Application of Three Plan Evaluation Procedures to a Highway Alignment Problem

BRYAN H. MASSAM and IAN SKELTON

ABSTRACT

In this paper is offered a comparison of three formal methods of assessing alternate highway alignments. The methods are probabilistic linear vector analysis, a multiattribute trade-off system, and concordance analysis. Data for testing the methods are taken from a study of the evaluation of eight proposed alignments for I-75 north of Atlanta, Georgia. Scores for a set of six variables for each alignment are used. Sensitivity tests are incorporated in the analyses. The need for a policy-making environment in which formal methods are used to improve decision making is stressed.

Currently there is available a variety of formal procedures that can be used to evaluate alternate plans using multiple criteria. These procedures use as basic input data information on the relative merits of alternate plans for a set of criteria. The evaluations can be considered from the point of view of different interest groups. The information can be characterized by a three-dimensional matrix of the style shown in Figure 1. Recently Voogd (1) has suggested that it is appropriate for planners to compare the merits of different procedures, and to this end he has undertaken a comparative study of cardinal and qualitative techniques. A Monte Carlo analysis of more than 30 techniques was undertaken, and Voogd notes (1,p.209) that

> In general it can be concluded that there is a minimum of a 40 percent chance that a technique results in a different ranking [of the alternate plans] from any other technique.

Clearly, it is difficult to recommend a specific procedure to be used to tackle a precise plan evaluation problem; however, the present authors subscribe to the view offered by Midgley and Piachaud (2,p.6) that

> Although it is recognized that planning techniques have many limitations . . . we believe that they are helpful aids to policy-making which enhance objectivity and efficiency. To reject their use is to deny the need for greater rationality in decision-making.

In this paper three specific procedures will be applied to a plan evaluation problem. The data are drawn from a practical study that involved the comparison of alternate alignments for an Interstate highway in the United States.

The three procedures are

1. Probabilistic linear vector analysis (PLVA) (3),
2. Multiattribute trade-off system (MATS) (4), and
3. Concordance analysis (CAS) (5).

The technical details of these procedures will not be given here; they are available in the cited references. This project complements recent studies that offer a critical comparison of CAS with the following procedures:

- Structural mapping,
- Utility scores,
- Lexicographic ordering (6),
- Factor analysis,
- Electre III,
- Keeney-Raiffa approach (7), and
- Additive utility models (8).

It is suggested that CAS appears to provide planners and policy makers with a procedure that can assist in the systematic collection and analysis of

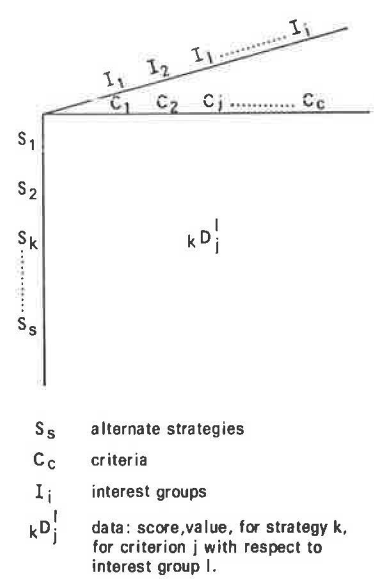

FIGURE 1 A three-dimensional plan evaluation matrix.

Department of Geography, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada.

plan evaluation data. The technique is highly flexible and allows a number of different types of sensitivity analyses to be conducted. The authors suggest that CAS is a suitable multicriteria evaluation procedure for addressing a variety of practical planning problems.

DATA

The data have been abstracted from Zieman et al. (9). Their study examined eight alternate alignments for an extension to I-75 north of Atlanta, Georgia. A set of 56 variables was used to evaluate each proposed alignment. The variables addressed four areas of concern:

1. Economics and highway engineering,
2. Environment and land use,
3. Recreation, and
4. Social and human factors.

The study group selected weights that were assigned to each criterion. Using the full set of data and PLVA it was concluded that the alternatives could be classified in two distinct sets. The most attractive ones included routes G, G-1, T, and T-1. These codes are used following the designations in Zieman et al. (9) and Odum et al. (3). The four easterly alignments (F, F-1, O, and P) were clearly inferior. It should be noted that a preliminary study by the Georgia Department of Transportation had offered F as the preferred route. Protests by environmentalists and others caused a fuller set of data to be analyzed and this gave rise to the report by Zieman et al. (9). Using PLVA on the four better alignments allowed the authors to conclude that T-1 and G-1 were marginally better than G and T. However, the differences were not pronounced.

The study reported here uses the same set of eight routes, and a set of six variables has been selected. The weights from the original study have been preserved. The basic data are given in Table 1. Voogd (1) has offered arguments for restricting the number of criteria to about eight. For this reason and for ease of computation, the authors have opted to use a small set of data for comparing the three procedures.

RESULTS OF PROBABILITY LINEAR VECTOR ANALYSIS

In PLVA, scores are calculated for each alternative by adjusting raw scores and weights and then combining them. The selection of a standardization procedure depends on the nature and distribution of the raw scores. In the Zieman study, and in this one, raw values were standardized by dividing each by the largest value. The weights were standardized by dividing each one by the sum of all the weights to give the values given in Table 1.

The score for alignment j is calculated as follows:

$$I_j = \sum_{i=1}^{n} (w_i X_{ij} + e w_i X_{ij})$$

where

i_j = overall impact value or utility for alignment j,
w_i = scaled weight for criterion i,
X_{ij} = scaled weight for criterion i for alignment j,
e = random number between +0.5 and -0.5, and
n = number of criteria being considered.

For each alignment 20 simulations were run using a set of random numbers. The mean ($\bar{I}$) and the 95 percent confidence intervals were calculated. The results are shown in Figure 2 for both the full set of data and the small set. The overall results are quite similar for the $\bar{I}$-values, though the distinction between the two sets that is apparent when all of the variables are used tends to be lost when the group of six variables is used.

RESULTS OF MULTIATTRIBUTE TRADE-OFF SYSTEM

MATS allows the incorporation of different function forms into the calculation of the I-values. Whereas PLVA assumes a linear function between I_j and X_{ij}, MATS considers alternate shapes for the relationship. One of the critical and controversial aspects of MATS is surely the way in which the function forms are derived. Who is to be asked? How is the precise function to be determined? How reliable are the opinions and preferences of respondents? What is the level of comprehension of the respondents regarding technical terms such as "function form"? Instead of pursuing these issues, three alternate types of function that have general application are offered, and results of sensitivity tests are presented. The three general function forms used here are

1. $I_j = \Sigma w_i \pm 1\ (X_{ij})$,
2. $I_j = \Sigma w_i \pm 1\ (X_{ij})^{1/2}$, and
3. $I_j = \Sigma w_i \pm 1\{[1/(1 + e)\ (a - b)]\ (X_{ij})\}$

where a = 5 and b = 10.

The first equation represents a positive linear relationship between I-values and the attribute values. The second describes the situation of diminishing marginal utility for I as the value for an attribute increases. The third function form, the logistic

TABLE 1 Basic Data for Route Alignment Problem with Six Variables[a]

		Alignment							
	Weight[b]	G	G-1	T	T-1	F	F-1	P	O
Potential for economic development[b]	0.28	10	10	10	10	8	8	4	6
Total costs (x $10 million)	0.03	108	101	013	95	106	98	89	82
Area of water removed from right-of-way (acres)	0.05	17	27	23	33	22	32	52	19
Area affected by great noise (acres)	0.06	33	33	50	50	84	84	95	66
Visual disturbance[b]	0.02	-2	-3	-2	-3	-5	-6	-5	-2
No. of lives saved up to 1993	0.56	377	377	389	389	385	385	301	305

Note: The larger the number the more attractive the alignment.

[a]After Zieman et al. (9).
[b]Units not given in original report.

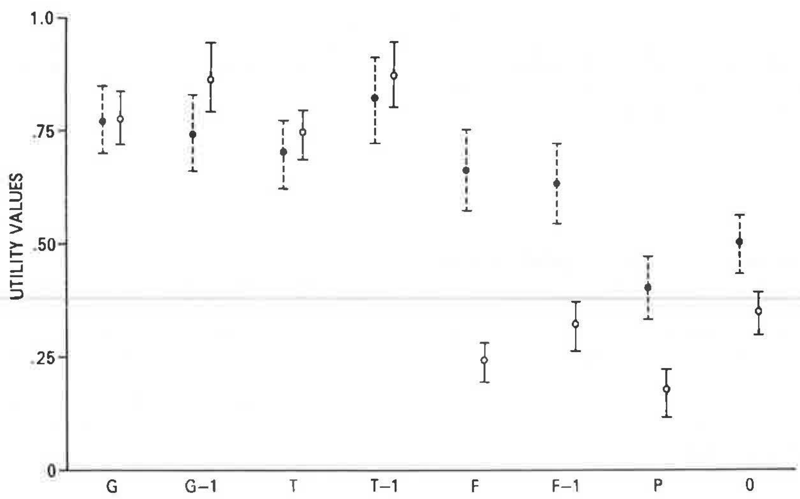

FIGURE 2 Probabilistic linear vector analysis: eight highway alignments, mean values, and 95 percent confidence limits.

curve, allows I to increase sharply for the lower range of values for an attribute, and later the marginal utility decreases. In this exercise the basic scores were scaled from zero (worst) to unity (best) before the application of the function forms.

A series of 21 experiments was undertaken using different weighting schemes for the criteria. In Weighting Scheme A, two criteria, the economic and environmental or the human pair, were assigned a weight of ±0.20, and the others ±0.15. Weighting Scheme B used ±0.30 and ±0.10, respectively. The results are given in Table 2. The first three experiments assume equal weight for all criteria. The values for I are highly stable for the different function forms.

The results suggest that Weighting Scheme A introduced some variation into the I-values, though the basic classification of the set of routes into two groups of better and worse remains stable. Weighting Scheme B produces less agreement with respect to the ordering of routes within the two categories. An overall classification of the routes can be derived by considering the I-values for the set of 21 experiments. These results are shown in Figure 3. The mean value for each alignment is given, and the 95 percent confidence intervals are indicated.

Overall, this analysis confirms that the westerly located alignments (G, G-1, T, and T-1) appear to be consistently superior to those in the east (F, F-1, P, and O).

TABLE 2 Results of Experiments Using Multiattribute Trade-Off System

Experiment No.	Weight	Scheme	Function Form[a]	Alignment G	G-1	T	T-1	F	F-1	P	O
1	Equal		L	0.81	0.76	0.79	0.75	0.49	0.45	0.16	0.63
2			S	0.82	0.67	0.69	0.60	0.44	0.40	0.10	0.63
3			E	0.82	0.81	0.81	0.82	0.49	0.46	0.16	0.59
4	Economic	A	L	0.77	0.75	0.77	0.75	0.48	0.46	0.18	0.63
5		A	S	0.78	0.66	0.68	0.60	0.44	0.41	0.11	0.65
6		A	E	0.79	0.78	0.78	0.81	0.48	0.47	0.19	0.59
7	Environmental	A	L	0.82	0.77	0.79	0.74	0.50	0.45	0.14	0.63
8		A	S	0.83	0.67	0.67	0.57	0.43	0.38	0.09	0.62
9		A	E	0.84	0.82	0.82	0.81	0.49	0.45	0.15	0.60
10	Human	A	L	0.82	0.76	0.81	0.76	0.50	0.46	0.16	0.62
11		A	S	0.83	0.67	0.72	0.61	0.45	0.41	0.09	0.63
12		A	E	0.84	0.82	0.83	0.83	0.49	0.46	0.15	0.58
13	Economic	B	L	0.68	0.71	0.71	0.75	0.44	0.48	0.24	0.64
14		B	S	0.69	0.63	0.63	0.61	0.44	0.45	0.15	0.69
15		B	E	0.69	0.70	0.69	0.79	0.46	0.49	0.28	0.58
16	Environmental	B	L	0.88	0.80	0.78	0.70	0.50	0.42	0.09	0.66
17		B	S	0.89	0.69	0.63	0.52	0.41	0.33	0.06	0.58
18		B	E	0.89	0.86	0.86	0.79	0.49	0.41	0.10	0.63
19	Human	B	L	0.85	0.78	0.87	0.80	0.53	0.46	0.14	0.58
20		B	S	0.87	0.68	0.81	0.66	0.49	0.43	0.08	0.62
21		B	E	0.89	0.86	0.88	0.87	0.50	0.47	0.11	0.55
	Mean			0.81	0.74	0.76	0.72	0.47	0.43	0.14	0.61
	Standard deviation			0.06	0.06	0.07	0.09	0.03	0.03	0.05	0.03
	Minimum 95 percent level			0.80	0.73	0.75	0.71	0.47	0.43	0.13	0.61
	Maximum 95 percent level			0.82	0.75	0.77	0.73	0.48	0.44	0.14	0.62

[a] L = linear, S = square root, and E = exponential.

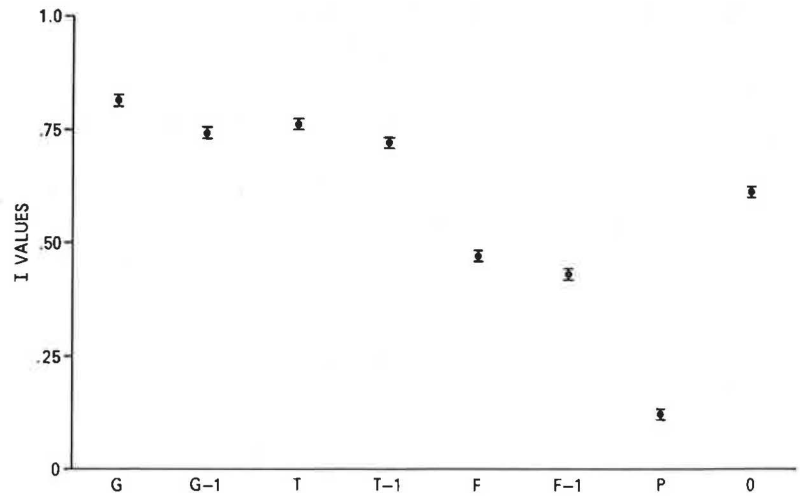

FIGURE 3 Multiattribute trade-off system: results of 21 experiments, mean values, and 95 percent confidence limits.

RESULTS OF CONCORDANCE ANALYSIS

The data given in Table 1 were examined using concordance analysis. A series of 28 experiments was defined using a variety of weighting schemes and four alternate just-noticeable-difference (JND) values. Concordance analysis is based on consideration of the scores for pairs of alternatives for each criterion. If JND = 100, any difference between scores for two alternatives for a criterion is sufficient to identify a preferred alternative. If JND = 95, a difference of less than 5 percent is judged to indicate that the alternatives are similar. The use of JND values allows the introduction of a systematic confidence level into the analysis. If there is absolute certainty that no errors exist in the basic data, JND = 100 can be used for each criterion. If there is less certainty about the accuracy of the impact scores, the JND values can be adjusted accordingly. For this analysis four different JND values were used: 100, 95, 90, and 85. These values were applied to all of the six criteria for each set of experiments.

Given eight alternate alignments, there are 56 pairwise comparisons. For each pair i and i′, for each criterion, three possible outcomes can be identified: $i > i'$, $i = i'$, or $i < i'$. Concordance analysis provides a way of combining this information as a concordance index (cii′) for alignments i and i′.

The index is defined as

$$cii' = [\Sigma w\ (i > i') + 1/2\ \Sigma w\ (i = i')]/\Sigma w$$

where

$\Sigma w\ (i > i')$ = the sum of the weights of the criteria for the cases in which i is preferred to i′,

$\Sigma w\ (i = i')$ = the sum of the weights for the criteria for the cases in which i is judged to be the same as i′,

Σw = the sum of the weights for all the criteria.

The value of cii′ ranges from zero to unity. It takes on the former value when i′ is preferred to i for all criteria. If i is preferred to i′ for all criteria, cii′ is unity.

Values for all cii′s for this problem can be summarized in an eight-by-eight square concordance matrix. By summing the values across each row, the alternatives can be ordered from highest to lowest values. An index of agreement (A) can be defined to measure the correspondence between this ordering and the information in the concordance matrix. If A = 1.0, the level of agreement is perfect. Full details of this index are given in Massam (5). The results for this set of experiments are given in Table 3. The A-values are consistently high.

The two sets of experiments that involve weighting the economic factors give rise to relatively high positions for alignment O. For all other experiments this alignment and F, F-1, and P are clearly inferior. There is a distinct classification of the eight alternatives into two sets. These results agree with those provided by PLVA and MATS.

OVERVIEW

In Table 4 a summary of the results for the three procedures is given. Although there is a certain level of consistency and identification of the best four is easy, beyond that the selection of the single best alignment depends on the specific procedure used.

There are two results that stem from this observation. First, the choice of an appropriate procedure can depend on the nature of the basic impact data. CAS can accommodate ordinal or interval scores, whereas MATS and PLVA require interval values. Second, formal techniques such as PLVA, MATS, or CAS can help in data collection and some basic analysis. For example, they can be used to undertake a series of experimental runs; however, the final choice for implementation must surely involve a choice procedure that is ot mechanistic. To this end the authors argue for the incorporation of the procedures into the general planning process. This begins with the identification of a need for an alignment study, through data collection and involvement of interest groups, before the final selection and implementation of a particular alternative. Formal methods surely have a useful role to play, but policy makers cannot rely solely on such methods for making decisions. The methods do not deserve to be rejected; instead policy-making environments within which formal procedures can play a role need to be designed.

TABLE 3 Results of Experiments Using Concordance Analysis

Experiment No.	Weight	Scheme	JND	A	Alignment							
					G	G-1	T	T-1	F	F-1	P	O
1	Equal		100	0.96	2	4	1	3	6	7	8	5
2			95	1.0	1	3	2	4	6	7	8	5
3			90	1.0	1	3	2	4	6	7	8	5
4			85	1.0	1	3	2	4	6	7	8	5
5	Economic	A	100	0.91	2	3	4	5	7	8	6	1
6		A	95	0.91	2	4	3	5	7	8	6	1
7		A	90	0.96	1	4	3	5	6	8	7	2
8		A	85	0.91	1	4	3	5	6	8	7	2
9	Environmental	A	100	0.93	1	4	2	3	6	7	8	5
10		A	95	0.96	1	3	2	5	6	7	8	4
11		A	90	0.96	1	3	2	5	6	7	8	4
12		A	85	0.91	1	3	2	5	6	7	8	4
13	Human	A	100	0.96	2	5	1	3	6	7	8	4
14		A	95	0.96	1	3	2	4	6	7	8	5
15		A	90	0.96	1	3	2	4	6	7	8	5
16		A	85	0.98	1	3	2	4	6	7	8	5
17	Economic	B	100	0.84	4	2	5	3	6	7	8	1
18		B	95	0.86	3	5	4	2	8	7	6	1
19		B	90	0.88	1	5	3	4	7	8	6	2
20		B	85	0.84	1	4	2	5	6	7	8	3
21	Environmental	B	100	0.96	1	3	2	5	6	7	8	4
22		B	95	0.96	1	3	2	5	6	7	8	4
23		B	90	0.96	1	3	2	5	6	7	8	4
24		B	85	0.95	1	2	3	5	6	7	8	4
25	Human	B	100	0.93	3	5	1	2	6	7	8	4
26		B	95	0.96	1	3	2	4	6	7	8	5
27		B	90	0.96	1	3	2	4	6	7	8	5
28		B	85	0.98	1	3	2	4	6	7	8	5

Note: JND = just-noticable-difference value and A = index of agreement.

TABLE 4 Comparison of Results Using Probabilistic Linear Vector Analysis, Multiattribute Trade-off System, and Concordance Analysis

	Alignment							
	G	G-1	T	T-1	F	F-1	P	O
PLVA	2	3	4	1	5	6	8	7[a]
MATS[b]	1	3	2	4	6	7	8	5
CAS	2	4	1	3	6	7	8	5[c]

[a] See Figure 2.
[b] These ranks were derived from the sum of the values calculated under the linear, square root, and exponential function forms given in Table 2.
[c] See Table 3.

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