Condition-Based Treatment Recommendation for Project-Level Pavement Management

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A methodology is presented for developing preliminary treatment recommendations for candidate pavement projects. Emphasis is placed on the efficient use of available pavement management data. The condition-based evaluation procedure is structured into two subproblems, depending on the complexity of pavement condition. Projects exhibiting simple surface distress undergo only initial screening. Projects with complex condition are identified by the initial screening process and then further evaluated in a detailed analysis. The initial screening uses a matching between distresses, treatments, and treatment classes to analyze projects. The detailed analysis explores both surface distress and nondistress characteristics such as traffic loadings and deterioration rate to generate recommendations about a scope of work. The methodology has been implemented on the New York State Thruway pavement system. The generated results and their validation are presented and discussed. It is concluded that the treatment recommendation methodology is a viable technique that will be further developed for use in project-level pavement management. Results of the analysis support future work in the areas of life-cycle cost analysis, multiyear planning, and program optimization.

One of the primary objectives of project-level pavement management is to generate a prioritized annual needs list. Such condition-based needs assessment facilitates consistent planning, programming, and resource allocation. A state-of-the-art pavement management system (PMS) uses five methodologies to achieve this goal: (a) condition assessment, (b) project determination, (c) treatment recommendation, (d) cost estimation, and (e) project priority ranking.

This paper describes a treatment recommendation methodology that is applied at a level of detail appropriate for pavement management. It is part of the PMS of the New York State Thruway Authority (NYSTA). The methodology combines matrix and decision-tree methods in a staged approach that increases analysis complexity for projects with more complicated conditions. For each project, the objectives are to (a) identify specific treatments required, (b) suggest the scope of work for implementing treatments, and (c) generate feasible alternatives for use in network-level analysis. For all projects, treatments appropriate to pavement condition are determined on the basis of previous maintenance and rehabilitation experience.

The sequence of major tasks in the treatment recommendation methodology is shown in Figure 1. The initial input for each project consists of pavement condition expressed in terms of distress ratings. Surface distress is assessed in terms of type, severity, and extent, as documented by Grivas et al. (*1*). All projects are subject to an initial screening, which matches pavement condition to appropriate treatments, treatment classes, and triggers, and generates an itemized list of treatments to address the existing distresses. A preliminary classification based on these results identifies each project in terms of its scope of work, namely, do nothing, preventive, corrective, or rehabilitation. Pavement projects with relatively simple needs are recommended for either a do-nothing or preventive scope of work. As shown in Figure 2, the initial screening process completes the analysis of scope of work for these projects.

The detailed analysis uses additional data (such as accident rates, deterioration rates, traffic characteristics, pavement age, etc.) and an enhanced decision-making process to further refine the scope of work for projects with complex condition. Corrective candidates undergo resurfacing evaluation to establish whether resurfacing should be performed in addition to the suggested corrective treatments. Rehabilitation candidates undergo rehabilitation evaluation to examine whether resurfacing, rehabilitation, or reconstruction is the appropriate scope of work.

Once the recommended scope of work is identified, alternatives can be generated. An alternative consists of itemized treatments and a scope of work. The recommended scope of work and the itemized standard treatments are designated as the preferred alternative for the unconstrained problem. A project treatment recommendation consists of all feasible alternatives and their associated cost estimates; the preferred alternative is noted for consideration by network-level analysis.

INITIAL SCREENING

The initial screening process generates a preliminary scope of work based on a tally of properties associated with the distress states (distress type–severity–extent combinations) present on a project. Each distress state is associated with its properties through rules generated with the aid of maintenance personnel, on the basis of their experience with local conditions, past maintenance practices, and treatment performance. Five properties were derived for each distress state: (a) treatment class, (b) standard treatment, (c) quick-fix treatment, (d) resurfacing trigger, and (e) drainage trigger. Figure

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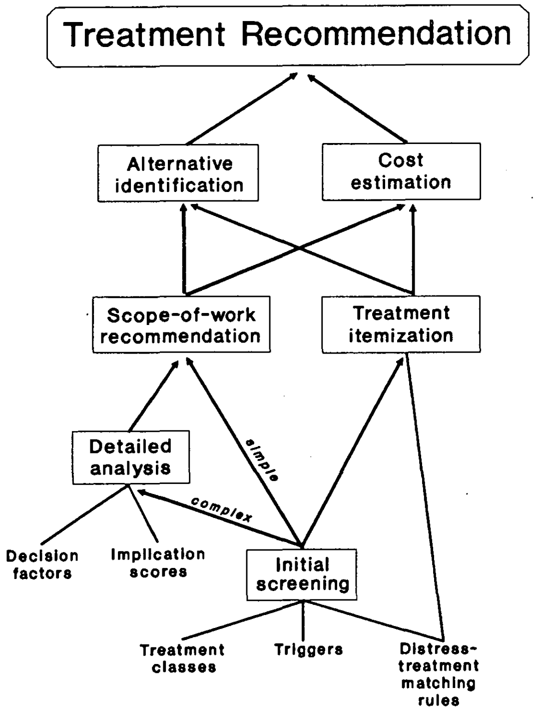

FIGURE 1 **Sequence of major tasks in treatment recommendation.**

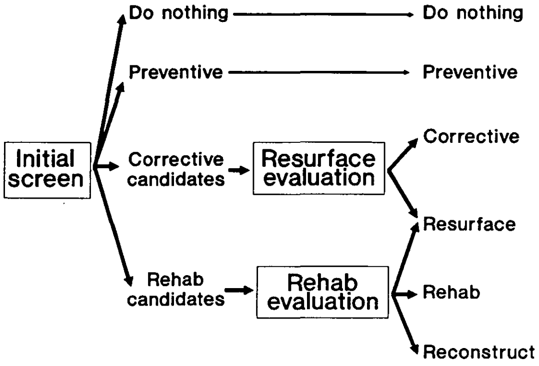

FIGURE 2 **Determining recommended scope of work.**

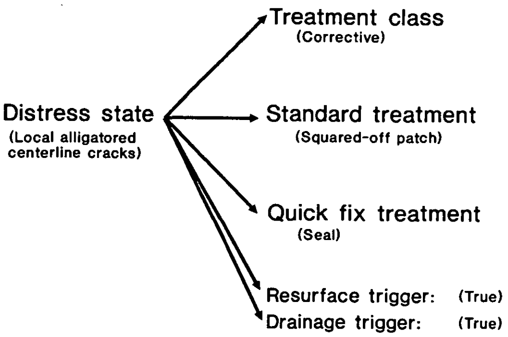

FIGURE 3 **Distress-treatment matching example.**

3 illustrates an example of the manner in which each distress state is associated with its properties.

Treatment classes were derived to indicate the degree of action required to address the condition associated with each distress state (the classes are do nothing, preventive, corrective, and rehabilitation evaluation). Standard treatments are those that maintenance personnel find to be most effective at mitigating further deterioration of the pavement structure. Quick-fix treatments are the recognized deferral action when the standard treatments cannot be implemented.

Triggers were developed when participants observed that certain distress states are indicative of drainage problems. Because the need for drainage work cannot be easily determined through distress-treatment matching, the drainage trigger concept was introduced to flag projects for further investigation on the need for drainage work. The resurfacing trigger was incorporated to facilitate evaluation of distress combinations that require an overlay, even when no single distress requires that treatment. Thus, each distress state is associated with two triggers: one that indicates that there may be a drainage problem, and one that indicates that the project may need to be overlaid. The triggers are Boolean in that they take only the values true and false. The value for each type of trigger for each distress state is defined by a rule generated with the aid of maintenance experts.

The matrix of all distress states and their associated properties is the basis of the initial screening process. The properties of a project are determined by first matching each distress state on a given project to its corresponding properties and then tallying the properties of all distress states at all locations on the project. The preliminary classification of scope of work is based on the percentages of all distress states in the project that require various classes of treatments and that have true resurfacing triggers. The process followed in preliminary classification was initially defined on the basis of natural breaks in the distribution of this data for 1989 projects. These decision points will be reviewed as implementation continues.

For projects with relatively simple needs, the preliminary classification completes the project scope recommendation process. The suggested scope of work is either do nothing or preventive, depending on the distribution of treatment classes determined from distress ratings. Projects with more complex conditions are classified as either corrective candidates or rehabilitation candidates and advanced to a detailed analysis.

DETAILED ANALYSIS

The resurfacing and rehabilitation evaluation procedures, which compose the detailed analysis, are similar in concept. They suggest an appropriate scope of work in a timely manner, without the requirements of lengthy analysis. Both use implication scores to refine the preliminary classification of scope of work. The scoring process aims to model the interaction between factors that affect decision making. Those projects eventually identified as rehabilitation or reconstruction become candidates for more in-depth analysis that is outside the scope of the current study (e.g., life-cycle cost analysis, pavement design characteristics).

Data Requirement

Factors such as climate, pavement design, deterioration rate, drainage, lane condition, safety, shoulder condition, and traffic may contribute to decisions for resurfacing or rehabilitation. However, only those factors that can be measured or estimated reliably should be incorporated in project-level analysis. The underlying requirements are that the decision process should be tailored to the information available and that data satisfy standards of objectivity and integrity. The primary requisites for an initial implementation are that data be available, accessible, and appropriate.

Available data may be of varying integrity depending on the information source. Project-level analysis and other pavement management activities can be effective only when the information that supports decision making is accessible in a timely manner for all projects under evaluation. This is the primary motivation for the requirement of a data base in a pavement management system. Once the requirements of availability and accessibility have been met, it is judicious to subject the remaining data sources to a review of their appropriateness for measuring the desired factor.

Factor Assessment

Table 1 summarizes decision factors that can be measured for use in the current study and indicates how data are obtained. Data are available in a variety of forms, such as alphanumeric, numeric, and Boolean. In some cases, several data items are combined into a single index.

Functional Adequacy

Functional adequacy represents the quality of the pavement surface in terms of its ability to provide a comfortable (smooth) ride to the user. For the preliminary implementation, it is derived as a function of three quantities: a subjective ride quality assessment, a ride index derived from distress ratings, and patching (expressed in terms of severity and extent). Ride quality and patching assessments are collected through questionnaires to local field personnel, who provide evaluations based on their daily experience with the candidate projects. The ride index is calculated on a scale of 0 to 100, with 100 representing the least ride disruption. The index is determined like a composite distress index, but with weighting factors adjusted to reflect ride disruption.

Because no available measure is known to be a complete and unbiased descriptor of functional adequacy, ride quality, patching, and the ride index were combined into a functional adequacy index. Each of the measures was converted to a similar scale (three point, increasing severity), and weighted averages of the scaled measures were taken.

The values of functional adequacy index range from 0.0 to 3.0. Values greater than 1.75 are defined as indicative of functional inadequacy, for the purposes of the current study. In the future, functional adequacy may be derived from direct, objective roughness measures, such as the international roughness index (*2*).

Structural Adequacy

Structural adequacy is indicated by the degree of load-related distresses that are present throughout the project. A structural

TABLE 1 Decision Factors for Rehabilitation Evaluation

Factor	Measure	Data Source	Type of Measurement
Functional adequacy	ride quality patching severity/extent ride-affecting distress	questionnaire questionnaire distress survey	alphanumeric alphanumeric numeric
Structural adequacy	load-related distress	distress survey	numeric
Deterioration rate	maintenance effort	questionnaire	alphanumeric
Traffic loads	AADT for truck classes	traffic data	numeric
Pavement safety	accident rate rutting	police rpts, traffic data distress survey	numeric numeric
Shoulder condition	shoulder distress	distress survey	numeric
Drainage problems	problem locations	questionnaire	numeric
Pavement history	surface age	questionnaire	numeric
Appurtenance safety	deficient guiderail	guiderail survey	numeric
Traffic control	restricted work hours	agency policy	boolean

adequacy index is calculated similarly to the ride disruption index but with weighting factors adjusted to reflect structural damage. For the purposes of the current study, structural adequacy index values greater than 50.0 are interpreted as structural inadequacy.

Deterioration Rate

In the initial implementation, deterioration rate is inferred directly from field personnel reports of the relative amount of maintenance effort spent on each project. A low rate is assumed if the project requires only scheduled preventive maintenance. A normal rate is assumed if the project requires occasional work in addition to scheduled preventive maintenance. A high rate is assumed if the project requires considerable maintenance work. In the future, deterioration rates may be determined from historical progressions of distress data.

Traffic Loads

Traffic load assessments are based on the average number of trucks that traverse a candidate project each day. In the current study, trucks are defined as all vehicles receiving toll tickets of a certain class; actual vehicle weights are unknown. More than 2,500 trucks a day is considered a high traffic load. At those locations where counts are not available, local personnel estimate whether truck traffic is high.

Pavement Safety

Safety is divided into two components: pavement and appurtenance. Pavement safety represents the degree of hazard due to pavement surface deficiencies. On overlaid pavements, pavement safety is determined as a function of the accident rate and average rut distress rating. Rutting is a potential hazard due to the likelihood for hydroplaning caused by water pooled in wheel track depressions. Pavement-related accident rates are considered a good indication of pavement safety deficiencies. However, they do not generally correspond to rutting as recorded by the distress survey. Several formulations were investigated to combine accident rates and rutting into a pavement safety index, which is used in rehabilitation evaluation.

Accident rates are reported as the number of accidents not related to alcohol, drugs, or animal per 100,000 vehicle-mi traveled on the project. The average rut distress rating is taken as the arithmetic mean of integer-mapped rut ratings determined by the distress survey. Each of these measures was converted to a similar scale (three point, increasing severity), and weighted averages of the scaled measures were taken.

The values of pavement safety index determined by this method range between 0.0 and 3.0. Values greater than 0.85 were defined as indicative of a high pavement safety deficit. This value corresponds approximately to an accident rate of 25 per 100,000 vehicle-mi traveled.

Shoulder Condition

Shoulder condition was assessed using a composite shoulder distress index, obtained by a weighted combination of shoulder distress ratings. Values less than or equal to 50.0 (on a scale of 100.0) were defined as indicative of inadequate shoulder condition.

Drainage Problems

Drainage problems are assessed through field personnel reports of locations with drainage problems. Drainage deficiencies are measured as percentage of 0.1-mi segments in projects with reported drainage problems. Thus, the deficiency measure considers only the extent of drainage problems. When more than 40 percent of the length of a project has reported problems, drainage deficiencies are defined high.

Pavement History

Pavement history is incorporated by considering the age of the surface layer. This is currently the only historical maintenance data that are reliably available for most projects. The information on surface age was initially collected through questionnaires to field personnel; it will eventually be available from the pavement data base. The definition of old pavement depends on the pavement type. Concrete pavements more than 15 years old and overlaid pavements more than 7 years old are considered to be old. Resurfacing evaluation also uses pavement type as a decision factor.

Appurtenance Safety

Appurtenance safety refers to items such as lighting, traffic barriers, and guiderails. The results of a guiderail condition survey have been adapted to provide an indication of appurtenance safety. Projects for which 40 percent or more of the existing guiderail is clearly substandard are defined as having high appurtenance safety deficits.

Traffic Control

Agency policy has defined locations at which work hours are restricted because of problems with traffic control and congestion. Locations at which there are year-round limitations on the roadway occupancy of maintenance crews were considered high urban with respect to traffic control.

Implication Scoring

Condition-implication (C-I) tables are used to score the appropriateness of the various scopes work evaluated for each project undergoing detailed analysis. The C-I tables for rehabilitation evaluation are given in Table 2.

TABLE 2 C-I Table for Rehabilitation Evaluation

CONDITION		IMPLICATION								
		Resurfacing			Rehabilitation with overlay			Reconstruction		
Factor	Level	Support	Ambiv.	Negate	Support	Ambiv.	Negate	Support	Ambiv.	Negate
Function	Adequate	13.1	13.1	–50.2	–6.6	29.4	–50.2	–50.2	29.4	–6.6
	Inadequate	–50.2	–6.6	29.4	24.0	7.6	–61.0	51.2	–39.3	–61.0
Structure	Adequate	30.6	–29.4	–29.4	–29.4	30.6	–29.4	–70.2	–70.2	–71.2
	Inadequate	–63.3	–63.3	64.5	13.6	19.3	–63.3	13.6	19.3	–63.3
Deterioration rate	High	–66.9	–54.0	61.5	50.7	–38.8	–60.5	61.5	–54.0	–66.9
	Medium	–28.1	7.6	7.6	50.7	–38.8	–60.5	–28.1	45.4	–60.5
	Low	50.7	–38.8	–60.5	–17.3	–17.3	18.4	–49.7	–28.1	40.0
Traffic loads	High	–51.8	–33.3	43.4	–24.0	–5.5	15.7	–5.5	15.7	–24.0
	Other	–14.8	15.7	–14.8	–14.8	15.7	–14.8	–14.8	–14.8	15.7
Pavement safety deficits	High	3.1	9.4	–20.3	–4.6	5.5	–4.6	0.0	0.0	0.0
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Shoulder condition	Adequate	21.6	–20.9	–20.9	13.6	–4.8	–20.9	64.2	–4.8	–4.8
	Inadequate	–24.0	1.6	13.6	29.7	–12.8	–44.9	29.7	–12.8	–44.9
Drainage deficits	High	–19.6	20.3	–19.6	–19.6	–19.6	20.3	–19.6	–19.6	20.3
	Other	–48.1	–36.0	42.8	35.2	–27.0	–42.1	20.3	–4.5	–34.5
Surface age	Old	–16.1	2.4	6.0	6.0	2.4	–16.1	6.0	2.4	–16.1
	Other	–5.5	11.2	–16.1	–5.5	13.0	–19.6	–9.1	–5.5	7.8
Appurtenance safety deficits	High	–16.6	–9.4	13.3	13.3	–9.4	–16.6	0.0	0.0	0.0
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Traffic control	High urban	–19.1	–15.4	17.6	–1.8	8.4	–14.2	8.4	–1.8	–14.2
	Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table Organization

In the C-I tables, individual cells correspond to hypotheses that incorporate (a) a decision factor, (b) a measured level of the decision factor, (c) a scope of work, and (d) an indication of the degree of support for the hypothesis. The implication score recorded in each cell represents an engineering judgment about the truth of the corresponding hypothesis. For example, the cell in the extreme upper left-hand corner of the rehabilitation C-I table (Table 2) corresponds to the hypothesis that if the pavement function is adequate, then this is supporting evidence that resurfacing is the appropriate scope of work. The implication score associated with this hypothesis is 13.1. (Derivation of implication scores is presented in the following section.) Scores may be either positive or negative, depending on whether the hypothesis is judged to be true or false, respectively. The greater the absolute value of the score, the greater the engineer's confidence in his judgment. A score value equal to 0.0 indicates that the measured-level of the given factor provides no information about whether the proposed scope of work is appropriate or not.

Implication Score Derivation

The implication scores in Table 2 are derived on the basis of engineering judgement accumulated over years of experience with Thruway pavements. First, the decision factors for initial implementation were evaluated to provide an importance score, which represents the importance of that factor in decision making, and a measurement confidence score, which represents the confidence that the factor is well measured (Table 3). Then the hypotheses in the C-I tables were evaluated to provide subjective probabilities for each hypothesis to be true for any given project. The sum of the probabilities of the three hypotheses associated with each factor, level, and project scope combination is equal to 1.00, as the three events are mutually exclusive and exhaustive. To facilitate handling of cases where the factor-level combination does not provide any information about project scope, the subjective probability values were transformed to a scale symmetric about zero.

The transformed values associated with each factor were then multiplied by a constant (determined from the measurement confidence and importance scores) to account for the greater impact of factors with higher importance and measurement confidence. Therefore, the maximum possible score varies from factor to factor. Table 3 gives the measurement confidence scores, importance scores, and maximum implication scores for each of the factors involved in the rehabilitation and resurfacing evaluations.

Project Scope Scoring

A project scope score is determined for each scope of work considered. This is a three-step process. First, each of the

TABLE 3 Factor Importance for Detailed Analysis

Factor	Importance Score	Measurement Confidence Score	Maximum Implication Score
REHABILITATION EVALUATION			
Functional adequacy	10	6	71.9
Structural adequacy	10	10	74.6
Deterioration rate	10	5	71.2
Traffic loads	8	10	61.1
Pavement safety	7	6	51.6
Shoulder condition	7	8	52.9
Drainage problems	7	3	49.5
Pavement history	3	4	23.1
Appurtenance safety	3	5	23.7
Traffic control	2	10	20.4
RESURFACING EVALUATION			
Functional adequacy	10	5	73.9
Accident rate	9	5	66.9
Rutting	7	3	51.4
Deterioration rate	5	4	38.0
Surface type	4	10	35.2
Surface age	4	9	34.5

decision factors must be evaluated for the project. Second, the arithmetic mean of the implication scores that correspond to the factor levels present is calculated for each column of the C-I table. Scores of 0.0 are omitted from the calculation, because they indicate that the corresponding factor level provides no information useful for inferring the scope of work. Third, the arithmetic means are combined into a final project scope score (PSS) by the formula

$$PSS = S^* + A + N^* \quad (1)$$

where

$$S^* = \begin{cases} 2S & \text{for } S > 0 \\ S & \text{for } S \leq 0 \end{cases}$$

S = arithmetic mean of nonzero implication scores corresponding to factor levels in supporting column;

A = arithmetic mean of nonzero implication scores corresponding to factor levels in ambivalent column;

$$N^* = \begin{cases} -2N & \text{for } N > 0 \\ N & \text{for } N \leq 0 \end{cases}$$

N = arithmetic mean of nonzero implication scores corresponding to factor levels in the negating column.

The scope of work with the maximum project scope score is recommended as the most appropriate. Several formulations for calculating the final score were investigated. Scope of work recommendations are relatively robust with respect to the formula used.

TABLE 4 Summary of Scope-of-Work Recommendations, 1989

Recommended Scope–of–work	Mean Project PDI	Number of Projects	Percent* of System
Reconstruction	29.2	13	3.9
Rehabilitation	51.9	49	18.8
Resurfacing	71.2	18	15.9
Corrective	73.8	27	13.5
Preventive	88.7	56	37.9
Do–nothing	99.4	13	7.0
(unrated)	–	8	3.0

* based on centerline miles

PROJECT ALTERNATIVES

For each project, a recommended scope of work is generated from the initial screening and detailed analysis procedures. The scope of work defines alternatives to be considered in the network-level analysis by indicating that alternatives involving a greater scope of work than the recommended one need not be analyzed. There is one preferred alternative for each project, other alternatives being deferral or holding strategies. Generally, the preferred alternative entails performing the itemized standard treatments in the context of the recommended scope of work.

The preferred alternative for corrective, preventive, and do-nothing projects is to perform the standard treatments indicated by distress-treatment matching. The only other alternative is to perform the itemized quick-fix treatments. For do-nothing and preventive projects, the quick-fix treatments are often to do no work.

Resurfacing projects have four alternatives. The preferred alternative is to do the standard treatments followed by resurfacing. Different methods of resurfacing may be applicable, depending on project characteristics. Deferral alternatives are to perform standard treatments only, or quick-fix treatments only, or a disposable overlay. Choice of a deferral treatment will be made by network-level analysis based on considerations of cost, condition, and time.

Identification of alternatives for rehabilitation and reconstruction projects is a more complex procedure. In this case, the scope of work recommended by detailed analysis is only a preliminary suggestion. Alternatives for implementing rehabilitation and reconstruction projects are generated by considering methods of both rehabilitation and reconstruction and the alternatives associated with corrective and resurfacing scopes of work. Although all such projects will initially have the same alternatives, the characteristics of alternatives (cost, service life, etc.) generally vary between projects, due to local variations in performance characteristics. Evaluation of the long-term costs of each alternative will provide an indication of the preferred alternative and feasible deferral alternatives for each project. Such a life-cycle cost analysis is critical to identify the alternatives that could be most cost-effective over time. The implications of the large budgetary outlays associated with these types of projects warrant a detailed financial analysis that is beyond the scope of the current study.

COST ESTIMATION

The procedure for estimating the cost of an alternative varies depending on the scope of work. The cost of alternatives with corrective, preventive, or do-nothing scope of work is estimated from the unit costs of performing the indicated individual treatments. Alternatives with a resurfacing scope of work are cost-estimated by adding the costs of performing individual (preparatory) treatments to the cost of resurfacing. The cost of alternatives with a rehabilitation or reconstruction scope of work is a preliminary estimate based on average costs (on a lane-mile basis) of similar projects. Refined cost estimates can be performed using the NYSTA's "engineer's estimate" system, after details of nonpavement work are determined.

Alternatives with rehabilitation or reconstruction scope of work are typically associated with significant amounts of nonpavement work (e.g., rock slope remediation, bridge work). Moreover, implementation constraints (e.g., mobilization, user delay) generally result in the combination of several adjacent projects into a single job. Thus, costs of these projects cannot be easily estimated. Currently, preliminary lump-sum cost estimates are obtained on the basis of cost per lane mile from projects of similar nature implemented in recent years. The cost of resurfacing is estimated similarly, but as mentioned, the cost of individual (preparatory) treatments is calculated separately and added to the resurfacing cost to obtain the total cost of alternatives with resurfacing scope of work.

IMPLEMENTATION

The first implementation of the described treatment recommendation methodology performed in 1990, based on pavement condition in 1989. The initial screening and detailed analysis were developed using a series of spreadsheet macros. Implementation of cost-estimation spreadsheets is currently under way. Refinement of treatment completion rates is pending. Alternatives have not been explicitly listed, as the data required for their cost estimation are not yet available. Table 4 presents the results of the scope-of-work recommendations.

A preliminary comparison of NYSTA's current empirically derived paving program and the more systematic treatment recommendation results indicates relatively good agreement between the two. Key findings of the preliminary validation study are summarized in the following:

- The treatment recommendation methodology identified 62 candidates for rehabilitation evaluation. Of these, half were scheduled for paving in 1990 or 1991. Most of the remainder (24) have paving scheduled before 1996.
- The treatment recommendation methodology identified 45 candidates for corrective treatment. Of these, 18 were suggested for resurfacing. The paving program designated 14 of the 45 corrective candidates for paving 1990 or 1991; 8 of the 14 were those suggested for resurfacing by the treatment recommendation methodology. Eight other corrective candidates are scheduled for paving before 1995.
- Only 35.4 mi of pavement identified by treatment recommendation as having the scopes of work do nothing or preventive are scheduled for paving before 1993.

The treatment recommendation methodology was implemented for 1989 projects in early 1991. This time lag between distress assessment and treatment recommendation is an artifact of the research and development process. It is not expected to persist after the system becomes operational. When developing sequential methodologies, outputs of prior procedures must be obtained before development of subsequent procedures can be initiated.

DISCUSSION OF RESULTS

The goal of project-level analysis is to recommend and rank procedures for the remediation of each pavement segment. While organizing tasks needed to achieve this goal, it became apparent that it is efficient to structure the problem into two subproblems based on the complexity of project condition. Such a formulation facilitates the efficient use of resources for data collection and analysis. Because it is expensive to collect, store, and analyze data, it is judicious to tailor data requirements and analysis complexity to the needs of the decision process. Just as superfluous data need not be considered, those that contribute to decision making must not be excluded. Available resources are used most effectively by increasing data requirements and analysis complexity only for those projects with relatively complicated conditions. This concept is the basis of the staged problem-solving formulation.

The applied structure of the problem of project-level analysis leads to a cost-effective strategy for pavement management in which focus is placed on complex projects, with due consideration for preventive maintenance. It takes advantage of the fact that conditions requiring preventive maintenance are quickly and easily identified. An important finding of this study is that more than 40 percent of Thruway pavements currently exhibit simple condition. Early identification and rapid evaluation of these simple projects allows resources and effort to focus on those with complex condition. Complex projects account for the majority of annual funding requirements.

Analysis of complex projects incorporates a series of increasingly refined classifications. For example, a project may be initially characterized as complex, then as a rehabilitation candidate, and finally recommended for reconstruction. This classification accommodates the customization of analytical procedures for achieving specific tasks. As an illustration, rehabilitation and resurfacing evaluation routines incorporate only the decision factors relevant to the types of projects being analyzed. By customizing the analyses, more specific recommendations can be made. Note however, that specificity is only possible when the detailed data necessary to support it are available. The types and amount of data required for pavement management decision making are a function of system size and analysis detail.

The use of data at any level of decision making is constrained by its availability, accessibility, and appropriateness for measuring a given characteristic. These practical limitations can significantly affect the validity of an analysis. In the NYSTA detailed analysis procedure, the problems associated with factor measurement are mitigated by the assessment of factor levels. Factors are appraised in binary or tertiary levels such as adequate versus inadequate or high versus normal versus low. This facilitates use of data of varied types and degrees of accuracy. Each factor can be evaluated at the highest possible level of accuracy, whether it is subjective or objective, discrete or continuous. For the initial implementation, boundary values for defining factor levels were defined at natural breaks in the distribution of values for 1989 projects. Recall that the implication scores incorporate an adjustment that reduces the impact of those decision factors that are not well measured. The equations used to characterize factor levels were derived from the data available during the 1989 implementation. The validity of these equations cannot be proved at the current stage of development.

The implication scoring technique evolved as an alternative to using decision trees for rehabilitation decision making. Initial knowledge acquisition activities identified conditions that affect decision making but generally could not detail the impact of a given factor. The decision trees derived from these results were unsatisfactory. The large number of possible combinations of decision factor levels precluded an investigation of each such scenario.

SUMMARY AND CONCLUSIONS

Methodologies for distress assessment, project characterization, treatment recommendation, and project ranking have been developed and implemented as part of the NYSTA's pavement management system. The goal of the present study was to develop a methodology to generate condition-based project treatment recommendations for a single year. The analysis was structured into two subproblems, depending on the complexity of pavement condition. The results of the analysis support future work in the areas of life-cycle cost analysis, multiyear planning, and program optimization.

The described formulation aimed to determine systematically project requirements in a manner consistent with the authority's current practices and experience. Field personnel and management have participated extensively in system development and implementation. The treatment recommendation methodology combined matrix and decision tree methods to identify specific treatment requirements, suggest the scope of work for implementing treatments, and generate feasible alternatives for use in network-level analysis. The procedure for suggesting a scope of work followed a staged approach that increases analysis complexity as the pavement exhibits more complicated conditions. Treatment recommendation has been implemented for the 1989 projects.

The treatment recommendation methodology is currently undergoing review and adjustment and is expected to continue evolving after it becomes operational. Because of the sequential nature of the development process, some modules are currently more mature than others.

On the basis of the development and preliminary implementation presented in this study, the following conclusions were drawn:

- Decomposition based on the complexity of pavement condition enables clear communication with a wide range of experts and efficient development of decision methodologies.
- A decision process that generates treatment recommendations through a process of increasingly refined classifications of the scope of work fosters efficient use of resources for data collection and analysis.
- Acquisition and use of experience is a critical part of the development activity. Good communication between experts and developers is a fundamental requirement for creating a system compatible with agency operations.

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