Operation of the Washington State Pavement Management System

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ABSTRACT

The Washington State Pavement Management System (WSPMS), recently developed for Washington State's highway construction program, is described. The pavement management system, using four computer data processing programs, provides state decision makers with prioritization guidelines for administering the state's highways by recommending the most cost-effective strategies for both individual rehabilitation projects and network-level, 6-year programs. Creation of data files, operation of the data processing programs, operation of the rehabilitation optimizing programs, and how Washington State is using them to manage its pavement network are discussed.

Washington State decision makers budget $100 million annually for contract pavement rehabilitation. To help administrators and legislators more efficiently manage such a large investment in the state's pavements, engineers at the Washington State Department of Transportation (WSDOT) have developed the Washington State Pavement Management System (WSPMS).

WSPMS operates as part of the state's highway construction programming process and provides state decision makers with prioritization guidelines for managing the state's pavements. The WSPMS computer data processing programs recommend the most cost-effective strategies for both individual rehabilitation projects and network-level, 6-year programs (1).

The WSPMS computer program produces a list of pavement projects that is used in establishing a priority array, as well as additional information used by all districts to develop their highway construction programs.

The priority array is a list of pavement projects in order of rehabilitation need. The priority array is essentially created on the basis of observed deficiencies and consists of three categories: bridge life expectations, pavement condition, and accident locations.

In Washington, the priority array has been directed by state law. The law requires that WSDOT "establish a policy of priority programming for highway development having as its basis the rational selection of projects according to factual need, systematically scheduled to carry out defined objectives within limits of money and manpower, and fixed in advance with reasonable flexibility to meet changed conditions."

Specifically, the law requires that WSDOT establish a financial plan and objectives for a 6-year program, and that these be stated in terms of highway improvement categories. The law also states that improvement funds shall be allocated for categories in the following order:

- Category A--Improvements necessary to sustain the structural and operating integrity of the non-Interstate highway system.
- Category B--Improvements for the continued development of the Interstate system, funded at the regular Interstate match rate (90 percent federal, 10 percent state).
- Category C--Major improvements on all highway classes other than the Interstate system. This category includes additional lanes, passing lanes, and new interchanges, as well as the replacement of certain major, narrow rural bridges. The prime objective of Category C is to reduce congestion while improving safety.

The law also requires that WSDOT consider the following priorities when selecting projects for Categories A and B:

- Structural ability to carry loads,
- Capacity to move traffic,
- Adequacy of alignment, and
- Accident experience (including fatal accident experience).

For Category C additional consideration must be given to

- Continuity of highway development;
- Coordination with other modes;
- Area planning;
- Social, environmental, and economic impacts;
- Public acceptance of the project;
- Conservation of energy; and
- Feasibility of financing the full project.

In the state of Washington, a predominant portion of effort and funding is spent on Category A projects. In this category the major emphasis and funding are directed toward maintaining the pavement structure.

The WSPMS process operates in four phases, each employing a different computer program:

1. Building a master data file,
2. Interpreting the data file,
3. Running a project-level optimizing program, and
4. Running a network-level program.

Output from the first two programs is used to establish the pavement deficiency portion of the priority array and to provide input used in the second two programs. These next two programs make the evaluations and recommendations that are available for aid in developing the highway construction program. Figure 1 is a conceptual flow chart of these four phases.

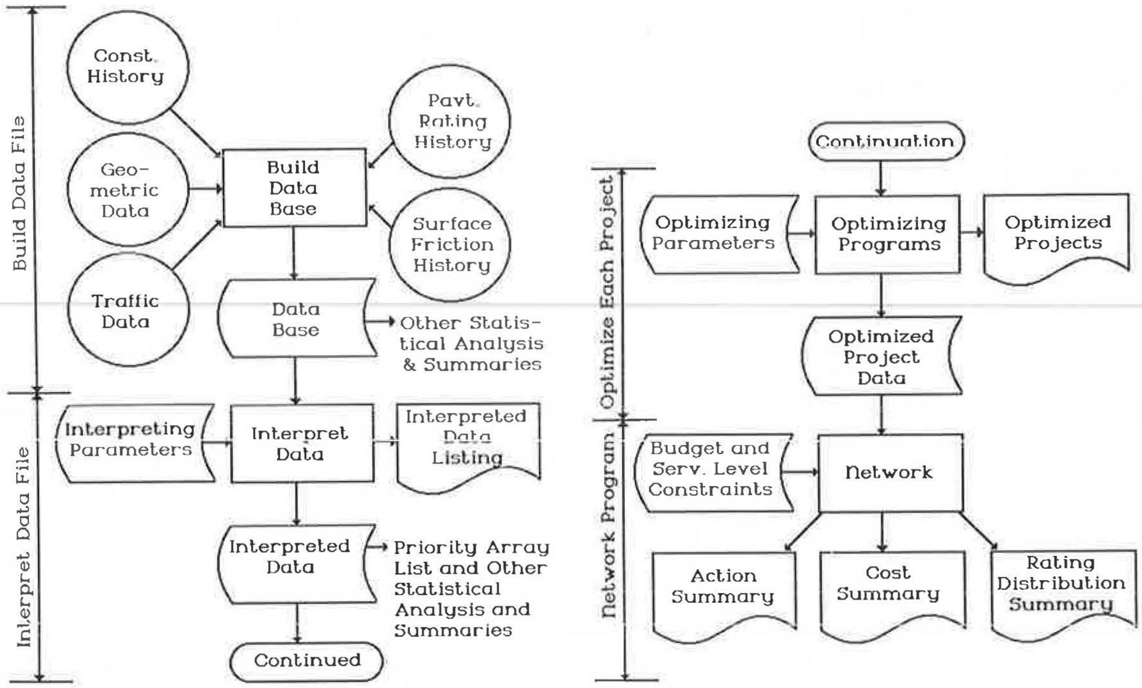

FIGURE 1 Flow chart of four WSPMS phases.

Traditionally, discussions of pavement management systems emphasize project- and network-level programming. These two elements will be discussed first; however, the programs are run in the aforementioned order, and the priority array is used in running the second two programs.

REHABILITATION OPTIMIZING PROGRAMS

Project-Level Optimizing Program

This program uses performance equations produced for the interpreting program, to be described later, to establish the most cost-effective rehabilitation strategy for each project.

Figure 2 is a typical performance curve relating the pavement rating (serviceability) to the age of the pavement. As a pavement ages, its condition gradually deteriorates to a point where some type of rehabilitation should be applied, a state at which distress is showing but might not be severe enough to call for immediate action. Unfortunately, this point is all too often ignored and the pavement continues to deteriorate until something must be done to rehabilitate it. These two points on the performance curve, aptly named the "should" and the "must" levels, define the most probable rehabilitation period. In the event that the "must" level is surpassed without action, maintenance forces are faced with applying temporary fixes until a major remedy can be applied. Temporary fixes tend to retard the rate of deterioration and flatten out the performance curves. However, the application frequency and associated cost of a temporary fix are high compared to the benefit returned.

When rehabilitation treatment is eventually applied, the pavement rating increases abruptly, marking the beginning of a new cycle. During its life, a pavement receives many restorative actions like this, initiating a new performance cycle each time. Obviously many different restorative methods are possible, and each method generates its own performance curve following its application. Not only are many methods possible, but a tremendous number of combinations occur when the timing, sequence, or type of action is changed over an extended period. A rehabilitation strategy is thus defined as a combination of rehabilitation alternatives designated by type, sequence, and application time. Figure 3 illustrates this concept.

The project-level optimizing process analyzes all strategies economically possible within a set time frame, or "consideration period" (Figure 3). Basic

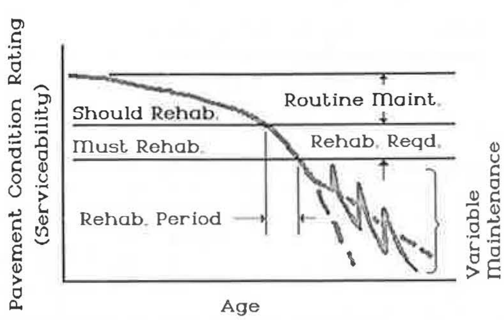

FIGURE 2 Typical performance curve.

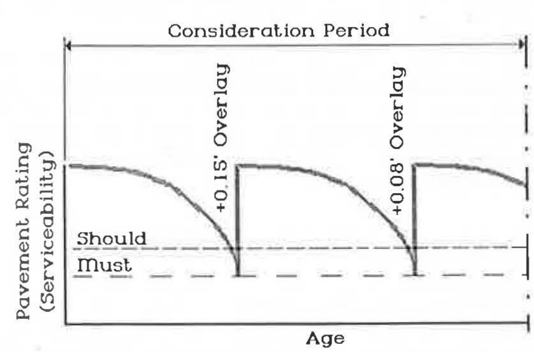

FIGURE 3 Example of a strategy.

to the analysis is the stipulation of a minimum level of serviceability ("must level") to be maintained through the consideration period. All costs associated with each strategy can then be totaled and brought back to present worth for comparison with those of other strategies. The desired strategy is the one with the least total cost. Costs considered include

1. Construction costs of each rehabilitation alternative,
2. Annual routine pavement-related maintenance costs,
3. User-incurred costs related to the condition of the pavement,
4. User-incurred costs related to travel delay during rehabilitation, and
5. Salvage value of the pavement at the end of the consideration period.

Figure 4 is a flow chart that shows the optimizing program's operation and work flow. Each box on the flow chart represents a program subroutine that can be easily replaced or modified as new data become available and expertise in each of these areas is improved.

This program also uses a second data set containing optimizing parameters, as shown in Figure 4. Included are constants and coefficients for the cost models, should and must trigger levels, all considered rehabilitation alternatives, a selection matrix for the array of alternatives to be considered for each project, and the effective interest rate (current interest less current inflation rate) to be used for discounting to present worth.

Output from this program is used in the network-level program to provide a standardized rehabilitation plan for each project. Output for one project is sent to each district, indicating the benefits and consequences of applying rehabilitation alternatives in certain sequences. Also provided are all performance data produced by the interpreting program; all optimizing parameters; a description of the rehabilitation alternatives with performance equations, construction costs, and the amount of time predicted to reach should and must levels after application; and a summary of the best rehabilitation strategies and their itemized costs.

Network-Level Program

The basic function of this program is to establish a network-level, 6-year rehabilitation program based on the optimum strategies determined by the project-level optimizing program. By combining the recommended rehabilitation alternatives with the performance of all project segments on the network, a schedule of anticipated action, cost, and performance can be predicted for a number of years. By applying budget and condition-level constraints for each year, the network program will produce an entire, balanced rehabilitation program. By varying the budget and condition-level constraints and tabulating the results of projected performance, correlations between proposed budgets and pavement conditions can be made.

The network-level program generates three summaries for each year of the proposed program: an action summary, a cost summary, and a rating distribution summary. The program summarizes the performance of existing projects--as analyzed in the interpreting program--and the recommended time of rehabilitation. It can be applied using various program constraints. In Washington's case the program is run using various accumulated mileage constraints. Overall system conditions can then be compared to the accumulated mileage addressed each biennium. WSDOT uses this to help define the accumulated mileage that must be addressed in the priority array to maintain the system's present condition.

Another variation of this run is made for the districts to use in evaluating the long-term effects of various rehabilitation strategies. Alternative runs are made using various rehabilitation strate-

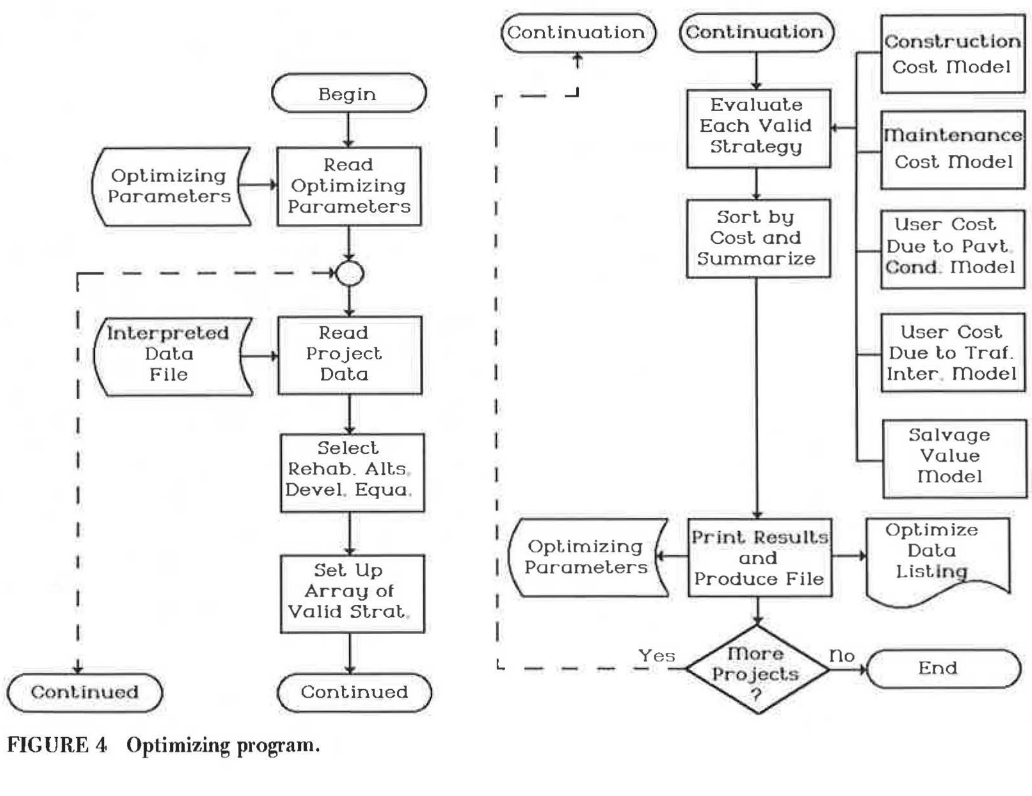

FIGURE 4 Optimizing program.

gies in the operating program. The relative merits of the various strategies can be evaluated on the basis of projected pavement conditions for the total district.

DATA PROCESSING PROGRAMS

Building a Master File

In the system's beginning phase, the data essential for evaluating current pavement conditions and future pavement performance are assembled in a computer to create a master file. The master file combines information from five other existing data files, including roadlife history (construction history), roadway inventory (geometric data), annual traffic file, surface friction file, and pavement condition rating file. These existing files are continually updated or rebuilt every 2 years.

The master file is indexed according to milepost limits of the most recent paving contracts and is used in two ways:

1. To track the progression of distress over the service life of a pavement and
2. As data for the first of three computer programs in the system, the interpreting program.

The process of assembling the master file consists of dividing the highway network into project segments, based on the limits of the most recent pavement surfacing contracts found in the "road life history" file, and then associating data from the other files, one file at a time, with each project. To do this, a hierarchical record structure was designed for three levels: all data related to the project regardless of time or specific location, all data related to generation time, and all data related to both generation time and a specific location within the project.

The primary function to this file, of course, is to relate 2-year pavement condition ratings to specific project limits. These ratings are acquired through a combination of subjective and objective evaluations: subjective, by judging the severity of a pavement distress, and objective, by measuring the actual extent of a distress. These evaluations are performed by two-man teams using a detailed evaluation form, part of which is shown at the top of Figure 5. The ride score is obtained by using a modified PCA Road Meter mounted in a vehicle and measuring rear axle deflections along a pavement profile.

Bituminous Pavement						
Rutting, Pavement Wear	Corrugation, Waves, Sags, Humps	Alligator Cracking	Ravelling or Flushing	Longitudinal Cracking	Transverse Cracking	Patching
n	n	2	n	1	2	1
(0)	(0)	(40)	(0)	(5)	(10)	(15)

Weighting Values

$\Sigma D = 0 + 0 + 40 + 0 + 5 + 10$

FIGURE 5 Example of weighting values assigned to ratings.

Because the master file is based on construction history and the last surfacing contracts, an update necessarily begins with recording all recently completed surfacing contracts. All other files are also updated and the whole process of combining files is repeated to produce a new generation master file.

Interpreting the Data File

The interpreting program translates the raw distress codes contained in the master file into average ratings for each project. This is accomplished by applying weighting values to the extent and severity of each distress category. Regression analysis is then applied to the ratings to match them with performance and a potential rehabilitation date.

The output from the interpreting program consists of the following information for each project:

1. Tabulated summary of performance history,
2. Summary of traffic information for the project,
3. Constants for the performance equation with related statistical data, and
4. Plot of average ratings with high and low ratings for each survey year shown and the performance curve fitted to the points.

The interpreting program also generates a new data processing file that contains all of this information on a project-by-project basis. This file is used both to study the correlation between other parameters--such as design mixes, environmental effects, or traffic characteristics--with trends in pavement performance, and as input to the third major program in the system, the project-level optimizing program.

The interpreting program analyzes the data in the master file on a project-by-project basis so that both the limits of the last paving project and major changes in pavement ratings apparent in the master file are considered. The raw coded data, including severity and extent of each distress type, are then translated into combined ratings. These combined ratings are calculated with the following equation:

$$\text{Rating} = (100 - \Sigma D)\ [1.0 - 0.3\ (\text{CPM}/5000)^2]$$

or

$$\text{Rating} = (\text{Pavement rating})\ (\text{Ride rating})$$

In this equation, ΣD represents the sum of weighted values for all distress categories as shown in Figure 5, and CPM represents the rating section's counts per mile acquired with the ride meter. Because the ratings are acquired for each mile of the system and project limits occur at odd mileposts, the mean combined rating for each project is computed using length as a weighting factor.

By plotting the history of combined mean ratings for each paving project, the progression of pavement deterioration is tracked over time and projected into the future. The interpreting program accomplished this by using three different methods of producing performance equations:

1. When the project being considered does not have at least three ratings, a typical equation for the pavement type, surfacing depth, and geographic area is assigned. This is justifiable because the

pavement is relatively new and should not need rehabilitation for some time. The equation generated is used primarily in network analysis. Should the project have only two ratings, with the second rating falling beyond that allowed in the typical equation, the performance equation is modified to reflect that rating.

2. Regression analysis is applied to all projects that have at least three ratings. This is the basic approach to fitting performance equations.

3. When regression analysis does not produce a reasonably good fit (R^2 value less than minimum acceptable), a "typical" curve is fitted through the first and last values.

These three methods of developing performance equations are applied in the interpreting program as an algorithm for automation that can be considered a general rule with many exceptions. They do not always produce well-fitting curves with reasonable equations.

To ensure that the performance curves and equations for each project are reasonable and represent the best pavement condition forecast, each project's plotted ratings with fitted curves are carefully reviewed one at a time. The type, thickness, and date of last surfacing are noted and inspection of the curve shape, fit, and time to failure are studied. Most projects demonstrate reasonable curve fit as analyzed by the interpreting program. Those that do not fit well (usually caused by a random fluctuation in ratings) are reviewed in detail in the master file. Trends in distress are inspected carefully and engineering judgment is used to provide a performance equation for predicting pavement ratings as well as the type of rehabilitation necessary. It is important to note that the equation provided with this approach is intended only to forecast ratings and may not precisely fit past ratings.

Figure 6 shows the model relating pavement rating (serviceability) to age that is used in the interpreting program. The general form of the adapted performance equation is

$$R = C - mA^B$$

where C usually approximates 100; R and A represent rating and age, respectively; m is a coefficient controlling the slope of the curve; and B is an exponent that controls the degree of curvature.

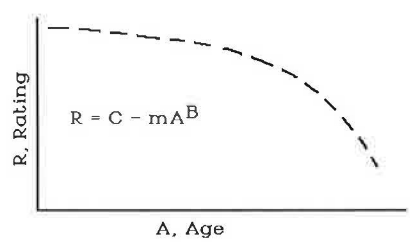

FIGURE 6 Pavement rating model.

Figure 7 is an example of the different shapes the curve might assume. Curves 1 and 2 are linear and demonstrate the influence of the slope (m). Curves 2, 3, and 4 demonstrate the control that B exerts on the degree of curvature. Note that exponents greater than one indicate curvature increasing from the horizontal, and exponents less than one indicate curvature increasing from the vertical.

In using regression analysis to fit the best curve with the acquired ratings, the program substitutes a number of different exponents (B) in order

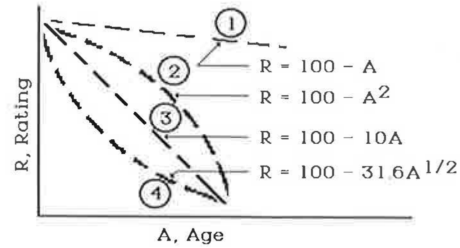

FIGURE 7 Curves generated from pavement rating model.

to transform the independent variable, age. The best fit is determined by the highest R^2 value (coefficient of determination). Statistics generated with the performance equation are the R^2 value and the standard error of estimate.

Figure 8 is an example of the interpreted data listing that is dedicated to the plot of ratings since the last surfacing activity. This plot also shows the performance curve fitted to the ratings and indicates the range of ratings for each generation by plotting the high and low values.

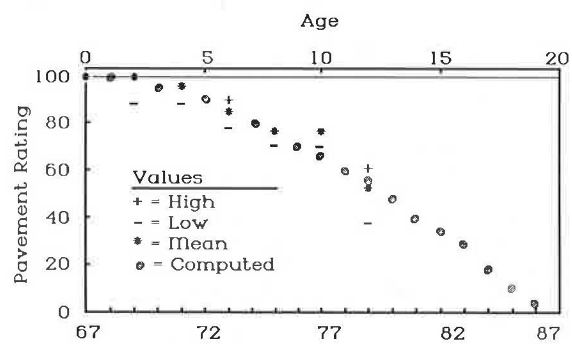

FIGURE 8 Example of performance listing.

From these listings a computer program computes the projected pavement condition rating to the middle of the next operating program's biennium and ranks the individual projects by functional class, pavement type, and district. This ranked list of projects is then used to define pavement conditions for the priority array on the basis of deficiency. It is the official document for that purpose.

REPORTS AVAILABLE FROM WSPMS PROGRAMS

The reports developed from execution of WSPMS's four phases are described next.

- Master index file. This file contains data related to roadlife history, roadway inventory, and traffic for each project identified from the most recent paving contracts.
- Master file. For each project identified in the master index file, the master file contains pavement condition ratings for each generation year and each mile in the project.
- Pavement condition summary. This output lists the pavement condition data from the last condition survey with project length summaries.
- Interpreting program output. This output contains a summary of the performance history; traffic data; the form of the performance equation; and a plot of the performance equation with high, average,

and low values shown. This information is produced for each project in the master file.

• Priority-ranked project list. This output lists specific projects ranked from worst to best by district, pavement type, and functional class.

• Summaries of rating distributions. These are summaries of the distribution of pavement condition ratings and distress types by districts and by functional classes, and are produced for each pavement type. Statewide distributions of rating and distress types are also summarized by functional classification and by district.

• Summaries of ratings by generation. These summaries list raw pavement ratings and the translated score for each consecutive mile along a route for one generation of survey data.

• Optimizing program output. For each project, the output of the optimizing program summarizes the economic evaluation of alternative rehabilitation strategies. The following parts are contained in the output:

a. Project description and performance history;

b. Performance standards in terms of should and must levels (i.e., pavement condition when some type of rehabilitation should be applied and pavement condition when something must be done to rehabilitate it);

c. Description of rehabilitation alternatives and their performance equations; and

d. Ranking of rehabilitation strategies based on total life-cycle costs.

• Network action summary. For each project, the proposed rehabilitation action and its cost are listed for each year of a 6-year maintenance program. The projects are listed by district.

• Network cost summary. For each year, the number of miles that are rehabilitated and the cost are listed by functional class for each district, as well as for the whole state.

• Network rating distribution summary. This summary lists the number of miles present in different pavement condition rating groups before and after the completion of all proposed actions for each year. This summary is produced for each district as well as for the whole state.

FUTURE DIRECTION

The Washington State Pavement Management System is now complete enough to provide the input necessary for the WSDOT construction programming process. A system of this type obviously has potential for application to other levels of state government as well as to project-specific pavement performance data for a variety of current research needs.

The Washington State Department of Transportation has contracted with Washington's Thurston County and a private consultant to evaluate the feasibility of adopting WSPMS for use by Washington's counties. A recently published study (2) reports that "it will be feasible and desirable to adopt and operate the WSPMS so as to assist the Washington counties in improving the process of pavement management." Phase 2 of this project, a trial of WSPMS by two counties, is just beginning. If this trial implementation is successful, engineers will most likely develop an operational procedure so that WSPMS will be functional at all levels of state government.

Because a project-specific program such as WSPMS offers so many advantages, WSDOT plans additional study in the area of pavement performance. Specifically, engineers will soon study the effects of construction variables, the environment, and traffic load on pavement performance. They will use the findings from these studies to further refine the input data for WSPMS as well as to provide important performance data for pavement rehabilitation design procedures and construction specifications and procedures.

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