Development of a Procedure for Assessing Routine Maintenance Needs of Highways

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In this paper is described a procedure that can be used to estimate routine maintenance work loads by highway section for a coming year or season. Although the approach can also be extended for use in maintenance budget planning, the primary area of application of the proposed procedure is in determining the amount of maintenance work that is to be undertaken on what highway sections within a subdistrict subject to the constraint of a given maintenance budget. The procedure is based on periodic surveys of highway distress by unit foremen and subsequent use of a set of quantity standards, termed "present quantity standards." These standards were developed by relating the foremen's subjective ratings of road conditions to objective field measurements of distress and subsequently transforming the subjective ratings to expected work loads. A statistical regression analysis was used to develop the necessary relationships. The field data were collected from 18 maintenance units in Indiana.

One of the most important functions of a maintenance management system is to estimate the amount of maintenance work to be performed on various highway sections within a maintenance unit during a coming year or season. For the state highway system in Indiana, the budgeting for routine maintenance work is established primarily by subdistrict foremen on the basis of historical quantity standards and judgment *(1)*. The procedure, used in most states, is based on Roy Jorgensen's work in the 1960s *(2,3)*. However, this historical-empirical approach may not provide an assessment of actual needs by specific highway sections for use in scheduling activities in the field.

PROPOSED SYSTEM

In the present study a system is proposed for assessing routine maintenance work load on the basis of a condition survey of roadways by unit foremen. It is believed that the proposed system can provide a tool to assist in the assessment of work loads by highway section. The proposed procedure can have several added benefits. Subdistricts and districts will be able to have systematically gathered and uniformly defined maintenance needs data. Maintenance management at all levels can thus have another tool to check the maintenance levels of service throughout the state and to help keep maintenance policies consistent.

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Maintenance Management Systems

The present version of the maintenance management systems in most states is based primarily on the development of appropriate standards. These standards are then used to control and plan various maintenance activities:

1. Quality standards are used to represent maintenance levels of service.
2. Quantity standards are the means by which inventory units are converted into work load. For example, if a certain network has 10 mi of bituminous road, multiplying this by the quantity standard for shallow patching, such as 2 tons per mile of bituminous road, will lead to the expected amount of shallow patching: 20 tons. Quantity standards are developed primarily from historical data as well as from input from the unit foremen. These standards are averages of past requirements per unit of inventory for each maintenance activity.
3. Performance standards help to translate expected work load per activity to man-hours, material, and dollars per activity. They provide the average requirement of manpower and materials to accomplish one unit of a maintenance activity. Thus, when the work load per activity is known, these quantities can be multiplied by their respective performance standards to arrive at the requirements for labor and materials.

The Indiana Department of Highways (IDOH) *Management System Procedures Manual (4)* and the *Field Operations Handbook for Foremen (5)* provide a good insight into the maintenance management system in use in Indiana. The procedure is based on the three sets of standards described earlier.

Condition Evaluation Procedures

Present condition survey procedures were developed mainly for pavement management systems, and they are directed to decisions regarding rehabilitation needs. However, in the present study it was necessary to develop a survey procedure that could identify conditions that trigger routine maintenance needs. The proposed procedure is to have unit foremen conduct a visual condition survey on a periodic basis.

DEVELOPMENT OF THE PROPOSED APPROACH AND DESIGN OF EXPERIMENT

Development of the Condition Survey Form

A simple survey form was developed on the basis of current procedures and consultation with the unit foremen and sub-

TABLE 1 ROUTINE MAINTENANCE ACTIVITIES INCLUDED IN THE STUDY

Pavement		Unpaved Shoulders		Drainage	
No.	Activity	No.	Activity	No.	Activity
201	Shallow patching	210	Spot repair of unpaved shoulders	231	Clean and reshape ditches
202	Deep patching	211	Blading shoulders	234	Motor patrol ditching
203	Premix leveling	212	Clipping unpaved shoulders		
204	Full-width shoulder seal	213	Reconditioning unpaved shoulders		
205	Seal coating				
206	Sealing longitudinal cracks and joints				
207	Sealing cracks				

district personnel. The selection of maintenance activities and types of distress to be included in the survey procedure was based on maintenance personnel's opinion and information available in the literature on highway maintenance management. Table 1 gives the list of maintenance activities included in the study, and the types of highway distress considered in the survey are given in Table 2.

TABLE 2 TYPES OF HIGHWAY DISTRESS INCLUDED IN THE SURVEY

Flexible Pavements	Rigid Pavements
Blowups	Blowups
Bumps	Bumps
Depressions	Condition of longitudinal joints
Ditch condition	Condition of transverse joints
Linear cracks	Ditch condition
Potholes	Linear cracks
Raveling	Potholes
Rutting	Raveling in bituminous shoulder
Shoulder buildup	Shoulder buildup
Shoulder drop-off	Shoulder drop-off
Shoulder potholes	Shoulder potholes
Surface failures	Spalling
	Surface failures

Design of Experiment

The proposed approach was tested in the field to determine its validity and accuracy as well as to check whether the survey form represented actual typical conditions of the roadways. The work elements included

1. Collection of information on the physical condition of the highway by means of a visual inspection by unit foremen. The type of visual inspection was the same as that currently used by the IDOH. The units were selected in a stratified random sampling. The unit foremen were asked to generate two types of data: a subjective opinion about the degree of several deficiency conditions in the roadway stretch being analyzed and an estimate of the expected amount of work in the selected maintenance activities currently needed, based on the condition of the roadway.
2. Objective measurements of different deficiency conditions by the research team on the same highway stretches surveyed by the unit foremen.
3. Statistical correlation and analysis of the data collected in Steps 1 and 2.
4. Development of the criteria that would relate the unit foremen's evaluation of a deficiency condition to a certain level of routine maintenance activity.
5. Analysis of the variability of the subjective opinions about the roadway condition. This analysis can then assist in improving the consistency of future maintenance decisions.

The forms used requested information on the roadway condition and estimated maintenance needs. Foremen were required to estimate the work load so that the information could be used to analyze the validity of the proposed approach. It is not proposed to use this part of the survey form during actual implementation of the procedure.

Statistical Selection of Maintenance Units Surveyed

A stratified random sampling scheme was used in the study. A stratified random scheme is a restricted randomization design in which the experimental units are first sorted into homogeneous groups or blocks and then the required number of experimental units is randomly selected within each group *(6)*.

The northern, central, and southern parts of the state of Indiana were considered blocks from which the units to be surveyed were selected. This made it possible to take into account variations in climate and regional maintenance practices during the analysis of the validity of the proposed approach. Three subdistricts were randomly selected in each of these three regions. Within each of these subdistricts, two randomly selected maintenance units were surveyed. This made it possible to analyze the variations associated with both unit foremen and subdistricts when assessing the accuracy of the proposed condition survey method. A total of 18 maintenance units were included in the study. The survey covered asphalt and concrete highways in both the Interstate and the state highway systems. A total of 965 lane-miles were surveyed. The forms used to conduct the foremen's survey are shown in Figures 1 and 2.

Objective Measurement of Highway Distress

The highway stretches surveyed by the unit foremen were also surveyed by the research team and the types of highway distress observed were physically measured. This measurement took place within no more than 2 days of the foremen's survey. Every highway stretch that a foreman had evaluated was subsequently evaluated by objectively measuring its distress.

DISTRICT__________ HIGHWAY [S] [US] [IS] No:______

SUBDISTRICT__________ FROM__________

UNIT NO.__________ TO__________

DATE__________ TRAFFIC [LOW] [MED] [HIGH]

DIRECTION [N] [S] [E] [W]

ASPHALT PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	CRACKS	CRACK SEALING .... gals
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		FULL WIDTH SHOULDER SEAL ...... ft. miles
M	S	F	N	SLIGHT	RAVELING	
M	S	F	N	MODERATE		SEAL COATING ...... lane miles
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
M	S	F	N	SLIGHT	RUTTING, DIPS	LEVELING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD–UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR (210) .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP–OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		RECONDTING .... shldr. miles
M	S	F	N	SEVERE		
DRAINAGE						
P	F	G		DITCHES		DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

FIGURE 1 Asphalt pavement condition survey form used by the foremen in the study.

Because the measurement took place soon after the foremen's survey, the possibility of occurrence of any changes in the highway condition between the two evaluations was minimized. The form used to record the physical measurements of distress is shown in Figure 3.

ANALYSIS OF VALIDITY OF PROPOSED APPROACH

The subjective condition rating data were converted into a numerical scale so that quantitative statistical analysis methods could be used. A point estimation technique was applied for the conversion of the subjective category scale used during the field survey to a 0 to 10 numerical scale.

To analyze the data gathered, regression analyses were performed. Table 3 gives a summary of the results obtained. It shows the significance of the proposed approach in explaining the variability of maintenance work load for eight of the nine maintenance activities considered. The lack of significance in the case of Sealing Longitudinal Cracks and Joints can be attributed to the small sample size.

It can be seen in Table 3 that maintenance subdistricts showed a significant influence on the estimation of the work load of Shallow Patching, Crack Sealing, and Premix Leveling at a level of significance of 0.05. Individual estimator's influences were found significant in assessing the needs for Spot Repair of Unpaved Shoulders, Blading Unpaved Shoulders, and Cleaning and Reshaping Ditches. These results suggest that the amount of work in Spot Repair of Unpaved Shoulders, Blading Unpaved Shoulders, and Cleaning and Reshaping Ditches is particularly influenced by the personal judgment of unit foremen, whereas the amounts of Shallow Patching, Crack Sealing, and Premix Leveling are more subject to regional differences in maintenance materials, practices, or standards. The influences of subdistricts and foremen should be further studied in order to achieve consistency in maintenance needs assessment.

DISTRICT______ HIGHWAY [S | US | IS] No. ______

SUBDISTRICT______ FROM______ ______

UNIT NO.______ TO______

DATE______ TRAFFIC [LOW | MED | HIGH]

DIRECTION [N | S | E | W]

CONCRETE PAVEMENTS						
TRAFFIC LANES AND PAVED SHOULDERS						
M	S	F	N	SLIGHT	POTHOLES	SHALLOW PATCHING .... tons
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	BLOW UPS, BUMPS AND SURFACE FAILURES		DEEP PATCHING .... tons
M	S	F	N			
M	S	F	N			
P	F		G	LONGITUD. JOINTS		SEALING LONG. CRACKS & JOINTS ...... linear miles of cracks & joints
P	F		G	TRANSVERSE JOINTS		CRACK SEALING .... gals.
M	S	F	N	SLIGHT	CRACKS	
M	S	F	N	MODERATE		FULL WIDTH SHOULDER SEAL ...... ft miles
M	S	F	N	SEVERE		
M	S	F	N	RAVELING IN BITUMINOUS SHLDR		
UNPAVED SHOULDERS						
M	S	F	N	SLIGHT	BUILD–UP	CLIPPING .... shldr. miles
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	POTHOLES	SPOT REPAIR .... tons of agg.
M	S	F	N	MODERATE		
M	S	F	N	SEVERE		
M	S	F	N	SLIGHT	DROP–OFF	BLADING .... shldr. miles
M	S	F	N	MODERATE		RECONDTNG .... shldr. miles
M	S	F	N	SEVERE		
DRAINAGE						
P	F	G		DITCHES		DITCHING (231) ...... linear ft
						MOTOR PATROL DITCHING (234) .... ditch miles

FIGURE 2 Concrete pavement condition survey form used by the foremen in the study.

Work Load and Subjective Evaluation of Distress

A set of regression analyses was performed to relate the routine maintenance work load to the subjective evaluation of distress by unit foremen. The purposes of these analyses were

1. To develop models that could be used to estimate routine maintenance work loads on the basis of subjective evaluation of roadway distress,
2. To form the basis of the calculation of "present" quantity standards, and
3. To learn how much of the variability of estimated maintenance work loads can be explained by the foremen's survey.

These points were addressed by a stepwise regression procedure that gives "best" models for each of the analyzed maintenance activities. The following model was adopted:

$$y_i = a + \sum_{j=1}^{n_i} b_j X_{ij} \quad (1)$$

where

- y_i = square root of expected work load per activity per lane-mile, shoulder-mile, or ditch-mile;
- a = constant;
- b_j = regression parameters, $j = 1,2, \ldots, n_i$; and
- X_{ij} = subjectively rated distress (pothole frequency, pothole size, etc).

The variables listed in Table 4 were included in Equation 1 in the process of developing models to predict work load per activity. The "best" models arrived at are given in Table 5. The values of the coefficients of determination (R^2) represent the proportion of the variability of estimated work loads that can be explained by foremen's evaluation of distress. Except

HIGHWAY CLASS & No : Typical sample unit No: length: dist:

HIGHWAY FEATURE/ DISTRESS	TRAFFIC LANES	PAVED SHOULDER
WIDTH	1 2 3 ___ft	No Yes ___ft ___ft
SURFACE TYPE	ASPHALT CONCRETE	ASPHALT CONCRETE
POTHOLES	lth wth depth	length width depth
LINEAR CRACKS	sealed lth ___ wth ___ unsealed lth<1/8 wth	sealed lth ___ wth ___ unsealed lth<1/8 ..... wth .....
ALLIGATOR CRACKING	seal patch L M H sealed unsealed ft2	seal patch L M H sealed unsealed ft2
RAVELING	L M H ft2	L M H ft2
RUTTING	inside wheel in; outside wheel in	___in
DIPS CORRUG.	DEPTH FT2	DEPTH FT2
BLOW UPS	L M H No FT2	L M H No FT2
SPALLING	L M H No FT2	L M H No FT2
SURFACE FAILURE	L M H depth FT2 edge?	L M H depth FT2
BUMPS	L M H depth FT	L M H FT
LONG JOINTS	fault L M H No sldge LMH No	fault L M H No sldge LMH No
TRANSVERSE JOINTS	fault L M H No sldge LMH No	fault L M H No sldge LMH No
PATCHED SURFACE	L M H FT2	L M H FT2
LANE/SDR DROP OFF	length FT depth IN	out shder width ft
PAVSHDR/UNPSHDR DROP OFF	length FT depth IN	med shder width ft
BUILD UP	length FT depth IN dist from pav.shder	
POTHOLES	LENGTH WIDTH DEPTH	sod L M H length shape P F G lth dpth
DITCH	WIDTH FT DEPTH FT	REMARKS
DIRT DEBRIS	N F S M NO DITCH	
CLOGGED(SED.)	N F S M CEMENT DITCH	
VEGETATION	N F S M DITCH IN PRIVATE YARD	
EROSION	N F S M	
CROSS SECTION	GOOD (TRIANG.) BAD (SQ.)	

DAY: DISTRICT: SUBDISTRICT: UNIT:

FIGURE 3 Form used to record typical distress during field measurements.

for Crack Sealing, Premix Leveling, and Blading Shoulders, the R^2-values are reasonable. Some factors that might have lowered the R^2-values obtained are *(a)* the lack of full understanding on the part of some foremen of the meaning of some types of distress, such as raveling, when rating the roads; *(b)* the lack of consistency in the speed at which the foremen evaluated the roads (10 to 55 mph); *(c)* some foremen might have rated the extent of certain types of distress influenced by "nontypical" spots rather than on the basis of the overall extent of those types of distress over the highway stretches; *(d)* maintenance standards for certain activities may be based on usage and experience rather than on established maintenance levels of service (for example, unpaved shoulders may be clipped once every few years instead of being clipped whenever the buildup is greater than a determined height); *(e)* some of the types of distress evaluated trigger two or more maintenance options; for example, bumps may trigger either "Bumps Burning" or "Deep Patching," depending on severity; and *(f)* altogether different maintenance activities may be triggered by a given extent of a particular type of distress (for example, raveling can trigger sealing, patching, or major maintenance, depending on the extent and severity of raveling). It is believed that many of these items can be improved by training foremen and that the resulting future R^2-values can thus be increased.

A note of caution should be given. The models developed in this section are statistical in nature. No mechanistic or cause-

TABLE 3 TESTS FOR THE SIGNIFICANCE OF THE APPROACH AND OF THE EFFECTS OF SUBDISTRICTS AND INDIVIDUAL ESTIMATORS

	Approach (related "assessed" distress)			Subdistrict Effect			Individual Estimator's Effect		
Maintenance Activity	Significant at $\alpha = 0.05$	F	α	Significant at $\alpha = 0.05$	F	α	Significant at $\alpha = 0.05$	F	α
Shallow patching	Yes	6.98603 (4,41)[a]	<0.001	Yes	2.9448 (8,50)	0.01–0.025	No	1.2666 (9,41)	>0.1
Crack sealing	Yes	4.6951 (4,41)	0.001–0.005	Yes	2.5729 (8,50)	0.01–0.025	No	1.7119 (9,41)	>0.1
Deep patching	Yes	2.9663 (7,38)	0.01–0.025	No	0.8495 (8,47)	>0.1	No	1.0688 (9,38)	>0.1
Premix leveling	Yes	2.9248 (3,32)	0.01–0.025	Yes	2.3576 (8,41)	0.025–0.05	No	1.7193 (9,32)	>0.1
Sealing longitudinal cracks and joints	No	49.3049[b] (3,1)	>0.1	No	3.5725 (4,2)	>0.1	No	4.3236 (1,1)	>0.1
Clipping unpaved shoulders	Yes	25.8952 (2,43)	<0.001	No	1.6044 (8,52)	>0.1	No	1.3799 (9,43)	>0.1
Spot repair of unpaved shoulders	Yes	5.9417 (4,41)	<0.001	No	1.9063 (8,50)	0.05–0.1	Yes (9,41)	2.4455 0.05	0.025–
Blading unpaved shoulders	Yes	4.2549 (4,41)	0.005–0.01	No	1.7162 (8,50)	>0.1	Yes	4.0648 (9,41)	0.001–0.005
Cleaning and reshaping ditches	Yes	26.7146 (1,44)	<0.001	No	1.4627 (8,53)	>0.1	Yes	3.782 (9,44)	0.001–0.005

[a]Degrees of freedom are in parentheses.
[b]Sample size is much smaller in this case and therefore the power of the tests is lower.

and-effect relationship between work load and "assessed" distress was established.

Analysis of the Field Survey Data

A regression of maintenance work load per activity on related measured distresses was done. The objective was to highlight major types of distress that need to be included in the survey form proposed for implementation. The extent of patched surface was found to be the only additional significant highway feature that contributed to the explanation of the variation in estimated needs of Premix Leveling.

Proposed Quantity Standards

On the basis of the models developed in this study "present" quantity standards (QS) were computed for various combinations of highway distress frequency and severity. As an illustration, the following example can be considered. The QS for Shallow Patching in roadways assessed as having "Many" "Slight" potholes was calculated using the model for Shallow Patching. In that model, expected shallow patching per lane-mile is a function of the assessed frequency (X_1) and severity of potholes (X_2). The model was solved with the numerical values associated with the categories "Many" and "Slight" potholes, 8.01 and 1.79, respectively. The resulting QS-value can thus be computed as 1.20 tons per lane-mile. Similar computations were done for other activities under various combinations of frequency and severity of distress. The resulting QS-values are shown in Figure 4.

The procedure proposed for use in estimating future routine maintenance work loads appears to be conceptually sound; it involves an assessment of maintenance needs based on present needs (evaluation of types of distress that trigger those needs) rather than past experience or arbitrary guesses.

PROPOSED PLAN FOR IMPLEMENTATION

The steps that could be followed to implement the proposed approach are outlined next.

1. Unit foremen would perform the condition survey in early fall and early spring each year. Condition data would be recorded for each highway stretch within the boundaries of a maintenance unit. One form should be filled out for each highway stretch. Figures 5 and 6 show the proposed forms for asphalt and concrete pavements. These forms are modified versions of the forms used in the study. Unlike the forms used in the study, the proposed forms include "patched area" as one of the distress indicators, and a three-category scale is used for the frequency of distress. The analysis conducted in the study indicated that these changes would improve the survey results.

2. Unit foremen would drive along the entire stretch of a roadway at a reduced speed of about 30 mph before making their ratings. It should be noted that the proposed survey was designed to be fast enough that an entire highway stretch could be surveyed without resorting to sampling sections so the foremen could base their judgment on the overall condition of

TABLE 4 VARIABLES CONSIDERED IN THE DEVELOPMENT OF REGRESSION MODELS

Maintenance Activity	Types of "Assessed" Distress Considered
Shallow patching	Frequency of potholes (X_1) Severity of potholes (X_2) Frequency of cracks (X_3) Severity of cracks (X_4)
Crack sealing	Frequency of cracks (X_3) Severity of cracks (X_4) Frequency of raveling (X_5) Severity of raveling (X_6)
Deep patching	Frequency of potholes (X_1) Severity of potholes (X_2) Frequency of cracks (X_3) Severity of cracks (X_4) Frequency of raveling (X_5) Severity of raveling (X_6) Frequency of bumps, blowups, and surface failures (X_7)
Premix leveling	Frequency of ruts and dips (X_8) Severity of ruts and dips (X_9) Frequency of bumps, blowups, and surface failures (X_7)
Sealing longitudinal cracks and joints	Frequency of cracks (X_3) Severity of cracks (X_4) Condition of longitudinal joints (X_{10})
Clipping unpaved shoulders	Frequency of buildups (X_{11}) Severity of buildups (X_{12})
Spot repair of unpaved shoulders	Frequency of potholes in unpaved shoulder (X_{13}) Severity of potholes in unpaved shoulder (X_{14}) Frequency of drop-off (X_{15}) Severity of drop-off (X_{16})
Blading shoulders	Frequency of potholes in unpaved shoulder (X_{13}) Severity of potholes in unpaved shoulder (X_{14}) Frequency of drop-off (X_{15}) Severity of drop-off (X_{16})
Cleaning and reshaping ditches	Condition of roadside ditches (X_{17})

the stretch. Only one combination of frequency and severity of a particular deficiency condition should be selected. For example, if a unit foreman thinks that there is extensive cracking of low severity in a highway stretch, he will mark the cell corresponding to "Many" "Slight" cracks.

3. An estimation of maintenance work load for each activity and for each highway stretch can be made by matching the condition data recorded on the forms shown in Figures 5 and 6 during the spring survey with the appropriate "present" quantity standards shown in Figure 4. These quantity standards are functions of the "assessed" levels of frequency and severity of distress. For example, when a stretch has "Many" "Moderate" potholes, 2.05 tons of Shallow Patching for each lane-mile of the stretch would be considered. By multiplying the corresponding "present" quantity standards by the number of lane-miles, shoulder-miles, or ditch-miles of the highway stretch, various maintenance work loads for each highway stretch would be obtained. The maintenance needs for any maintenance unit, subdistrict, district, or the state can be computed by adding the needs for each road stretch within that area. The estimated work loads by highway sections can then be used to determine the actual work loads within a budget constraint.

4. The aggregation of the evaluation data for each maintenance subdistrict would provide a periodic indication of the overall condition of the highways within the subdistrict. These data can be used to check the effectiveness of different maintenance policies related to field work.

SUMMARY AND CONCLUSIONS

The principal objective of this study was to develop an approach that could be used primarily to determine how much of a routine maintenance activity is to be performed on a highway section during a given time period subject to a given budgetary constraint. This approach is based on the subjective rating of highway distress by maintenance unit foremen. Rou-

TABLE 5 MODELS FOR ESTIMATION OF WORK LOAD

Maintenance Activity	Best-Suited Models (estimated regression coefficient)	R^2 (%)
Shallow patching	$y'^a = 0.157 + 0.09253\ X_1 + 0.10865\ X_2$	37.15
Crack sealing	$y' = 5.261 + 1.03834\ X_4$	21.46
Deep patching	$y' = -0.362 + 0.11716\ X_1 + 0.15267\ X_7$	30.66
Premix leveling	$y' = -0.187 + 0.46177\ X_8$	16.21
Sealing longitudinal cracks and joints	No significant model was developed because of lack of sufficient sample size	–
Clipping unpaved shoulders	$y' = -0.067 + 0.06746\ X_{11} + 0.05793\ X_{12}$	55.43
Spot repair of unpaved shoulders	$y' = -0.004 + 0.21536\ X_{13} + 0.26212\ X_{16}$	31.30
Blading shoulders	$y' = 0.239 + 0.08648\ X_{13}$	12.71
Cleaning and reshaping ditches	$y' = 34.845 - 4.26425\ X_{17}$	47.98

NOTE: The variables $X_1, X_2, \ldots, X_{17}$ are defined in Table 4.

[a] y' = y transformed = square root of expected work load in 6 months per lane-mile, shoulder-mile, or ditch-mile.

Premix Leveling

(Tons per Lane Mile)

"Assessed" Frequency of Ruts and Dips

N	0.02
S	2.50
M	12.30

Crack Sealing

(Gallons per Lane Mile)

"Assessed" Severity of Cracks

Sl	7.0
Mo	10.0
Se	14.0

Clipping Unpaved Shdrs.

(Shdr. Miles per Shdr. Mile)

"Assessed" Frequency of Buildups

"Assessed" Severity of Buildups	N	S	M
Sl	0.01	0.10	0.33
Mo	0.07	0.25	0.50
Se	0.20	0.45	0.90

Deep Patching

(tons per Lane Mile)

"Assessed" Pothole Frequency

"Assessed" Bumps, Blow-Ups and Surface Failure Frequency	N	S	M
N	0.0	0.04	0.50
S	0.10	0.50	1.30
M	0.90	1.70	3.25

Spot Repair Unpaved Shdrs.

(Tons per Shdr. Mile)

"Assessed" Frequency of Potholes in Unpaved Shdr

"Assessed" Severity of Dropoff	N	S	M
Sl	0.40	1.70	4.80
Mo	2.00	4.45	9.10
Se	5.10	8.60	14.70

Blading Shdrs.

(Shdr. Miles per Shdr. Mile)

"Assessed" Frequency of Potholes in Unpaved Shdrs

N	0.10
S	0.30
M	0.90

Shallow Patching

(Tons per Lane Mile)

"Assessed" Pothole Frequency

"Assessed" Pothold Severity	N	S	M
Sl	0.20	0.50	1.20
Mo	0.60	1.10	2.10
Se	1.20	1.90	3.10

Clean and Reshape Ditches

(Ft per Ditch Mile)

"Assessed" Condition of Roadside Ditch

P	693.0
F	190.0
G	2.0

FIGURE 4 Proposed present quality standards.

DISTRICT________ HIGHWAY [S | US | IS] No.________
SUBDISTRICT________ FROM________
UNIT NO.________ TO________
DATE________ TRAFFIC [LOW | MED | HIGH]
DIRECTION [N | S | E | W]

ASPHALT PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	RAVELING
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, BUMPS AND SURFACE FAILURES	
M	S	N	SLIGHT	RUTTING, DIPS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	PATCHED SURFACE
M	S	N	MODERATE	
M	S	N	SEVERE	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

FIGURE 5 Asphalt pavement form proposed for implementation.

DISTRICT________ HIGHWAY [S | US | IS] No.________
SUBDISTRICT________ FROM________
UNIT NO.________ TO________
DATE________ TRAFFIC [LOW | MED | HIGH]
DIRECTION [N | S | E | W]

CONCRETE PAVEMENTS				
TRAFFIC LANES AND PAVED SHOULDERS				
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	BLOW UPS, SPALLING, BUMPS AND SURFACE FAILURES	
P	F	G	LONGITUD. JOINTS	
P	F	G	TRANSVERSE JOINTS	
M	S	N	SLIGHT	CRACKS
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	RAVELING IN BITUMINOUS SHLDR	
UNPAVED SHOULDERS				
M	S	N	SLIGHT	BUILD-UP
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	POTHOLES
M	S	N	MODERATE	
M	S	N	SEVERE	
M	S	N	SLIGHT	DROP-OFF
M	S	N	MODERATE	
M	S	N	SEVERE	
DRAINAGE				
P	F	G	DITCHES	

FIGURE 6 Concrete pavement form proposed for implementation.

tine maintenance needs are connected to their immediate cause, highway deficiencies. It is envisioned that the implementation of this approach would give a more structured approach to maintenance planning because estimation of maintenance needs would be based on present needs rather than historical averages or arbitrary guesses.

This study developed both the methodology to perform the proposed foremen's surveys and the criteria to relate the subjective data obtained to certain levels of routine maintenance activities. Regression analyses allowed the development of estimation models for expected work load based on foremen's subjective evaluation of distress. Finally, the concept of "present" quantity standards was introduced. It should be noted, however, that before the procedure can be implemented, further work is necessary to establish increased consistency in foremen's evaluation of distress conditions and the subsequent estimation of work loads.

The use of this approach can provide decision makers with information and tools to monitor the condition of the highway network. This can help not only to assess maintenance needs but also to check the efficiency and quality of maintenance field work.

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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.