Mathematical Programming Models for the Development of a Unified Ranking System

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ABSTRACT

An important component of any rehabilitation and maintenance programming is an index or scale for selecting candidate projects for rehabilitation and establishing priority among the candidate projects. In the past two decades, tools and concepts of multiple attribute decision making (MADM) have been applied to developing an index for establishing priorities for pavement rehabilitation. However, virtually no effort has been made toward developing a unified ranking system for both rigid and flexible pavements. Presented is a univariate time series model dealing with a single common attribute existing in both rigid and flexible pavements, such as roughness. The single attribute method is extended by adding more attributes such as cracking, rutting, punchouts, and so forth is in order to form a MADM method. The goal programming model determines the relative weights for the multiple attributes. Several advantages of these models for practical application are discussed.

During the past 40 years, more than $1 trillion has been invested in the highway system of the United States. With much of the highway network system completed, national attention and interests have been directed toward the problems of maintaining highways. State and local governments spend $15 billion annually to maintain the nation's 4-million-mile network (1). Massive investments, which are estimated to be $400 billion by the year 2000, will be required for rehabilitating and maintaining pavement. Consequently, it has become necessary to develop a system for effectively programming the rehabilitation and maintenance of the pavement network.

Some agencies developed a combined index to express the overall condition of the pavement for rating purposes. This combined index is computed by adding up the deduct values for specific distress types and subtracting the sum from the perfect score, 100. The combined index method using deduct values is one of the so-called multiple attribute decision making (MADM) methods that have long traditions in many other disciplines (2).

In the past decade, the tools and concepts of MADM have been applied to the development of an index for establishing priorities for pavement rehabilitation. However, virtually no efforts have been made toward developing a unified ranking system for both rigid and flexible pavements based on the different sets of pavement attributes. Recently, the Texas State Department of Highways and Public Transportation (SDHPT) has indicated its interest in the development of a unified ranking system for selecting candidate projects in order to distribute rehabilitation funds to both types of pavement rehabilitation projects on an equitable basis.

The next section consists of a univariate time series model dealing with a single common attribute that exists in both rigid and flexible pavements, such as roughness. Then the problem with a single attribute is extended by adding more attributes such as cracking, rutting, punchouts, and so forth in order to form a multiple attribute decision making problem. Next, the goal programming model, which determines the relative weights for the attributes, is described. The paper concludes with a discussion of the practical applications of these models.

UNIVARIATE TIME SERIES OF SERVICEABILITY INDEX MODEL

The present serviceability index (PSI) represents a means for using objective data, such as roughness, to estimate present serviceability rating (PSR). Generally, a pavement section that is deteriorating, for example, losing serviceability index (SI) at a fast rate, should be ranked higher for rehabilitation than others because rapid loss of SI indicates probable rapid future deterioration of pavement. An increasing deterioration rate might be due to inadequate design, traffic heavier than was expected, more severe environmental conditions than expected, and so forth.

This concept can be demonstrated by comparing three pavement sections, as shown in Figure 1. The three pavement sections are currently at the 3.0 SI level and are 5, 8, and 10 years old, respectively. The question is, Which section should be ranked higher for rehabilitation? The time-dependent phenomenon of pavements includes many unknown factors and it is not possible to develop a deterministic model that allows exact calculation of the future pavement condition ranking. However, it can be observed that these pavements should be ranked in the order of A, B, and C, based on the different past performance histories of the pavements.

The model discussed here is based on a single time series that is a sequence of observed SI data at equally spaced time intervals, say X_t, $t = 1, 2, \ldots n$ (years). It is presumed that the observations in a time series are correlated. Therefore, the model relating X_t, X_{t-1}, and X_{t-2} can be developed as

$$X_t = b_1 X_{t-1} + b_2 X_{t-2} + a_t \qquad (1)$$

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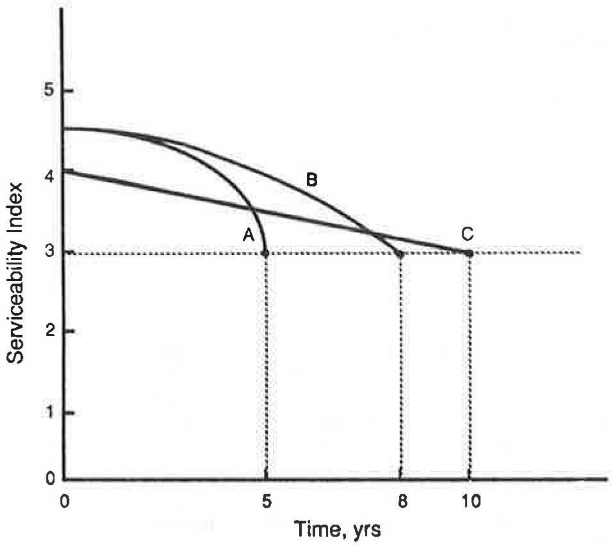

FIGURE 1 Three pavement sections with the same present SI but different rate of loss of SI

where

X_t = SI at time t;
b_1, b_2 = parameters to be estimated; and
a_t = random error entering the the model at time t, which is assumed to be an independent, normally distributed random variable with mean zero and constant variance σ_a^2.

The model (Equation 1) expresses the dependence of the variable on itself at different points in time; in other words, the variable X_t is regressive. A set of data points is needed to estimate b_1 and b_2. To do this, data were obtained from the SI data base at the Center for Transportation Research (CTR), University of Texas at Austin, where historical SI data have been collected from the 22 test sections over 3 years beginning in 1982; these data are given in Table 1. By using an ordinary least-squares method, the cross-sectional data were fitted to the model as follows:

$$\text{FSI} = 0.98\ \text{PSI} - 0.55\ \text{LSI} \qquad R^2 = 0.96 \tag{2}$$

where

FSI = future serviceability index (X_t),
PSI = present serviceability index (X_{t-1}), and
LSI = loss of serviceability index during the previous year ($X_{t-2} - X_{t-1}$).

This model can be used to predict SI in the future by using the current serviceability index and the LSI over recent time. This predicted SI can be used as a common index for rehabilitation. The model can be updated from time to time as more data become available. In those cases in which past history data for more than 3 years are available, the model can be expanded to consider the more distant past history of SIs.

VALIDATION OF THE MODEL

In this section, diagnostic checks are applied to the fitted model. To check the prediction capability of the model, the observed values were plotted against the predicted values, as shown in Figure 2. It can be observed that the model predicts the future serviceability reasonably well. High R^2 value supports this explanatory power of the model. The F-statistic value of the fitted regression falls in the critical region at a 1 percent level of significance. Therefore the null hypothesis (H: $b_1 = b_2 = 0$) is rejected, and thereby the notion that the regression slopes are different from zero purely by chance is also rejected (3). Parameters of independent variables were found to be significantly different from zero, by using a t-statistic at the level of significance $\alpha = 0.01$.

TABLE 1 Annual SI Data for 22 Test Sections in Austin

	Year		
Section No.	1983	1984	1985
7	4.47	4.77	4.69
5	4.54	3.64	3.41
33	4.48	4.42	4.33
36	4.42	4.45	4.37
32	4.41	4.42	4.33
23	4.20	4.18	3.98
34	3.96	3.94	3.82
28	3.81	3.06	3.03
8	3.70	3.67	3.49
40	3.66	3.60	3.68
19	3.62	3.61	3.54
9	3.60	3.27	3.19
3	3.57	3.35	3.25
12	3.53	2.82	2.14
41	3.50	3.50	3.53
15	3.38	2.32	1.07
2	2.62	2.11	2.00
35	2.48	2.69	2.44
6	2.39	2.41	2.36
38	2.08	1.88	1.62
44	1.17	1.21	1.12
39	1.05	0.90	0.77

An error term exists in any model unless the model is a perfect representation of reality. In a good regression model, an error term is assumed to be normally distributed with a mean of zero and a constant standard deviation. Furthermore, the errors are assumed to be independent. The residual is an estimate of the error. The residuals can be used to test the original assumptions: normality, constant variance, and independence in the error term.

To check the normality assumption, a frequency histogram for the residuals was constructed. The bell-shaped distribution that was observed in the frequency histogram is supportive of the normal distribution. A normality of residuals was assured by the Shapiro-Wilk test (W = 0.937). A hypothesis of normality could not be rejected at $\alpha = 0.05$ (4).

To check common variance and independence assumptions, residuals were plotted against the PSIs. It is difficult to detect heteroscedasticity (the case in which the error term has no constant variance) because of the randomness of errors. A pattern in the residuals neither supports the heteroscedasticity nor shows any dependency of residuals. A hypothesis of autocorrelation (that successive residuals tend to be close together) was rejected by the Durbin-Watson test (D = 2.64) at $\alpha = 0.05$ (5).

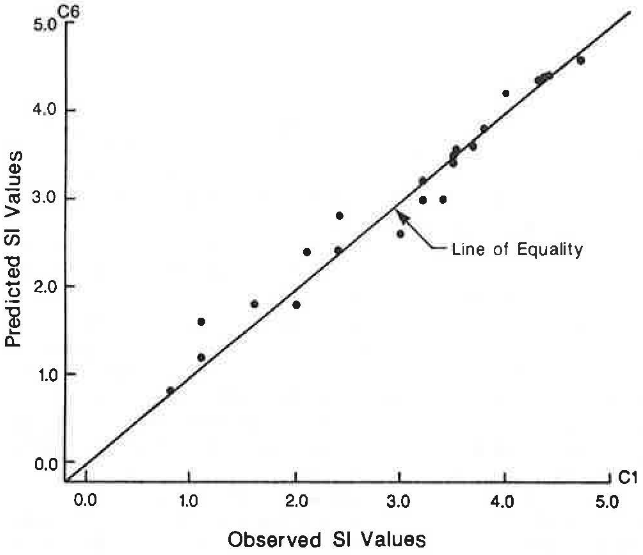

FIGURE 2 Plot of predicted SI values against observed SI values.

Multicollinearity is said to exist when any independent variable is correlated with another independent variable. It is one of the main causes of misinterpretation and misuse of regression. The correlation between variable PSI and LSI in Equation 2 is -0.219. This low value indicates that the correlation between these two independent variables is not significant. In other words, a hypothesis of no correlation could not be rejected at $\alpha = 0.05$ (6).

All of these test statistics and plots indicate that the regression equation satisfies all the assumptions and requirements. The negative parameter associated with the rate of loss of SI indicates that rapid loss of SI probably indicates rapid deterioration of a pavement in the future. The intercept was not significant enough to be included in the final equation. The model should be further verified as more data become available.

APPLICATION OF UNIVARIATE TIME SERIES MODEL

To show how the procedure is used for developing a common index, a number of hypothetical pavement sections were set up, as presented in Table 2. By using Equation 2, the predicted SI was calculated for each of the sections given in Table 2. The predicted SI can be used as a common index for assigning priority rankings to the given sections. These rankings are included in Table 2.

The results indicate that the pavement with the faster deterioration rate should be ranked higher for rehabilitation work. This equation may give some credit to rigid pavements, which generally deteriorate at a slower rate than do flexible pavements.

GOAL PROGRAMMING MODEL FOR MULTIPLE ATTRIBUTE DECISION MAKING

In the past two decades, a substantial advancement in MADM has been made. The results of a literature review of methods and applications using MADM have been classified systematically by Hwang and Yoon (2). In recent years, a great deal of research has been done on MADM; in particular, there has been rapid theoretical development in multiattribute utility theory, which is a solution approach to MADM uncertainty (7). However, the basic proposition that motivates pavement research is the idea that pavement selection for rehabilitation is influenced by perceptions of and values for specific attributes of the pavement sections.

This concept has been used in marketing research to predict consumer preferences for brands of a particular product class (8). The methods require that the decision maker be able to indicate his preference between two alternatives. LINMAP techniques (LINear programming techniques for Multidimensional Analysis of Preferences) were originally developed to explain, rationalize, lead to understanding of, and predict decision behavior, but they are well fitted for normative decision making (9-11). The original model

TABLE 2 Hypothetical Pavement Sections Ranked According to Future Serviceability Index

Section No.	Pavement Type	Present SI	Loss of SI	Future SI	Ranking for Rehabilitation
1	Flexible	3.40	0.80	2.89	18
2	Rigid	3.40	0.60	3.00	20
3	Flexible	3.20	0.50	2.86	17
4	Rigid	3.20	0.40	2.92	19
5	Flexible	3.00	0.30	2.78	16
6	Rigid	2.90	0.20	2.73	15
7	Flexible	2.80	0.10	2.69	14
8	Rigid	2.70	0	2.65	13
9	Flexible	2.60	0.80	2.11	10
10	Rigid	2.50	0.60	2.12	11
11	Flexible	2.40	0.50	2.08	9
12	Rigid	2.40	0.40	2.13	12
13	Flexible	2.20	0.30	1.99	7
14	Rigid	2.20	0.20	2.05	8
15	Flexible	2.00	0.10	1.91	6
16	Rigid	1.90	0	1.86	5
17	Flexible	1.80	0.80	1.32	1
18	Rigid	1.70	0.60	1.34	2
19	Flexible	1.60	0.20	1.46	3
20	Rigid	1.50	0	1.47	4

was modified to estimate weights for both flexible and rigid pavements simultaneously.

Consider a set of preference judgments (j,k) such that pavement section j is preferred to section k in a pairwise comparison. It is assumed that the judgments are implicitly made by a highway engineer or other professional on the basis of some global criteria, possibly with some error. A highway professional makes paired comparison judgments such as the following: pavement section k needs to be rehabilitated before section j. Overall, pavement performance is the global criterion; presumably a highway engineer makes his overall judgment considering some of the pavement attributes, such as cracking, punchouts, and so forth, but exactly which attributes are considered cannot be known.

Let d_{jq} denote the difference of the condition of pavement section j from the perfect condition in terms of pavement attribute q. Let W_q denote the weight or importance of the attribute q. Then the global criterion D_j for the pavement section j is given by

$$D_j = \sum_{q \varepsilon Q} W_q \, d_{jq} \qquad (3)$$

The global criterion model states that given any pair (j,k), the condition of pavement section j is better than the section k only if $D_j < D_k$.

The global criterion is but a model of a highway engineer's decision-making process. It is not necessary that a highway engineer solve Equation 3 to arrive at his decision. The objective of this model is to develop a set of weights such that the global criterion D_j defined in Equation 3 is as consistent as possible with the given pairwise comparison judgments by a highway engineer. Inconsistencies of judgments will be minimized by assigning lower weight to the attributes that involve inconsistent decisions. This leads to the following formulation, which belongs to a particular class of linear programming problems known as goal programming (7,12,13).

$$\text{Minimize} \sum_{(j,k) \varepsilon S} Y_{jk} \qquad (4)$$

Subject to the constraints

$$\sum_{p \varepsilon P} W_p \, d_{kp} - \sum_{q \varepsilon Q} W_q \, d_{jq} + Y_{jk} \geq 0 \text{ for } (j,k) \varepsilon S$$

$$\sum_{p \varepsilon P} A_p \, W_p - \sum_{q \varepsilon Q} A_q \, W_q = 1$$

$$Y_{jk} \geq 0 \qquad \text{for } (j,k) \varepsilon S$$

$$W_p, W_q \geq 0 \qquad \text{for } p \varepsilon P, \; q \varepsilon Q$$

where

j = pavement section that decision maker prefers to section k;
S = set of all ordered pairs (j,k) of the n pavement sections;
Y_{jk} = amount of violations to be minimized by selecting optimum W_p, W_q;
p = pavement attribute of nonpreferred section k;
P,Q = {1, 2 . . . t}: t pavement attributes of either rigid or flexible pavement;
W = {W_q}, qεQ: weights to be assigned to pavement attribute Q;
d_{kp} = distance of pavement section k from ideal point of attribute p;
q = pavement attribute of preferred section j;
d_{jq} = distance of pavement section j from ideal point of attribute q;
$A_p = \sum_{k \varepsilon S} d_{kp}$; and
$A_q = \sum_{j \varepsilon S} d_{jq}$.

A goal programming model was developed to estimate the weights of multiple attributes in a global criterion measure. The inputs to this model consist of (a) a set of pavement sections, with each section defined by its pavement attribute values; and (b) a set of paired preference judgments that were made on the pavement sections by highway engineers in terms of the global criterion (Gestalt).

A survey was conducted using 27 highway engineers who were participating in the Pavement Management Training Program in Austin. A set of choices between two pavement sections in different types and conditions was obtained from highway engineers. A typical pairwise comparison set is shown in Figure 3 with four selected attributes for each pavement type. Eight pavement attributes were described briefly in the survey form. A total of 31 pairwise comparison sets were presented individually on a projection screen to prevent highway engineers from relating a current selection to the previous selections.

Flexible Pavement

Attribute Section	Section 1
Patching	0 %
Rutting (inches)	1.0 in
Alligator Cracking	20 %
Serviceability Index	2.5

Rigid Pavement

Attribute Section	Section 2
Patches (#/mile)	10
Spalled Cracks (#/mile)	5
Punchouts (#/mile)	0
Serviceability Index	2.0

FIGURE 3 Typical pairwise comparison set of flexible and rigid pavements.

The objective of this research is to estimate the average response of the group. A separate analysis of each highway engineer's judgments was also performed to ascertain whether his set of estimated weights differed significantly from others. An equation representing the group opinion of highway engineers has been developed by using a linear programming computer package as follows:

$$\text{Common Index} = 3.8 \cdot RD + 0.08\, AL + 2.86\,(5.0 - SI) + 0.38 \cdot PU \qquad (5)$$

where

RD = average rut depth (in.),
AL = alligator cracking (%), and
PU = number of punchouts.

Patches in either flexible or rigid pavements and spalled cracks did not affect the group's decision-making process significantly. They were dropped out of the equation because too much inconsistency existed with these four attributes in the decision-making process. Weights can be compared between attributes considering their different measurement units. For example, three punchouts will have the same effect on pavement performance as approximately 15 percent alligator cracking, according to Equation 5. The higher number in the common index means a higher priority for rehabilitation. Perfect pavement should have an index value of zero.

A second survey was conducted to verify the equation derived by using the data from the first survey. A highway engineer may perceive pavement attributes differently in different situations. He may make pairwise comparison judgments differently with different sets of comparison pairs. He may possibly commit some error because of fatigue, boredom, or other reasons. The main objective of the second survey was to find whether these errors significantly affect his decision-making process.

The same group of highway engineers was asked to evaluate another 31 comparison pairs under conditions different from those during the first survey. Another equation was derived in the same way as was the first equation, but by using data from the second survey, as follows:

$$\begin{aligned}\text{Common Index} = {} & 0.03\ PA + 3.54\ RD + 0.06\ AL \\ & + 2.71\ (5.0 - SI_F) + 0.24\ PU \\ & + 3.43\ (5.0 - SI_R) \qquad (6)\end{aligned}$$

where

PA = percentage patching in flexible pavement,
RD = rut depth (in.),
SI_F = SI of flexible pavements, and
SI_R = SI of rigid pavements.

Patches or spalled cracks in rigid pavement still did not affect the group's decision-making process significantly in the second survey. The second equation is similar to Equation 5 except that patching was included in flexible pavements, and the weight for the SI of rigid pavement went up whereas the weight of punchouts went down. Equation 5 is proved to be stable over random errors discussed previously by Equation 6. Equation 5 will be further verified by Equation 6, using a Spearman rank correlation measure with a sample application of the model in the next section.

APPLICATION OF GOAL PROGRAMMING MODEL

In this section, an application of the goal programming model is briefly presented. To demonstrate how Equation 5 is used in establishing priorities for rehabilitation work, a set of hypothetical pavement sections was set up, as presented in Table 3. By using Equation 5, the common index was calculated for each of the sections listed in Table 3. The rankings based on this common index are included in Table 3. The results indicate how the procedure produces a common index using multiple pavement attributes. The ranking numbers appear to be realistic and applicable in practice.

VERIFYING CONSISTENCY OF GOAL PROGRAMMING MODEL

An application of the goal programming model was made by using the set of hypothetical pavement sections in Table 3. However, Equation 5 was developed by using only a subset of the entire highway network. Therefore, the consistency of Equation 5 needs to be verified with random errors associated with other pavement sections in different conditions. To do this, another equation, Equation 6, was developed with the results of the second survey, which was conducted by using another set of pavement sections under different conditions. Even though there is no direct statistical test of the hypothesis that the two equations are identical, correlation analysis can be applied if the equations are expressed as ranked data.

The rankings of 20 hypothetical pavement sections based on Equation 5 are given in Table 3. Another ranking of the same pavement sections, using Equation 6, is given in Table 4, together with the rankings obtained by using Equation 5. The consistency of the two rankings is of interest.

The measure of the degree of association between the two rankings can be obtained with a nonparametric method called rank correlation. A widely used measure of the correlation between ranked series is a coef-

TABLE 3 Hypothetical Pavement Sections Ranked According to Common Index by Using Condition Survey Data

Section No.	Pavement Type	Patching (Percent)	Rut Depth (Inches)	Alligator Crack (Percent)	Punchout (Percent)	SI	Common Index	Ranking for Rehabilitation
1	Flexible	0	0	25	---	4.0	4.86	19
2	Rigid	---	---	--	0	4.0	2.86	20
3	Flexible	25	0	25	---	3.5	6.29	16
4	Rigid	---	---	--	5	3.5	6.19	17
5	Flexible	0	0	50	---	3.0	9.72	13
6	Rigid	---	---	--	0	3.0	5.72	18
7	Flexible	0	1.0	25	---	3.0	11.52	9
8	Rigid	---	---	--	10	3.0	9.52	14
9	Flexible	25	0	50	---	2.5	11.15	10
10	Rigid	---	---	--	0	2.5	7.15	15
11	Flexible	25	1.0	25	---	2.5	12.95	7
12	Rigid	---	---	--	10	2.5	10.95	11
13	Flexible	0	0	75	---	2.0	14.58	3
14	Rigid	---	---	--	5	2.0	10.48	12
15	Flexible	50	0.5	25	---	2.0	14.48	4
16	Rigid	---	---	--	10	2.0	12.38	8
17	Flexible	0	1.0	50	---	2.0	16.38	1
18	Rigid	---	---	--	15	2.0	14.28	5
19	Flexible	25	1.0	0	---	1.5	13.81	6
20	Rigid	---	---	--	15	1.5	15.71	2

TABLE 4 Hypothetical Pavement Sections Ranked According to Equations Developed by Using First and Second Surveys and the Difference in Their Rankings

	First Survey		Second Survey		Difference in Ranking	
Section No.	Common Index	Ranking	Common Index	Ranking	d	d^2
1	4.86	19	4.21	19	0	0
2	2.86	20	3.43	20	0	0
3	6.29	16	6.32	18	-2	4
4	6.19	17	6.35	17	0	0
5	9.72	13	8.42	15	-2	4
6	5.72	18	6.86	16	2	4
7	11.52	9	10.46	12	-3	9
8	9.52	14	9.26	13	1	1
9	11.15	10	10.53	11	-1	1
10	7.15	15	8.58	14	1	1
11	12.95	7	12.57	8	-1	1
12	10.95	11	10.98	10	1	1
13	14.58	3	12.63	7	-4	16
14	10.48	12	11.49	9	3	9
15	14.48	4	12.90	5	-1	1
16	12.38	8	12.69	6	2	4
17	16.38	1	14.67	2	-1	1
18	14.28	5	13.89	3	2	4
19	13.81	6	13.78	4	2	4
20	15.71	2	15.61	1	-1	1
					$\Sigma d = 0$	$\Sigma d^2 = 66$

ficient of rank correlation developed by Spearman in 1984 (8). This measure is expressed by

$$r_s = 1 - \{(6 \Sigma d^2)/[n(n^2 = 1)]\} \quad (7)$$

where d is the difference in rank between paired items in a series and n is the number of pairs of ranked items in a series.

Using the value of d in Table 4,

$$r_s = 1 - \{(6 \times 66)/[20(400 - 1)]\} = 0.95 \quad (8)$$

Coefficient r_s computed from sample data should be tested for significance because it is subject to a sampling error. The value of $r_s = 0.95$ obtained from a sample of 20 paired pavement section rankings is significant at the 0.01 level of significance. This result confirms that the rankings obtained by using Equation 5 are highly correlated and, therefore, consistent with the rankings obtained by using Equation 6.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Two methodologies are presented for the selection of pavement sections for rehabilitation. An application of the univariate time series of SI method is shown to be useful in establishing an objective way to assign priorities by taking the past history of the pavement into consideration. As expected, the deterioration rate is shown to be a significant factor in the model. However, this empirical result is by no means definitive. The equation was generated by using a rather small sample of data collected from flexible pavements in Austin, Texas. The model should be tested with a broad range of data in different situations, such as cold weather for rigid pavement.

The goal programming model using pairwise comparison data appears to be useful in explaining the process of how decisions are made. This method does not place significant judgmental demand on the decision maker as do other methods, such as utility function. The procedure is generalized so that a common set of weights can be estimated using the paired comparison judgments of a group of highway engineers, who use two different types of pavements with different pavement attributes. Only five of eight pavement attributes were found to be used by the raters for comparing rigid pavements with flexible pavements.

The goal programming formulation is extremely flexible; thus, many additional features can be built into the basic model, such as the following:

1. Additional constraints on weights can be readily imposed. For example, if it is known from a previous analysis that SI is more important than the number of spalled cracks, such a constraint can be added.
2. The quadratic utility concept can be used instead of the linear utility function used in the model procedure developed.
3. An individual highway engineer may state his confidence in comparing a pair of pavement sections.

The application of this method to developing a common index will be helpful in understanding the behavior of decision makers in aggregating information across the attributes, and improving the quality of their decision making.

In general, the analysis of setting priorities demonstrates the equivocal nature of the phenomenon. The different rankings resulting from different analyses of setting priorities could be considered as a strength rather than a weakness because (a) each procedure for setting priorities is based on some rational strategy and (b) each different strategic approach affords a different view of the phenomenon.

The time-series model can be considered a quick-and-simple solution to comparing rigid and flexible pavements, but the model is a good start toward the development of a unified ranking system. The model produces a reasonable answer and it can be easily applied in practice.

Highway engineers can provide information with more confidence through the pairwise comparison approach that through other approaches, such as the utility theory and the scaled rating method. Therefore, the pairwise comparison approach is recommended for collecting subjective opinions about two different types of pavements with different pavement attributes. Moreover, pairwise comparison is simpler and easier than probabilistic assessment of values for utility function development or direct rankings of pavements in different types and conditions.

One major limitation of the method is that it is not guaranteed with only paired preference data that an internally scaled multiattribute function exists. Even if such a function exists, the actual decision-making process of highway engineers may not be a simple additive function, which was assumed in the model. Another limitation of this procedure is that appropriate statistical tests of significance for the parameter estimates are lacking.

Consequently, it is recommended that future research effort be directed towards verifying the models developed with different sets of SI data and other groups of highway engineers. The model should be tested with more data obtained under different conditions in terms of traffic volume, pavement type and structure, environment, and so forth. It is also recommended that historical serviceability data should be collected for a longer time period, which will allow testing of the model at different points in time.

It is recommended that the goal programming model that uses pairwise comparison data be tested and implemented by using a group of engineers from the state highway agency. The group of raters should include one engineer from each highway district or region. The equation developed could be considered a consensus of different engineers' views about pavement rehabilitation programming, which would also allow testing of the model with different groups of people. The involvement of users such as district engineers in the modeling process would facilitate implementation of the goal programming model.

Finally, it is recommended that these two methods for developing a unified ranking system be implemented by state highway agencies at an early date.

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