PAVER prototype evaluation test at a military installation. Two analyses were performed: (a) an analysis based strictly on the data collected during the four-month PET (PET data comparison) and (b) an analysis based on average annual estimated data (estimated data comparison). The estimated data were based on the PET data and input from the Buildings and Grounds Division chief at the study installation.

The results of the economic analyses for the PET data comparison and the estimated data comparison are given in Table 6. Figure 2 graphically summarizes the results of the two methods of data comparison for an analysis period of eight years, an interest rate of 10 percent, and an inflation rate of 5 percent. The results of the PET data comparison clearly show that the annual cost of pavement management with PAVER is approximately 50 percent of the cost of the current system. The results of the estimated data comparison show that the annual cost of pavement management with PAVER is approximately 30 percent of the cost of the current system.

ACKNOWLEDGMENT

The views expressed in this paper are ours and do not necessarily reflect the views of the U.S. Department of the Army or the U.S. Department of Defense.

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Development of a Statewide Pavement Maintenance Management System

KAMRAN MAJIDZADEH, MICHAEL S. LUTHER, AND MICHAEL LONG

A framework for a statewide pavement maintenance management system (PMMS) is presented that describes the general system approach, criteria for monitoring pavement conditions, methods and types of data to be collected routinely to define pavement conditions, suggested computer data systems needed to support and implement the PMMS, and a system for establishing project priorities. The overall objective of such a system is to develop and implement maintenance management schemes for optimum selection of various repair strategies based on cost-effective analyses that consider repair needs and priorities. In this PMMS, criteria are applied to determine what portion of the total state network is likely to need maintenance and therefore should be monitored. Monitoring parameters in the form of maintenance needs indicators or "trigger values" are identified. These indicators—present serviceability index, skid number, age, and traffic—are also used to develop recommended sampling or monitoring frequency intervals. Procedures have been developed for nondestructive testing and analyses of structural remaining life for pavements that show structural distress of a certain extent and severity. These pavements are classified by using a visual pavement condition rating system, which provides a uniform method for assessing pavement conditions on a statewide basis. Finally, the PMMS includes a framework for establishing project priorities based on need and condition and presents guidelines to aid in formulation and evaluation of maintenance alternatives. The proposed system uses roughness, skid resistance, deflection, and traffic data currently maintained by most state transportation agencies. It is structured to facilitate implementation with minimal difficulty to a user agency and makes maximum use of the experience and judgment of agency engineers. Finally, it is modular, permitting easy future modifications and improvements to various aspects of the system as they become available.

Highway departments across the nation are experiencing serious monetary problems as aging highways and increasing rates of pavement deterioration are placing larger demands on pavement maintenance requirements. The nation's pavements are deteriorating faster than they are currently being rehabilitated, which results in increasing numbers of pavements needing repair. This situation is aggravated, to a large extent, by obsolete state funding structures that are unable to yield sufficient revenue in times of high inflation and reduced motor-fuel consumption as well as budgetary cutbacks at the national and state levels. As a result, many states have been forced to defer such repair, thus allowing many pavements to deteriorate to an even poorer condition that makes future rehabilitation more extensive and costly.

In light of such fiscal pressures, most state transportation agencies have recognized the need to establish a systematic, rational procedure for identifying pavement repair needs and priorities and selecting cost-effective design alternatives. The pavement maintenance management system (PMMS) framework appears to be providing a solution to highway agency problems, and many agencies have already developed and implemented such systems as a management tool to aid in prioritizing those projects that are in need of rehabilitation (1-4). A PMMS also provides a medium for feedback in which the consequences of past actions can be incorporated into the decision process; it facilitates consistency and uniformity in funding allocations to optimize and achieve the best values possible for public funds and provides improvements and cost savings by means of improved organization and coordination of activities.

Although the primary benefit of a PMMS is economic, in that improved maintenance management will provide greater values for dollars spent, the system also enhances the opportunities for optimal, correct decisions; this leads to improved technology and efficiency for various activities and provides capability to defend funding allocations. It is intended to provide a means for presenting information on in-service pavements that can be used to identify needs and program investments as well as design and construction requirements.

The essential requirements of a PMMS include the capacity for updating and modification as new data and better models become available, incorporation of alternative strategies, identification of optimum alternatives, and the capability for making decisions based on rational procedures. A thoroughly sophisticated and rational system can be formulated so that it provides its own lists of feasible strategies. A PMMS should provide the means for strategy evaluation and optimization and/or comparison of the consequences of the individual strategies.

Another major requirement of any PMMS is to identify condition parameters of a pavement system or network. In the system developed for the Ohio Department of Transportation (DOT), the parameters are skid number (SN), deflection, roughness, texture, and visual distress. The PMMS will provide information on the effect of maintenance activity on the condition parameters as well as the current values of these parameters. The condition parameters must be evaluated reliably and economically.

In a sophisticated PMMS, decisions are based on quantified standards and constraints and data base and information subsystems are an important part of the system. The information subsystem must separate the information needed for the network-level analysis from those data essential to project-level management. Caution is needed and steps must be taken to ensure that the PMMS is not drowned by the volume of data. One cannot expand project-level data bases to encompass the network.

The quality of a PMMS depends on the quality of the data and information available. A viable system should make optimum use of the types of data that are maintained or can be acquired by the user agency, including (a) field and laboratory data, (b) default values, (c) equipment and manpower, and (d) geometric, traffic, condition, unit cost, and materials data.

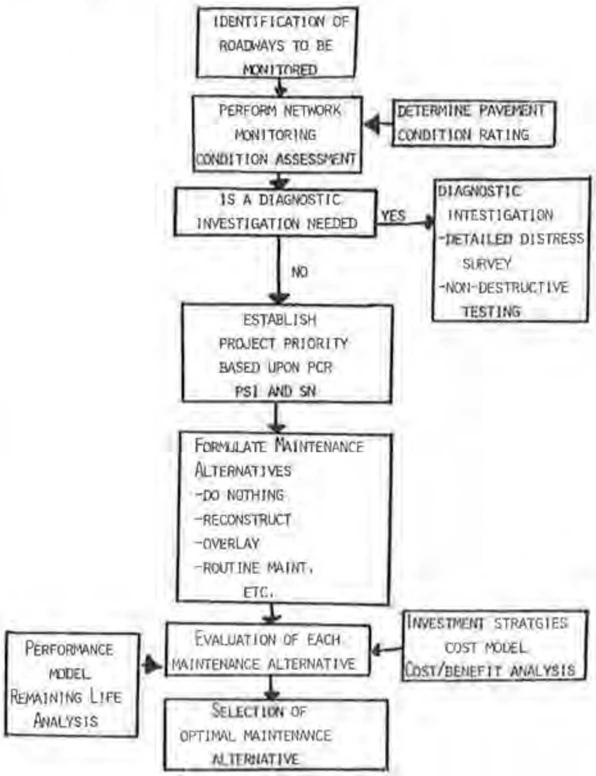
A PMMS is also considered a management tool for performance analysis and is designed to solicit subjective user responses. Therefore, the performance analysis is based, in part, on users' subjective views of the facility. This analysis is associated with serviceability-performance measurements and models.

FRAMEWORK FOR A STATEWIDE PMMS

In the current processes used by many state transportation agencies for programming pavement maintenance and improvement, engineering judgments and available funding are key elements. In many instances, no guidelines are available to district personnel regarding levels of deterioration, alternative repair strategies, or types of economic analyses to be considered in preparing maintenance recommendations. Standard repair policies or techniques have become accepted over the years without the use of documented performance data to indicate that the standard repairs perform satisfactorily. Criteria for identifying when nonstandard repair techniques should be considered are often lacking. Assessment of maintenance needs is sometimes nonuniform, since the judgment of one state district regarding pavement conditions may differ from that of another. This can result in maintenance not being performed for pavements where needs or cost benefits are the greatest and can thus produce nonuniform pavement conditions on a statewide basis.

The Ohio DOT has for more than a decade sponsored activities to develop and implement a comprehensive PMMS to minimize and/or eliminate the types of problems outlined above. Its primary research efforts have been directed toward developing a pavement monitoring system and prioritizing maintenance needs. As part of this research program, a recently completed study sponsored by the Ohio DOT (5) developed a proposed maintenance management program, shown in Figure 1, which incorporates the following components:

Figure 1. Framework of proposed PMMS.



1. Application of criteria to determine what portion of the total network is likely to need nonroutine maintenance and therefore should be monitored;
2. Procedures for nondestructive testing and analyses of structural remaining life for pavements that show structural distress of a certain extent and severity;
3. A framework for identifying alternative maintenance options and evaluating, when appropriate, standard maintenance options;
4. A methodology for selecting optional alternatives; and
5. A procedure for establishing project priorities.

The guidelines used in formulating the PMMS shown in Figure 1, which are considered essential to the development and implementation of a viable statewide PMMS, include the following:

1. The proposed system should use currently available user agency data, including roughness, skid resistance, deflection measurements, and traffic.
2. The proposed system should be structured so that it can be implemented with minimal difficulty by the user agency.
3. The system shall make maximum use of the experience and judgment of agency pavement engineers.
4. The system shall be modular to permit easy future modifications and improvements to various aspects of the program as they become available.

PMMS COMPONENTS

The PMMS developed as part of the Ohio DOT study (5) included four primary components:

1. Development of network monitoring criteria,

including monitoring parameters, maintenance-needs indicators or "trigger values", present serviceability index (PSI) and SN testing requirements and deterioration rates, and other parameters to be used for monitoring criteria;

2. A pavement condition rating (PCR) system, including a system for rating visual distress, field verification of the PCR, and identification of the need for structural investigation;

3. A system for determining project priorities and selecting the optimal repair method, including prioritization based on condition, formulation of maintenance alternatives and economic analysis, and selection of optimal maintenance alternatives; and

4. Suggested data systems, including pavement section files, pavement condition files, and scheduling.

These components are discussed briefly in the following sections.

Development of Network Monitoring Criteria

Monitoring criteria constitute that methodology or logic for deciding which portion of the total roadway network has deteriorated to the point where it is likely to need maintenance. Those criteria are a crucial part of the overall PMMS, since only those pavements identified by the monitoring criteria as being deteriorated will be considered by subsequent steps in the program. The criteria establish the type of pavement condition data to be collected for the network, identify data-collection intervals, and establish the magnitude of the data-collection program needed to support the management program. Two important aspects of the monitoring criteria are evaluating pavement conditions on a systemwide basis and defining unacceptable pavement conditions in terms of the parameters used to evaluate the pavements.

The PMMS included the identification of monitoring parameters and, as a key part of establishing monitoring criteria, a pavement evaluation and rating procedure was developed for defining unacceptable pavement conditions. Maintenance-needs indicators or trigger values were identified as SN, PSI, age, and traffic. Although it is not the principal purpose of a PMMS to identify slippery pavements, an SN of less than 30 was suggested for use in the monitoring criteria.

The research investigation indicated that PSI is a fairly reliable maintenance-need indicator or trigger parameter. The trigger values of PSI were selected on the statistical correlation of the estimated need for maintenance by district engineers and PSI values (based on roughness measurements) for various pavements in that district. Eighty-eight test sections were formed by combining continuous sections from roadways that had the same surface and base types and similar average daily traffic (ADT). Other criteria in defining the sections included a length of 1-4 miles, whether maintenance had been performed since the last PSI measurement (sections or portions of sections were omitted where overlays had been placed since the last PSI measurement), and a definite change in the visual condition of the pavement. In field visitations, district engineers were asked to answer yes, no, or maybe to the question, Will the pavement probably require some type of nonroutine maintenance within the next two years in order to maintain an acceptable level of serviceability and/or structural integrity? Based on the statistical relation between this estimated need for maintenance and measured PSI, trigger values for PSI were developed by using 1980 PSI data, as given below (an asterisk indicates facility types not studied, for which data were extrapolated from data for high-type, two-lane roads):

	PSI by Pavement Type		
System	Rigid	Composite	Flexible
Interstate	3.30	3.40	3.40*
Multilane and high-type, two-lane roads	3.10	3.20	3.20
Low-type, two-lane roads (ADT < 1000)*	2.90	3.00	3.00

Since PSI and SN were to be used as the basis for roadway monitoring, these parameters must be routinely collected on an inventory basis for the entire network. Suggested sampling intervals or monitoring-frequency intervals were established by studying the decline of PSI and SN with traffic and age, as illustrated in Figures 2-4. Representative deterioration rates of PSI and SN were defined for each pavement type, and these rates were used to establish suggested sampling intervals by calculating the required amount of time needed to produce a "statistically significant" change in mean PSI and SN values by using the Student's t-test to calculate that time interval. The recommended test intervals for PSI and SN data collection developed in our study (5) are given in Table 1. Monitoring-frequency requirements should account for climatic and traffic variations experienced in different regions of the state. Finally, since many states do not yet have a fully implemented PMMS and obtaining and compiling PSI data for a statewide roadway network takes considerable time and funds, parameters other than PSI might also be used in the monitoring criteria. In the study cited above, it was found that age and traffic volume "B + C" could be used as trigger parameters in the absence of PSI data. For rigid pavements, it was found that traffic volume is a better indication of maintenance needs than age.

By incorporating PSI and SN deterioration rates into the PMMS, corrective action can be initiated for pavements with high deterioration rates before they decline to a poor condition and pavements with low deterioration rates can be investigated to identify designs that produced good performance. Deterioration rates can be analyzed on a district or statewide basis to identify those regions or routes that are experiencing the highest deterioration and to obtain an estimate of the magnitude of future maintenance needs. A summary of the monitoring criteria is presented in Figure 5.

PCR System

The monitoring phase of a PMMS program involves evaluation of the current physical condition of pavements in the field. A rating procedure, identified as pavement condition rating, was developed (5) that reflects the physical condition of the pavement. The PCR method is based on visual inspections of pavement distress and includes standard descriptions of distress types and the process for defining distress severity and extent. The Ohio DOT PCR system was developed after a review of visual rating systems developed by other agencies (1,6,7).

The PCR system yields a numerical index that reflects composite effects of distress types, severity, and extent on the overall pavement condition. The computation of PCR is based on the summation of deduct points for each type of observable distress. Total deduct points are subtracted from 100 to yield the PCR. The scale used for PCR is shown in Figure 6. A PCR of 100 is assigned to a pavement that has no observable distress. The deduction for each distress type is calculated by multiplying distress weight times the weights for the severity and extent of the distress. Distress weight is the maximum number of deductible points for each different distress type. The PCR is calculated as follows:

$$\mathrm{PCR} = 100 - \sum_{i=1}^{n} \mathrm{deduct}_i \qquad (1)$$

where n is the number of distress types and deduct_i = weight for distress x weight for severity x weight for extent.

Figure 2. PSI deterioration.

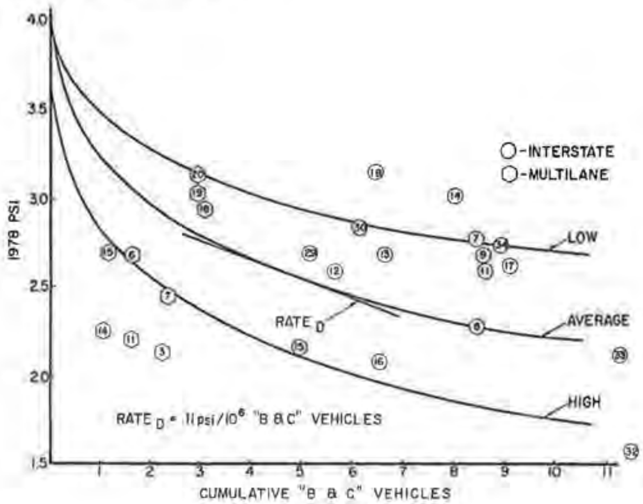
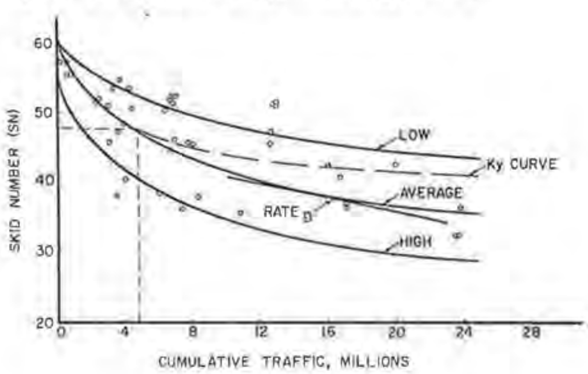


Figure 3. SN deterioration for asphalt-surfaced pavements.



The proposed PCR method developed (5) reflects the judgment of Ohio DOT engineers polled in the study and has been implemented in Ohio. However, as it becomes implemented on a statewide basis, expanded studies will be undertaken to measure test uniformity among PCR raters and to develop necessary adjustments to deduct values.

The Ohio DOT has incorporated a procedure through which the PCR system is used to identify and investigate pavements that may have inadequate load-carrying or structural capacity. Pavement sections that exhibit a certain degree of structural-related distresses and whose overall condition has reached a certain level of deterioration are investigated for structural integrity. The results of various research studies we have done over the past decade allow for the nondestructive evaluation of the structural condition of a pavement. The proposed PMMS program provides an opportunity for implementation of these nondestructive evaluation techniques (8,9). Diagnostic investigation criteria developed

Figure 4. SN deterioration for concrete-surfaced pavements.

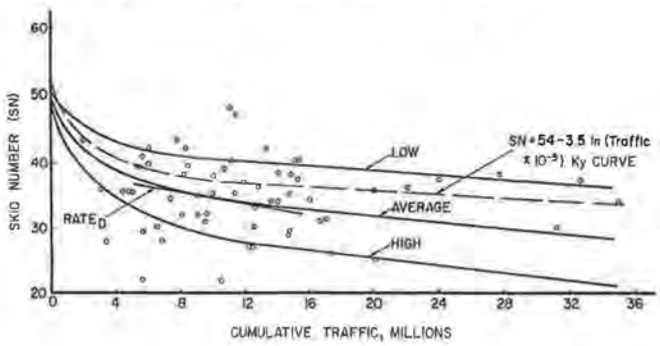
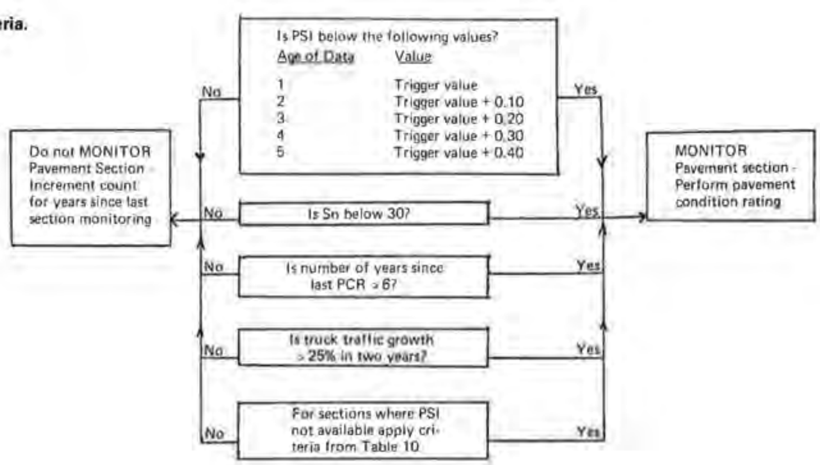


Table 1. Recommended sampling intervals.

Maintenance Classification	PSI	SN
Interstate	Each direction every three years	Each direction every two years
Multilane	Each direction every four years	Each direction every three years
Two-lane		
High type	Alternate directions every four years	Alternate directions every four years
Low type	Alternate directions every five years	Alternate directions every five years

Figure 5. Summary of monitoring criteria.



as part of the Ohio DOT study (5) are given below:

System	Sum of Deduct Points for Structural-Associated Distress	PCR
Interstate	>25	<60
Multilane and high-type, two-lane	>25	<55
Other two-lane	>30	≤50

System for Determining Project Priorities and Selecting Optimal Repair Method

Priority programming is probably the most important aspect of the PMMS. According to the proposed method, maintenance priority is established in terms of the condition parameters roughness (PSI), skid resistance (SN), and distress (PCR). Our research study (5) concluded that pavement distress should be considered most important in the priority system and roughness and skid resistance somewhat less important. Traffic is also considered as another parameter in the priority system. Urban districts generally consider traffic to weigh heavily in priority, whereas rural districts are less concerned about it.

The prioritizing procedures establish a maintenance urgency category (MUC), which is a simple method that simultaneously considers distress, roughness, and skid resistance to establish priority. Figure 7 shows the project prioritization criteria, and Figure 8 shows the determination of MUC. The table below defines the PCR groups:

Group No.	PCR Value	Condition
1	<40	Very poor
2	40-55	Poor
3	56-64	Fair to poor
4	65-74	Fair
5	75-89	Good
6	90-100	Very good

Figure 6. PCR scale.

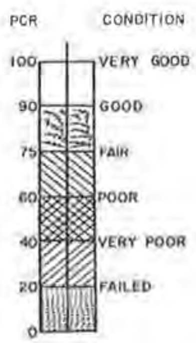
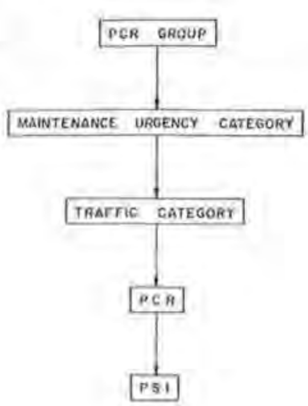


Figure 7. Project prioritization criteria.



For sections within the same MUC category, traffic is used to establish priority. For sections within the same PCR group, MUC, and traffic category, the actual values of PCR and, if necessary, the PSI are used to establish final section priority. The data given in Table 2 illustrate the priority system.

Suggested Data Systems

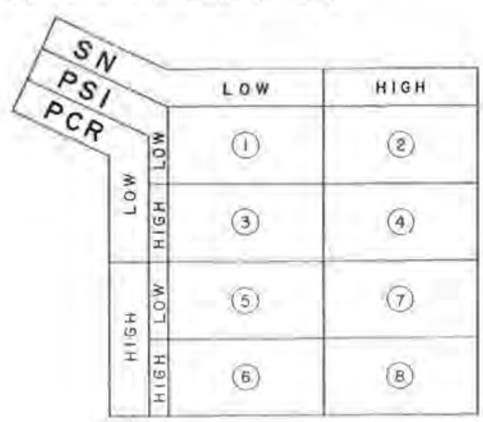
Implementation of both monitoring criteria and the condition rating aspects of a PMMS would require collection and analysis of large amounts of data. New data banks and additional programming efforts may be needed in some states to manipulate these data effectively and fully implement such a PMMS.

Three data files--the pavement section file, the pavement condition file, and the priority maintenance file--can constitute the primary data storage and retrieval program for a PMMS as described here. The pavement section file would contain data on section location, pavement type, traffic, age, and maintenance performed. Much of this information is usually available from current user agency files. The pavement section file would require program logic to create permanent sectioning of the roadway network; the logic should be similar to that currently used by the agency to define sections for skid testing and other purposes. Age of surface and maintenance class would also be contained in this file, which can be updated in the future as records of major maintenance performed are computerized.

The pavement condition file contains the PSI, SN, PCR, and deflection data for each roadway section and also program logic to determine PSI and SN deterioration rates for each section based on general trends. The pavement condition file would contain location data from the pavement section file and all information needed to identify pavement sections for monitoring, determined by using the monitoring criteria presented previously.

One important use of the pavement condition file would be to generate reports to assist maintenance engineers in evaluating repair needs. Such a report might essentially summarize all information col-

Figure 8. Maintenance urgency category.



LEVELS

PCR - Low is below 65 - Interstate
60 - Multilane & high-type two-lane
55 - Low-volume two-lane
PSI - Low is within bottom 10 percentile per maintenance class per pavement type statewide
SN - Low is <30

Rank within PCR group for each maintenance class:

1) Urgency category;
2) Traffic category within same urgency category;
3) PCR within same traffic category;
4) PSI for section with same PCR.

Table 2. Sample priority list for maintenance class 1, Interstate.

Section No.	ADT per Lane	SN	PSI	PCR	PCR Group	MUC	Traffic Category	Ranking
1350	5 000	40	2.5	80	5	8	B	14
1352	9 000	33	1.6	57	3	2	B	3
1354	3 000	53	2.2	69	4	8	C	12
1356	7 500	23	1.6	49	2	1	B	1
1357	2 200	59	2.6	71	4	8	C	13
1359	10 000	28	2.5	72	4	6	A	8
1360	3 500	57	2.5	74	4	8	B	10
1362	5 500	49	2.4	62	3	2	B	4
1364	6 100	29	2.2	68	4	6	B	9
1366	7 200	42	2.5	64	3	4	B	7
1367	4 200	54	2.0	53	2	2	B	2
1369	1 700	36	1.6	60	3	2	C	5
1381	2 900	55	2.2	67	4	8	C	11
1383	12 000	29	2.3	59	3	3	A	6

Note: Assume 10 percent PSI = 2.10.

lected by the maintenance management program about a particular roadway section.

The priority maintenance file would contain a listing of pavement sections and maintenance priorities established in accordance with the system presented previously. Section priorities can be assigned on both a statewide and districtwide basis, and sections should be listed by route so that district engineers can formulate maintenance projects by grouping together continuous sections of similar PCR groups or priority ranges. This file can be easily assembled by taking data from the pavement condition file and computing the priority by using the criteria shown in Figure 6. There should be cumulative mileage calculations for priority listings to enable early identification of total state or district network mileage for each PCR group or any given priority. Such listings should be completed by late fall or early winter of each year and be given to district personnel, together with the recommended trigger value of statewide priority ranking for maintenance planning, so that agency personnel can begin planning maintenance projects for sections that have priorities above the established value.

ACKNOWLEDGMENT

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Prediction of Pavement Maintenance Expenditure by Using a Statistical Cost Function

SUE McNEIL AND CHRIS HENDRICKSON

Effective management and control of pavement maintenance expenditures are becoming increasingly important as the magnitude of these costs increases. The use of a statistical cost function as a means of inexpensively and quickly forecasting the level of pavement maintenance expenditure is described. The statistical cost function predicts the level of real expenditures as a function of (a) traffic levels, measured in equivalent single 18 000-lb axle loads, and (b)