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The contents of this paper reflect the view of the authors who are responsible for the facts and the accuracy of the data presented herein.

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Development of Mathematical Models to Assess Highway Maintenance Needs and Establish Rehabilitation Threshold Levels

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Recent developments in methods of managing pavement investments have emphasized the importance of communication between the various subsystem components of a pavement management system. Historically, the maintenance element has been difficult to integrate. A systematic and objective means of assessing maintenance needs would improve the likelihood that funds would be optimally expended. This study was undertaken to examine the mathematical relationship between a variety of pavement attributes, and other quantifiable variables, on the one hand, and maintenance needs and priority evaluations made by district area supervisors on the other. A secondary objective was to establish threshold levels for preventive maintenance, capital maintenance, and rehabilitation. Descriptions, which conform to the Maine Department of Transportation's operations, were included in order to categorize various rehabilitation and maintenance strategies as well as to define various types of maintenance. A simple questionnaire was employed to obtain the required subjective input from maintenance staff. Measures of pavement distress routinely collected by trained observers and appropriately weighted, using a Delphi technique, proved to correlate the best. Roughness measured by a response-type road measurement device and correlated with the Quarter Car Index also proved significant, but to a lesser degree. A series of other variables made only nominal improvements in the models. A model to predict repair categories from similar data was also developed. Recommendations are offered for providing tabulated information to maintenance personnel to use as a "tool" in establishing priorities.

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During the past two decades a vast amount of research has been conducted on methodologies for improving the ability to manage pavement investments. The concept of a pavement management system (PMS) originated from this research.

Pavement management emphasizes the importance of the integration of planning, design, construction, maintenance, and evaluation of and research on pavements.

In 1981 the Maine Department of Transportation (MeDOT) initiated an in-house study to evaluate its pavement management process and developed short- and long-range plans for pavement management improvements. In 1982 the department released a report *(1)* that summarized the task force efforts. In 1983 an independent study *(2)* was conducted of pavement management practices in the department. A subsequent review by the department of the findings of that study indicated that from 1981 to 1984 the PMS process had progressed satisfactorily. However, several areas in which improvements could be made were identified. One weakness identified was the difficulty of integrating maintenance functions into the pavement management process. This research was undertaken to address that problem.

OVERVIEW

There is a variety of maintenance and rehabilitation strategies that a highway agency can adopt; each strategy provides a measurable benefit to the system. However, there are a large number of candidates competing for the limited available budget. Consequently, to optimize its available funding, an agency must determine the proper time and location for carrying out the appropriate strategies. To accomplish this, a methodology for identifying and establishing proper maintenance actions, in conjunction with other rehabilitation options, must be developed.

The state of Maine systematically measures and evaluates the condition of all 8,700 centerline miles of highway within its jurisdiction. This information, in the form of pavement condition ratings and serviceability indices, is routinely used to develop rehabilitation and other capital improvement programs. Maintenance actions are normally initiated by maintenance engineers on the basis of their best judgment and knowledge of budgeted monies. This effort is intended to develop a methodology, which incorporates the same kinds of data used to establish other programs, to objectively assess maintenance needs and priorities.

OBJECTIVES

The main goal of this research was to identify one or more objective measures that could be used to reliably predict the level of maintenance required on a highway section. There were six specific objectives:

1. Devise a rating scale to convert subjective ratings of maintenance needs (by operating personnel) to a numerical scale;
2. Conduct subjective evaluations of a sample of existing pavements by having a number of maintenance personnel rate the selected sites using the previously mentioned scale;
3. Obtain from department records all pertinent data on each of the selected sites;
4. Perform a multiple regression analysis to relate the subjective ratings to the available section data;
5. Develop a simple equation to provide a mechanism for identifying maintenance needs and priorities; and
6. Identify the appropriate priority levels or develop a unique index to establish the appropriate ranges of ratings that indicate the need for preventive maintenance, capital maintenance, and rehabilitation.

INITIATING RESEARCH

Before this study was undertaken, a series of informal discussions with several Bureau of Maintenance personnel was held. Personnel interviewed included a Division (District) Engineer, a Division (District) Superintendent, and Area Maintenance Supervisors. (The MeDOT is one of a few states that still call their geographic field units divisions.) The intent of those discussions was to explain the overall goal of the study and to see if the methods being considered would be properly interpreted by key maintenance personnel. These initial discussions confirmed some early assumptions and provided insight and guidelines on the subsequent evaluation of data.

After these early discussions a literature review was initiated. A Highway Research Information Service search on maintenance cost and needs generated 15 references that were reviewed *(3–17)*. Efforts were concentrated on methods that would accommodate existing departmental records and data.

AVAILABLE DATA

To meet the needs of its network pavement management process, the department periodically collects a variety of data. The three major types of data are

1. Pavement condition,
2. Ride quality (roughness), and
3. Structural adequacy.

These were considered the prime factors on which this study should be focused. A brief description of each is provided next.

Pavement Condition

The department performs a detailed survey of its entire highway network every 2 years. The survey is performed by a trained two-person team in each division. The 1,200± mi per division require approximately 1 month to complete. Depending on the uniformity of conditions, a minimum of one site per mile is evaluated. The survey team observes or measures, or both, the severity and extent of seven types of distress: longitudinal cracking, transverse cracking, load-associated cracking, edge cracking, distortion (rutting and crown), patching, and shoulder condition.

Ride Quality

The department performs an annual ride quality survey of its entire highway network. It employs a device known as a Mays ridemeter. The output is calibrated to a Quarter Car Index *(QI)* using a rod and level–generated profile. The data are further correlated with a panel-generated present serviceability index (PSI).

Structural Adequacy

In addition to the two statewide surveys, the department also performs nondestructive testing of selected pavement structures employing a Road Rater. This device measures the "deflection" of a pavement structure under a known dynamic load. This represents the capacity or strength of a pavement structure. It is primarily used to evaluate specific highway projects.

STUDY METHODS

Given the nature of the readily available data, the following methods were considered:

1. Employ the Pavement Condition Rating (PCR) developed from the department's biennial distress survey and correlate it with some measure of maintenance need;
2. Weigh the PCR to reflect maintenance;
3. Using data from the biennial pavement survey, develop an index totally independent of the PCR;
4. Use a measure of road roughness developed from Mays meter data; and
5. Use structural evaluations performed with the Road Rater.

After considerable examination, it was determined that there were no other known methods that could be adapted to the available data or to the time and resource constraints of this study. Therefore, the following conclusions were drawn:

1. Even though the first three methods would all rely on the same pavement survey data, the third method was preferred because it would introduce less error;
2. The fourth method was also considered a reasonable approach, and it could be used in parallel with pavement evaluation; and
3. The fifth method was considered impractical.

The approach selected consisted of three major tasks:

1. Identification of a method of assessing the significance of all of the factors observed or measured by the department in its biennial pavement evaluation process;
2. Development of methodology to "correlate" the sum of these distress factors with some measure of maintenance need; and
3. Examination of the relationship between the same measure of maintenance need and the *QI* obtained annually from the department's Mays meter survey.

MAINTENANCE SUBSYSTEM

To meet the objectives of assessing maintenance needs, it became imperative to define which specific activities, within the maintenance subsystem, were significant in establishing priorities. Emphasis was placed on defining the activities applicable to MeDOT policy, as well as identifying the broad categories of rehabilitation and capital maintenance.

DEFINING MAINTENANCE

The definition of maintenance varies among transportation departments. In a technical sense, maintenance includes a range of activities directed at keeping a pavement in an acceptable state. A variety of terms is used to describe the various components of maintenance. Although some maintenance activities have little or no effect on the performance of pavements, and are not considered directly in a PMS, they are of direct interest to the maintenance department in a maintenance management system (MMS).

CATEGORIZING MAINTENANCE ACTIVITIES

In general, maintenance activities in Maine can be divided into six basic categories. A few typical activities are listed for each.

1. Service maintenance, summer: mowing, litter patrol, and sweeping;
2. Service maintenance, winter: plowing, sanding, and salting;
3. Traffic maintenance: striping and sign repair or replacement;
4. Bridge maintenance: painting and deck repair;
5. Preventive maintenance: crack sealing and cleaning drainage structures; and
6. Capital maintenance: shimming ruts, base and pavement repair, shoulder repair, and filling potholes.

This study was directed to those activities listed in Categories 5 and 6.

The six categories were established to replace the term "routine maintenance," which is avoided throughout this study. One of the problems in attaining a uniform definition of maintenance originates with the use of that term. "Routine," to some agencies, covers the majority of roadway activities, many of which may be performed regardless of pavement condition. Some may, indeed, be triggered by one of several other factors such as traffic, safety, or aesthetics. In some other agencies "routine" refers to preventive or minor maintenance only. The categories established in lieu of "routine" are consistent with MeDOT operations and are more likely to be uniformly interpreted.

DEFINING REHABILITATION AND CAPITAL MAINTENANCE

One point that required clarification was that of defining rehabilitation as opposed to capital maintenance. For purposes of this study, specific definitions that conform to MeDOT's definition were established. A similar approach could be adopted by any agency. The definitions established were based on actual programs and activities undertaken and include

1. Any placement of a thin overlay, which exceeds ⅝ in. and is preprogrammed for sections of highway as part of the department's annual maintenance resurfacing program, is considered the dividing line between maintenance and rehabilitation. This activity is normally restricted to low-volume roads and always involves contract work. The activity ususally takes place on contiguous sections of highway that are longer than 1 mi.
2. Rehabilitation activities on the collector system, which are preprogrammed and involve contract work, are considered rehabilitation in present PMS strategies. These are normally at least ¼ mi in length and are usually performed on low-volume roads. They should not be confused with the contract work performed on the federal and state highway systems.
3. Paving activities involving state maintenance forces, applied to short stretches of highway of between ¼ and ½ mi as well as occasional longer stretches, are considered capital maintenance.

4. Localized rehabilitation performed by state maintenance forces on any system is considered capital maintenance. These activities are normally restricted to sections of less than ¼ mi.

STUDY LOCATION

After the objectives of the study were established a decision had to be made about the most effective way to implement the study. The first task undertaken was to establish appropriate field locations at which to perform the further investigations. Two fundamental approaches were identified:

1. Select a sample of highway sections on one or more systems or functional classes of highway throughout the state or
2. Examine in greater detail sections of highway within one of the state's seven highway divisions.

After both options had been evaluated, the second was selected because it offered the best opportunity to meet the study objectives within a reasonable amount of time. Initial estimates of the time required to collect and extract the required pavement data, as well as obtain the appropriate maintenance input under the first approach, were considered excessive.

SELECTING DIVISION AND SYSTEM

Both subjective and objective input were used in selecting a highway system and maintenance division. Four systems were considered: *(a)* Interstate, *(b)* rural arterials, *(c)* urban arterials, and *(d)* collectors.

The Interstate system was excluded because many of the maintenance activities of interest to this study rarely occur on it. The urban systems were excluded because a majority of their maintenance responsibilities are undertaken by local communities. Because of the volume of data required to address both remaining systems, a decision was made to concentrate on the rural arterial system. This remaining mileage comprises both the major and the minor arterial classes. These functional classes generally parallel the Federal-Aid Primary and Secondary State Highway Systems and amount to about 400 to 500 centerline miles per division, which is about ⅓ of their jurisdictional mileage.

To ensure a uniform and broad range of conditions, it was considered desirable to select a division with a wide distribution of pavement conditions. For this purpose, recent pavement condition data were examined. Using this criterion, the selection was narrowed down to Divisions 3 and 7. Division 3 was selected because

1. As a result of a prior pilot study, there were more objective data available on both pavement condition and maintenance priorities in Division 3.
2. Division 3 contained a better distribution throughout the entire range of conditions.
3. Division 7 would make an ideal candidate for a follow-up investigation because it had been selected for a parallel study to examine suggested modifications to the MMS.

SELECTION OF APPROPRIATE HIGHWAY SECTIONS

To satisfy the objectives of this study, the highway sections selected had to exhibit a wide range of conditions. To ensure that the sites represented all of the categories and levels of need encountered, a variety of records from both the Bureau of Maintenance and the Bureau of Planning had to be examined. To satisfy all of the requirements, a total of 84 sections representing 117 mi were selected. The sections were carefully selected to represent all crew areas and to be equally distributed among the three geographic areas in the division. Table 1 gives the breakdown and perecentage of the study mileages within each area and crew responsibility.

TABLE 1 DISTRIBUTION OF STUDY MILEAGE

Area	Crew	Total Miles	Study Miles	Total (%)
33	3321	70.0	8.6	12
	3322	71.0	26.7	38
		141.0	35.3	25
34	3421	59.0	22.4	38
	3422	62.8	8.3	13
	3423	33.2	6.6	12
		155.0	37.3	24
35	3521	53.9	29.1	54
	3522	66.9	15.8	24
		120.8	44.9	28
Division total		416.8	117.5	28

FACTORS CONSIDERED

Many factors in addition to pavement distress and ride roughness were considered. The following list summarizes all of the other factors eventually examined.

1. Average annual daily traffic *(AADT)*,
2. Daily 18-kip equivalent single axle load (ESAL),
3. Years since construction *(AGE)*,
4. Years since last improvement *(ASLI)*,
5. Drainage condition (DV), and
6. Cut or fill status (XV).

Because flexible pavements account for more than 95 percent of the total highway mileage, pavement type was not included as a study variable.

DELPHI DATA

To establish a starting point, a decision was made to examine data collected under an earlier study performed by the MeDOT *(18)*. That effort was directed at establishing the pavement condition rating (PCR) previously mentioned.

To develop the rating, a list of distress measures, which a panel of departmental experts agreed were the most predominant ones to consider, was identified. Thereafter, the Delphi technique was employed. Briefly, Delphi utilizes the opinions of "experts" to establish a measure of a particular study's objective. To obtain these opinions, two or more iterations of a questionnaire are used. The second and any subsequent round of questions are usually provided in a form summarizing the results of the previous one. This tends to "calibrate" the panel of experts and generally enables a convergence of opinions. One noteworthy effort that used a conventional Delphia approach was the development of maintenance levels-of-service guidelines as part of a NCHRP Study 223 conducted in 1980 (*19*, p.118).

When the objectives of the Delphi process had been determined, the PMS group selected 25 engineers representing the various disciplines within the department. These experts were asked to give their opinions about the significance of various levels of severity and extent of distress for five pavement attributes. A total of three rounds of questions were performed at that time.

The five attributes of interest were *(a)* pavement condition, *(b)* safety, *(c)* roughness, *(d)* structural adequacy, and *(e)* maintenance needs. Of the five attributes on which data were collected, only values representing pavement condition were analyzed at that time.

INITIAL DELPHI DISTRESS RELATIONSHIP

As previously noted, Delphi significance values had been obtained on the five attributes identified. The Delphi data associated with maintenance needs were selected as a starting point for this study. The final Delphi iteration results were analyzed, tabulated, and modified slightly to account for some minor format changes. These Delphi results represented significance values for each level of distress. These values were then normalized so that the total of the most severe case that could theoretically exist would equal 100. The maximum value of 100 deduct points represented a "terminal" state. The total range of deduct-values is given in Table 2.

To enable raw field data to be rapidly processed, a simple procedure was written using Statistical Analysis Systems (SAS) *(20)*. Total deduct-values were calculated for each section.

TABLE 2 NORMALIZED DEDUCT-VALUES FOR MAINTENANCE NEED

Distress	Severity Level	Deduct-Values for Extent Level (%) <25	25–50	>50
Transverse cracking	>Hairline	1	4	(6)
Longitudinal cracking	>Hairline	1	5	(7)
Load-associated cracking	Initial	2	5	9
	Advanced	5	10	15
	Severe	7	(16)	22[a]
Edge cracking	Initial	2	5	9
	Advanced	5	10	16
	Severe	7	16	(22)
Distortion	<½ in.	1	2	4
	½–1 in.	2	6	9
	>1 in.	4	10	(17)
Patching	Good	1	4	5
	Fair	2	9	13
	Poor	5	12	(22)
Shoulder condition	Deficient	2	6	(10)

NOTE: The maximum of 100 deduct points is the total of the values within parentheses.

[a]By definition it is not possible to have more than 50 percent of both severe load-associated and edge cracking.

SUPPLEMENTARY SECTION DATA

After the Delphi results were processed, the pavement management files were processed to extract appropriate section data. When this process had been completed there were still three variables for which data had to be obtained: axle loading (ESAL), drainage condition (DV), and cut or fill status (XV). The Bureau of Planning was contacted to obtain the required loading information. The remaining two items required field visits by a technician. Approximately 1 week was required for each of these operations. When these had been completed, all of the data were aggregated into one file.

INFORMATION NEEDS

To meet the study objectives, a shopping list of various types of desirable information was developed:

1. Verification of maintenance activities performed on each section,
2. An indication of where maintenance had been deferred,
3. A subjective measure of maintenance need on each study section,
4. A measure of a section's relative demand on maintenance crews, and
5. An indication of preference for maintenance or rehabilitation on each section.

It soon became apparent that maintenance personnel should be involved to obtain the desired information. After the list had been reviewed, a decision was made to employ a questionnaire. In developing the questionnaire, several factors were considered important if the information was to be consistent:

1. The survey should not rely on lengthy written responses,
2. The form had to be simple with check-off or numerical input,
3. The form should probably be confined to one page, and
4. Instructions and questions should be written in language understood by maintenance personnel.

Several versions were experimented with until one that met all of the guidelines was developed.

MAINTENANCE QUESTIONNAIRE

The questionnaire contained five questions. Two were directed at objectives beyond those discussed in this paper. Those findings can be found in a complementary document *(21)*. The major emphasis of the remaining questions was on obtaining the required subjective input on maintenance needs and priorities and preferences among preventive maintenance, capital maintenance, and rehabilitation on each study site.

To establish a yardstick against which the participants could subjectively rate, a scale was employed and described on the form. For consistency with other pavement indices, a 0 to 5 scale was adopted. The scale served to define extremities: out of service = 0 and new pavement = 5. Brief descriptions of increasing levels of maintenance were introduced at four points (1, 2, 3, and 4) along the scale. Participants were asked to place a mark along the scale at the point that best described each section evaluated. This scale provided the mechanism for establishing the required correlations.

CONDUCTING THE SURVEY

To initiate the survey, the Division 3 Engineer was contacted and it was agreed that the three area supervisors would be the most appropriate personnel to participate. They were contacted and agreed to take part. The questionnaires, instructions, and maps identifying each site were forwarded to each of the participants. They were instructed to visit each site when completing the form. The forms were completed with little difficulty and quickly returned. The entire field process was accomplished within a normal week's work load. In addition to the required responses, some additional and beneficial information was voluntarily provided.

MAINTENANCE NEEDS INDEX

The main purpose of this phase was to establish an objective measure of need for maintenance on specific sections of highway. The aim was to identify those significant measures that could reasonably predict the responses offered by a group of area maintenance supervisors.

Some uncertainty was introduced because only one person evaluated each section. However, in contrast, those selected were considered to be most knowledgeable and intimately aware of need. Even so, "between-area" differences were a possibility, and "calibration" of the raters would have required an expanded investigation. Suggestions about how to address this are offered later.

Initially, the eight variables identified earlier were each evaluated against the subjective rating in order to establish correlation tendencies. The variable that correlated best with the subjective rating was the total deduct points established from the Delphi weights. A second promising variable was the Mays meter roughness measurements represented by the *QI*.

DEVELOPMENT OF MODEL

To investigate possible rater variation, the most significant variable was evaluated against the responses of each participant. These initial evaluations produced fair-to-good results, and, as expected, variations did occur between raters. There were no data that indicated that the initial relationship was nonlinear within the range of values experienced in the study. Deduct-values ranged from 4 to 65.

The single-variable models obtained for the respective areas along with the composite model are

Maintenance Area	*Model*	R^2	
33	$MNI = 4.55 - 0.057$ (deducts)	0.56	(1)
34	$MNI = 4.74 - 0.056$ (deducts)	0.62	(2)
35	$MNI = 3.68 - 0.040$ (deducts)	0.39	(3)
Combined	$MNI = 4.41 - 0.050$ (deducts)	0.53	(4)

where *MNI* stands for maintenance needs index. Note that R^2 is a measure of the ability of an equation to predict actual values. A perfect model would have an R^2 equal to 1.

The models derived from Areas 33 and 34 were strikingly similar. A more detailed investigation of possible causes for the variation in the Area 35 responses revealed major clustering of subjective ratings around the whole numbers on the form where maintenance levels were described. This phenomenon appears to account for the observed inconsistency.

The two similar sets of data (33 and 34) were used to generate the following equation:

$$MNI = 4.65 - 0.056 \text{ (deducts)} \quad (5)$$

with a corresponding R^2 equal to 0.59. At this point the second most significant variable (*QI*) was introduced and another model was developed. Although *QI* was significant, it did not improve the correlations as greatly as anticipated. It did account for an increase of 5 percent in prediction. This model was

$$MNI = 5.25 - 0.044 \text{ (deducts)} - 0.02\ (QI) \quad (6)$$

with a corresponding R^2 equal to 0.64

To examine the effects of the remaining variables, a stepwise selection process was used to generate multiple regressions of the maintenance needs rating on all eight original variables in the correlation matrices. Stepwise selection builds the regression model incrementally, one variable at a time, so as to maximize predictability while carefully controlling for statistical significance. This process is terminated when no new variable can be added to the model, or substituted for a variable already in the model, while producing a significant increase in predictability.

This process generated a three-variable model of the form:

$$MNI = 5.00 - 0.044 \text{ (deducts)} - 0.018\ QI - 0.0001\ AADT \quad (7)$$

with $R^2 = 0.66$.

To this point all the significant variables consisted of readily available data. The process also generated a series of models beyond the three-variable form indicated. Although the variables introduced were statistically significant, improvements were minimal. The maximum R^2 obtained was 0.70. These extended models were not pursued because the slight improvements did not warrant the effort required to obtain the extra data.

MODEL EVALUATIONS

For purposes of this study the two-variable form (Equation 6) was further evaluated for statistical validity. The model was first employed to generate predicted values for each section. Residuals (difference between predicted and actual) were also generated for each of the 79 sections with available data. To check the prediction capability of the model, the subjective Maintenance Needs Ratings (MNRs) were plotted against the predicted values, as shown in Figure 1.

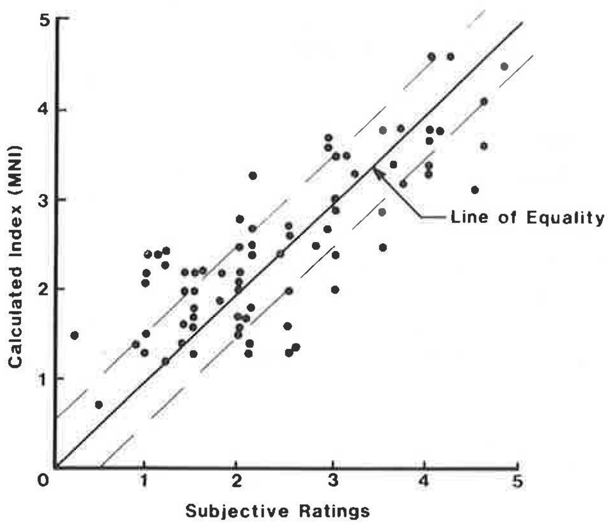

FIGURE 1 Plot of calculated needs index against ratings.

As with most models, an error term exists unless the model accurately predicts every observation. Residuals are estimates of error and used to test for normality and variance. In checking for a good regression model, the error is assumed to be normally distributed with a mean of zero and constant variation. To verify this, two diagnostic checks were performed. To check for normality, a frequency histogram for the residuals from Equation 6 was constructed. The bell-shaped curve that was observed supports normality (mean of zero and normal distribution).

To check for variance, the residuals were plotted against the predicted needs index for the model. The random distribution of errors confirmed constant variance.

ESTABLISHMENT OF A REHABILITATION THRESHOLD VALUE

One of the questions offered an opportunity for maintenance personnel to indicate their opinion about the most cost-effective strategy to perform. The three choices of strategy were

1. Preventive maintenance,
2. Capital maintenance, and
3. Rehabilitation.

Because some of the study sections were currently programmed for rehabilitation, this also offered an opportunity to examine those sections selected through the existing PMS programming process.

Before developing a separate model, each response to the subject question was matched with the calculated maintenance needs index previously recommended. The data were then analyzed to pinpoint any apparent "ranges" within which strategies were predominant. This exercise identified three significant ranges:

1. Perform preventive maintenance at index levels greater than 3.2,
2. Perform capital maintenance at index levels between 2.4 and 3.2, and
3. Perform rehabilitation at index levels below 2.4.

These ranges produced an overall prediction rate of 84 percent. To determine if these values could be improved on, a second exercise was performed starting with the same variables used earlier. Regressions were run between the responses and each variable. Again, deduct points correlated best.

Another set of evaluations, again employing a stepwise regression, was made using the study variables. After several versions, a final form was selected:

$$RSI = 0.563 + 0.031\,(\text{deducts}) + 0.021\,(QI) - 18\,IR \qquad (8)$$

where

RSI = repair strategy index and
$IR = [(AGE + 1) - ASLI]/AGE^2$.

This index represented a range from zero (no maintenance required) to four (pavement requires extensive rehabilitation).

Values were calculated for each section and matched with the associated response. Analysis of this data revealed the following:

1. An *RSI* below 1.5 accurately indicated sections for which preventive maintenance was optimum 100 percent of the time.
2. At index levels greater than 2.5, rehabilitation proved to be the response 91 percent of the time. The mean value of the index for this range was 2.90.
3. All 10 sections for which rehabilitation had been programmed exceeded an index of 2.8 with a mean value equal to 3.15.
4. Index values between 1.5 and 2.5 included all three strategies. However, a secondary break was identified around a level of 2.1.

As was the case for the maintenance index, the middle range proved the most difficult to tie down. There was a tendency in this area for participants to recommend rehabilitation when, in reality, adequate funds would probably never be available, given all of the other candidates. Selection of capital maintenance would be a reasonable alternative.

On the basis of this investigation the following ranges of index values were established:

1. Perform preventive maintenance at index values less than 2.1,

TABLE 3 SUMMARY OF INDEX RANGES, RESPONSES, AND PERCENTAGE AGREEMENT

	Needs Index Responses			Repair Strategy Index Responses		
Strategy	Range	No.	Percentage	Range	No.	Percentage
Preventive maintenance	3.2–5.0	22	77	0.0–2.09	22	82
Capital maintenance	2.4–3.19	17	71	2.1–2.49	15	71
Rehabilitation	0.0–2.39	40	93	2.5–4.0	42	93
Overall predictions			84			86

2. Consider capital maintenance for index values between 2.1 and 2.5, and
3. Consider rehabilitation when the index exceeds 2.5.

Using these ranges a reasonable prediction would have been made 86 percent of the time.

Table 3 gives a summary of both models with their associated prediction percentages. Although it is not apparent from the table, the results obtained by employing the *RSI* do not reflect much of a "spread" of responses. Simply put, this means that those responses that do not conform when the strategy index is used come closer to being correct than they do when the needs index is employed. The distributions of responses observed were extrapolated and frequency histograms by ranges of conditions were constructed. This is shown in Figure 2. The areas of conflict (the 15%± observed) is represented by the shaded overlapping tails of the distributions. This is probably due to nonquantifiable factors. It is doubtful that significant model improvements are probable or even necessary. It would appear that the minimal improvement offered by developing a separate model suggest that it is not necessary. However, initially it might be advisable to use both so that a more extensive evaluation of the spread of responses can be made.

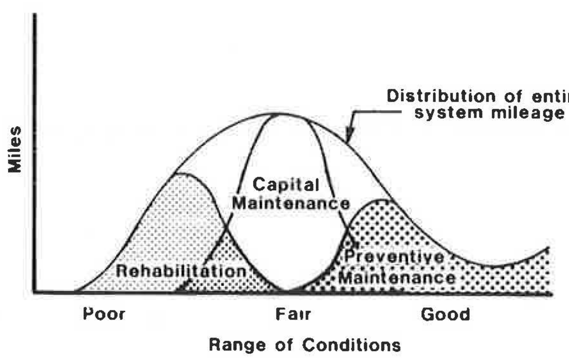

FIGURE 2 Distribution of preferred strategies by condition.

CONCLUSIONS

Findings from the study as well as comments on the research follow:

1. The MeDOT has designed a procedure for obtaining distress and serviceability data that are pertinent to the network pavement management process.
2. This research project has benefited from data pertinent to maintenance needs, collected earlier in a Delphi experiment.
3. The extensive volume of data routinely gathered provides a substantial data base on which to exercise the models developed in this research.
4. In all of the investigations, measures of pavement distress as represented by the total deduct points proved to be the most significant measure in predicting maintenance need as well as the appropriate repair strategy.
5. Although there may appear to be some redundancy between the pavement condition rating (PCR) and the maintenance needs index *(MNI)*, the latter specifically addresses maintenance. Consequently, it is intended for that purpose and should be used in parallel, not combined, with PCR for network analysis.
6. The recommended models offer an opportunity to provide the maintenance division a variety of tabulated information on all highway sections.
7. The same information that is provided to maintenance can be readily incorporated as complementary information into the network analysis process.
8. No data in addition to those that are routinely collected and updated for the network program are required to provide the indices suggested by this research.

RECOMMENDATIONS

The recommendations offered are reasonable and consistent with the department's overall goal of improving its pavement management process.

1. The maintenance needs regression model developed should be applied to the distress data routinely gathered by the department. The model should be added to the current PMS analytical process. This would allow automatic calculation of indices during data input.
2. The data should be tabulated by system and by division and provided to each maintenance unit.
3. A basic training session lasting just a few hours should probably be scheduled to familiarize maintenance personnel with terminology, location information, field interpretation, and use of the data generated.
4. In addition to the maintenance needs index the repair strategy model should be employed and values tabulated in parallel with the maintenance needs index so that a further evaluation of the ranges associated with the three categories can be made.
5. It is suggested that these tabulations be initially used for

preliminary assessment of the values to isolate any obvious discrepancies.

6. The rating provided is an estimate and should be used as a preliminary tool by maintenance operating personnel for comparing sections within similar systems (e.g., primary, secondary). The major advantage offered by the model is that it provides a ready and quick tool for eliminating the need to look at sections that do not require immediate attention.

7. As a means of improving the needs model, the department could consider expanding the original experiment by employing three participants in each area. This would have to be carried out in another field division. The final decision on this second exercise should be based on whether the increased confidence would be worth the effort. Because the information is initially intended as a planning or scheduling tool, it is doubtful that such an effort is warranted at this time.

8. The department should consider employing a similar approach to the Repair Strategy Index for identifying specific rehabilitation types (i.e., light, medium, and heavy overlay). This could be accomplished by employing a similar questionnaire on a sufficient number of field sites.

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