the nondomination degrees based on (c), and PE are the nondomination degrees (d).

Since we are not just looking for a *single* project, but for a satisfactory set of projects that can be developed with a certain budget, each group of projects should be considered as one project.

e) *Aggregated projects:* families of different projects are considered if the total cost is within an appropriate range -in this way the influence of cost is minimized-. The complete set of outputs should be then obtained for each families of aggregated projects, with appropriate scores (it was previously checked that the associated scores of any group of out single projects could be evaluated according to the additive assumption).

Obviously, the number of aggregated groups can become too large too easily. The following procedure was then applied, but it is clear that the model is open to *ad hoc* changes by the decision maker -even a tentative process with different cost ranges-, taking into account all the information available at each moment:

1.- Compare, by applying the PAT1 program, all *maximal* sets of aggregated projects within a fixed range in cost -that is, sets of projects that can be jointly developed within the budget and such that no other project can be added while remaining in the fixed cost range-. There were found 19 maximal groups in the *a priori* fixed range (7.5 to 8.0 million pounds). This PAT1 program is able to find all maximal sets in a fixed range of cost within any family of projects, developing the complete analysis for them.

2.- Consider just a *few* of those maximal aggregated projects, and apply the PAT2 program to each one in order to study if some projects inside them should be rejected (this PAT2 program develops the complete analysis for all the subsets within any family of projects). After a deep analysis of the PAT1 output -containing the summarized structure of all maximal groups- three maximal groups were chosen:

A = {2,6,7,8,9,10,11,12}

B = {1,2,4,7,8,9,11}

C = {1,4,6,7,8,9,10,11,12}

and no *single* project could be clearly rejected within them -remaining in the required range in cost-. As an example, see TABLE 2 for group A, where five subsets were found in the cost range:

A1 = {2,6,7,8,9,10,11,12}

A2 = {2,6,7,8,9,10,12}

A3 = {2,6,7,8,10,11,12}

A4 = {2,6,7,8,10,12}

A5 = {2,6,7,9,10,11,12}

TABLE 2

Project	Cost	RE x1000	Rank	ND	Rank	FE	Rank	PE	Rank
A1	7808	0.2109	1	1.0000	1	0.9929	1	1.0000	1
A2	7783	0.1885	4	0.2475	3	0.2465	3	0.2505	3
A3	7778	0.2022	2	0.5659	2	0.5641	2	0.5697	2
A4	7753	0.1797	5	0.0618	4	0.0618	4	0.0684	4
A5	7758	0.1893	3	0.0010	5	0.0000	5	0.0072	5

3.- Apply the PAT3 program in order to compare maximal aggregated projects. The decision maker should take the decision based on the PAT3 output (TABLE 3 shows a small portion of this output), where the complete analysis for any selection of aggregated projects is made (an initial proposal was to develop {2,6,7,8,9,10,11,12}, and it was considered an acceptable choice -an a priori idea was to develop principally cheap projects but only one expensive project-).

TABLE 3

Project	Cost	RE x1000	Rank	ND	Rank	FE	Rank	PE	Rank
A	7808	0.2109	2	1.0000	1	1.0000	1	1.0000	1
B	7928	0.2073	3	0.4473	3	0.4406	3	0.4469	3
C	7818	0.2395	1	0.6897	2	0.6889	2	0.6897	2

In this paper only a part of the outputs are included, always assuming linear interpolation in the basic formulas; other expressions -e.g., logistic curves- and fuzzy numbers are also being investigated in order to improve the appropriateness model to our particular problem and in order to increase its sensitivity. In any case, robustness can be studied through simulation, by including random errors in the initial data -though it can be complex since the number of parameters required in the model is usually large, even in a small case like the one analyzed here-. The complete programs can be obtained from the authors on request.

Finally, once again the difficulty of how capital cost should be included when analyzing problems of this kind should be pointed out. Aggregating projects allows a reasonable way of avoiding the difficulty in our case.

5 - GENERAL COMMENTS

This package of fuzzy multicriteria techniques has been applied to a to a particular transport planning problem in the U.K.; it is basically, an adaptation from the outranking method proposed by Siskos et al., 1984, initially developed for a complex decision making problem involving radioactive protection measures for a nuclear power plant, but with *ad hoc* formulas and an expanded output.

Some *a priori* advantages of building a fuzzy outranking relation should be noted:

1) On the one hand, any multicriteria technique should always be understood just as an aid to reaching a final decision: such a decision will be usually taken directly by the decision-maker, who only in special cases would leave it to be taken *automatically*. A classical value function approach gets in fact a solution through a representation on the real line; but it seems to be rather fictitious for any complex multicriteria decision making problem and, finally, such a classical additive model has a clear tendency to supply the decision-maker with extra work, providing not much insight about the structure of the set of alternatives (it does not take into account any kind of conflict, similarities or incomparabilities). In a way, our final set of fuzzy outranking relations can be considered as an intermediate level between the initial mass of data and the classical value function aggregation. Moreover, the whole package of programs can be structured by the decision-maker in many different ways, and such a flexibility should always be required to any decision making aid method.

2) On the other hand, Siskos's proposal takes out the main drawback in constructing a fuzzy preference relation: the decision maker's difficulties in establishing direct pairwise comparison values. Fuzzy outranking relations are defined from the scores, weights and the veto and significance thresholds: since scores will be evaluated by specialists, and weights can be known by applying some standard technique, then the decision-maker should define directly only the values of both thresholds. Moreover, this approach allows us to model incomparability phenomena, a relevant characteristic when dealing with practical multicriteria problems (a single criterion can inhibit direct outranking between alternatives).

The particular package of programs applied to our data provides a more complete knowledge about the structure of single and aggregated sets of projects through a flexible process.

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APPENDIX: DATA SET

PROJECTS (One criteria per row)

1	2	3	4	5	6	7	8	9	10	11	12	W(i)	S(i)	V(i)
0.400	0.433	0.367	0.000	0.133	0.833	0.000	0.100	0.067	0.000	0.167	0.033	0.004	0.200	1.000
0.133	0.133	0.067	0.067	0.067	0.200	0.067	0.067	0.200	0.000	0.067	0.000	0.024	0.200	1.000
0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.162	0.200	1.000
0.000	0.067	0.033	0.000	0.233	0.167	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.200	1.000
0.000	0.000	0.000	0.000	0.200	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.200	1.000
0.000	0.000	0.000	0.000	0.000	0.000	0.167	0.000	0.000	0.000	0.000	0.000	0.162	0.200	1.000
0.889	2.662	4.637	0.000	0.449	1.428	0.000	0.150	0.000	0.000	3.219	3.131	0.016	1.000	5.000
3.557	2.219	1.546	0.000	0.300	1.428	2.859	0.400	0.999	1.306	1.609	2.088	0.020	1.000	5.000
1.334	2.219	0.000	0.963	0.599	1.428	0.000	0.000	0.000	0.000	0.000	0.000	0.016	1.000	5.000
3.557	1.775	2.319	0.000	0.449	0.952	0.953	0.200	2.498	2.938	4.024	1.044	0.020	1.000	5.000
24.50	7.800	7.500	10.50	-21.0	47.30	5.300	3.300	0.000	0.000	2.200	2.300	0.002	10.00	50.00
3.100	1.200	1.100	1.100	-2.90	5.400	0.700	0.500	0.000	0.000	0.300	0.300	0.004	1.000	5.000
3.000	1.200	0.400	0.900	-1.60	2.000	0.700	0.300	0.000	0.000	0.200	0.200	0.005	1.000	5.000
0.100	0.100	0.100	0.100	-0.20	0.700	0.000	0.000	0.000	0.400	0.000	0.000	0.002	0.200	1.000
0.400	0.100	0.200	0.000	-0.30	0.800	0.000	0.100	0.000	0.000	0.100	0.100	0.002	0.600	3.000
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.200	1.000
52.90	16.80	16.20	22.60	-67.8	102.2	11.40	7.000	0.000	0.000	4.700	5.000	0.002	20.00	100.0
10.40	4.100	3.700	3.700	-14.0	17.80	2.300	1.600	0.000	0.000	1.100	1.000	0.002	4.000	20.00
10.80	4.200	1.500	3.300	-8.30	7.200	2.500	1.100	0.000	0.000	0.700	0.700	0.002	3.000	15.00
1.600	1.600	1.600	-4.90	1.600	11.30	0.000	0.000	0.000	0.000	0.000	0.000	0.002	2.000	10.00
-6.20	-11.9	-47.8	-19.0	-0.50	-2.80	-8.80	-4.50	-0.70	-1.30	-11.7	-7.80	0.002	10.00	50.00
0.176	0.436	0.000	0.000	0.798	0.046	-.001	0.000	0.000	0.400	0.000	0.000	0.071	0.200	1.000
0.023	0.033	0.000	0.000	0.000	0.030	0.002	0.000	0.000	0.000	0.000	0.000	0.040	0.100	0.500
-.017	-.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.100	0.000
-.001	0.004	0.000	0.000	0.001	0.060	0.000	0.000	0.005	0.001	0.000	0.000	0.048	0.100	0.500
0.002	0.001	0.002	0.000	0.005	0.001	0.001	0.000	0.011	0.002	0.004	0.003	0.028	0.010	0.050
-1.00	-.008	0.000	0.000	0.000	-.008	0.000	0.000	0.000	0.000	0.000	0.001	0.029	0.200	1.000
-.006	-.002	0.000	0.000	-.002	-.002	-.002	0.000	0.000	0.000	0.000	0.000	0.034	0.010	0.050
-.003	-.003	-0.02	0.000	-0.12	-.001	0.000	0.000	0.000	-.002	0.000	0.000	0.006	0.100	0.500
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.057	0.010	0.050
0.400	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.300	0.000	0.000	0.116	0.200	1.000
0.250	0.600	0.200	0.450	0.250	0.200	0.200	0.300	0.000	0.150	0.200	0.200	0.085	0.200	1.000

COSTS

1	2	3	4	5	6	7	8	9	10	11	12
2870.	3710.	6030.	850.	3700.	3600	201	50.	30	105.	25	87.

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Thank you very much for your cooperation.

Yours sincerely,

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