THE WSDOT PAVEMENT MANAGEMENT SYSTEM – A 1993 UPDATE

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Pavement Management Systems Modification — Phase I

THE WSDOT PAVEMENT MANAGEMENT SYSTEM — A 1993 UPDATE

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16. ABSTRACT

This first report documents some of the more fundamental features of the Washington State Pavement Management System (WSPMS). Included is an overview of pavement management principals. Recent additions to the WSPMS include the rehabilitation scoping technique and revised pavement rating scores. These are documented in the report.

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SECTION 1.0

INTRODUCTION

1.1 WHY AN UPDATE?

Since the original project reports were prepared [1.1, 1.2], the Washington State Pavement Management System (WSPMS) has continued to evolve. This report will provide a current review of WSPMS along with helpful background information on Pavement Management Systems (PMS) in general.

The report is not intended to be computer program documentation. The report was prepared primarily for WSDOT district and headquarters personnel.

1.2 REPORT ORGANIZATION

Section 2.0 will provide a brief overview of PMS (mostly based on guidelines developed by AASHTO), Section 3.0 an overview of the WSPMS file structure and performance equation concept, Section 4.0 typical results from the WSPMS and Section 5.0 a brief summary. The report contains six appendices which "stand alone." These are

- Appendix A: Contains documentation on the rehabilitation project scoping technique contained in the WSPMS (developed during the conduct of this study).
- Appendix B: Contains background information requested by District personnel about pavement prediction models (performance curves).
- Appendix C: Contains the significant state legislation which mandates priority programming (hence the original primary need for the WSPMS).
- Appendix D: Contains the most recent version of the FHWA Pavement Policy which includes the national mandate for PMS.
- Appendix E: Contains the documentation on calculation of pavement condition indices (these were substantially modified during this study).
- Appendix F: Contains summaries of interviews conducted in each District relative to pros and cons of the then current WSPMS and recommended changes.

SECTION 2.0

OVERVIEW OF PAVEMENT MANAGEMENT SYSTEMS

2.1 AASHTO GUIDELINES

The "AASHTO Guidelines for Pavement Management Systems" [2.1] were published in July 1990. That document reflects the current, broad aspects of what a PMS should be and can do. As such, it will be helpful to briefly overview a few of the more significant features of those guidelines.

2.2 FEDERAL PMS REQUIREMENTS

FHWA rulemaking resulted in a document (contained in Appendix D) which states policy toward PMS. From 23 CFR Part 626 Paragraph 626.5 "Policy", it is stated that:

(a) each SHA will have a pavement management system acceptable to the FHWA,

(b) these PMS's will be based on the concepts of the AASHTO PMS Guidelines (see paragraph 2.1 above),

(c) the SHA PMS's shall be used for Rural Arterial routes under their jurisdiction (urban arterials are desirable but not required),

(d) the use of pavement management systems for local jurisdictions and their associated route systems are desirable, and

(e) each SHA PMS shall be operational no later than January 13, 1993.

WSDOT was the first SHA to have a functional, operational PMS in the United States. Thus, meeting the federal rules should not be difficult.

2.3 PMS DEFINITIONS

The Federal Highway Administration (FHWA) developed a clear definition of a PMS [2.2]:

"A set of tools or methods that can assist decision-makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition."

This definition fits well the WSPMS as developed and used today.

Another description of a PMS [2.1] "... is that it will help make cost-effective decisions relative to what, where, and when. What treatment is most cost-effective, where treatments are needed, and when is the best time (condition) to program a treatment." As will be shown in this report, the WSPMS does all three in the following manner:

(a) What: Rehabilitation needs in terms of the amount of equivalent asphalt concrete overlay.

(b) Where: The selection of the pavement segments for rehabilitation is based on Pavement Structural Condition (PSC).

(c) When: The determination of when to rehabilitate a specific pavement segment is based on a PSC - Age performance curve (equation actually).

2.4 GENERIC PAVEMENT MANAGEMENT SYSTEM

From AASHTO [2.1]:

"A Pavement Management System is designed to provide objective information and useful data for analysis so that highway managers can make more consistent, cost-effective, and defensible decisions related to the preservation of a pavement network. While a PMS cannot make final decisions, a PMS can provide the basis for an informed understanding of the possible consequences of alternative policies.

Two major levels of pavement management decisions should be included in a PMS; network and project. Network level decisions are concerned with programmatic and policy issues for an entire network. Project level decisions address engineering and technical aspects of pavement management, i.e., the selection of site-specific ... actions for individual projects and groups of projects."

PMS's are composed of separate but related functions. Typical functional areas which comprise a PMS include:

(a) Database,

(b) Analysis methods, and

(c) Feedback process.

2.4.1 Databases

The database is fundamental to any PMS — without it one does not have a system. Some of the categories of data in a PMS database include:

(a) Inventory

(b) Pavement condition,

(c) Construction and rehabilitation histories (preferably maintenance histories as well),

(d) Traffic, and

(e) Cost data.

Optional categories could include information on:

(a) Materials,

(b) Accidents, and

(c) Geometrics.

2.4.2 Analysis Methods

The various analysis methods which have been used in pavement management systems can be grouped into three categories as follows (after AASHTO [2.1]):

(a) Pavement condition analysis,

(b) Priority assessment models, and

(c) Optimization models.

Each of these will be briefly discussed.

2.4.2.1 Pavement Condition Analysis

From AASHTO [2.1]:

"This method of analysis combines the pavement condition data for individual distress types, with or without roughness, into a score or index representing the overall pavement condition. The pavement condition score is generally expressed on a scale of 0 to 100, with 100 representing the best pavement condition and 0 representing the worst pavement condition. Alternate methods can be used to develop a combined index or score; however, the 0 to 100 scale is the most prevalent. The calculation of pavement condition score requires an assessment of weighting factors for different combinations of the severity and extent of each distress type. A combined index has several useful applications:

(a) as a relatively simple way to communicate the health of the system to upper management, planners and legislators,

(b) as one factor (or the only factor) in a priority rating scheme, and

(c) as a technique for estimating average costs to maintain, rehabilitate, or reconstruct a candidate project; e.g., pavements with condition score of 50 will, on average, require x dollars to repair.

The outputs from this module can include:

(a) ranking of all pavement segments according to types of distress and condition scores as a function of traffic or road classification,

(b) identification of maintenance, rehabilitation and reconstruction (MR&R) strategies, which define a set of criteria (e.g., combinations of different distress levels and traffic) for assigning a particular action to each pavement segment, and

(c) estimates of funding needs for the selected treatments.

The outputs are indicative of current needs based on current conditions. A prediction model is not necessary for this module; however, multi-year strategies and costs are not available from such systems unless assumptions are made regarding rates of deterioration and associated costs."

2.4.2.2 Priority Assessment Models

From AASHTO [2.1]:

"This analysis method uses a "bottom up" approach in which optimal MR&R strategies for individual projects are first determined based on life cycle costs over an analysis period of 20-30 years or at least one major rehabilitation treatment. Projects can then be prioritized, at the network level, using a variety of methods. The benefit/cost ratio and measure of cost effectiveness are the two most prevalent ways to prioritize;

however, alternate schemes are possible. The project-level analysis includes models to predict pavement conditions as a function of such variables as age, present pavement condition, traffic, environment, performance history, and the treatment selected. Alternative strategies, including current and future actions, are evaluated for each segment and compared based on life-cycle costing analysis, and the strategy with the highest priority over an analysis period is identified.

The output of this analysis method can include:

(a) a prioritized listing of projects requiring maintenance, rehabilitation or reconstruction,

(b) costs for MR&R treatments,

(c) estimates of funding needs in order to achieve specified network performance standards, and

(d) single-year and multi-year programs which identify segments recommended for maintenance rehabilitation or reconstruction, and the type, timing and cost of recommended treatments."

2.4.2.3 Optimization Models

From AASHTO [2.1]:

"The optimization models provide the capability for a simultaneous evaluation of an entire pavement network. The objective is to identify the network MR&R strategies which maximize the total network benefits (or performance) or minimize total network costs subject to such network-level constraints as available budget and desired performance standards. A network MR&R strategy defines the optimal treatment for each possible combination of performance variables such as: roughness, physical distress, traffic, environment, and functional class. This is a "top down" approach in which optimal network strategies are first determined and specific treatments for individual projects are then identified considering site-specific conditions and administrative policies.

Techniques of optimization, although somewhat new to highway engineers, have been used extensively in business decisions and are described in proceedings of the North

American Conferences on Pavement Management. Optimization models in a PMS are desired to analyze various management strategies and tradeoffs at the network level. For example, given a fixed network budget, should extensive and often expensive, treatments be applied on a smaller portion of the network, or should moderate, less expensive treatments be applied on a larger portion of the network?

The outputs from optimization models are essentially the same as those obtained from the prioritizing model with some variations. For example, the optimization model does not identify segment priorities; instead, it identifies an optimally balanced MR&R program for an entire network to meet specified budget and policy constraints."

2.3.2.4 Feedback Process

From AASHTO [2.1]:

"Pavement management systems, similar to any other engineering tool, must be reliable in order to be credible. The feedback process is crucial to verify and improve the reliability of a PMS.

If significant discrepancies are found between actual data and PMS projections, relevant PMS models and parameters should be revised appropriately."

SECTION 3.0

WASHINGTON STATE PAVEMENT MANAGEMENT SYSTEM*

3.1 BACKGROUND

The Washington State Department of Transportation (WSDOT) has had in operation through most of the 1980s a pavement management program referred to as the Washington State Pavement Management System (WSPMS). The WSPMS grew out of an earlier priority programming process mandated by the Washington State Legislature (Revised Code of Washington (RCW), Title 47.05, The Priority Programming Act — refer to Appendix C, which contains a "copy" of the act).

To satisfy the RCW, a priority programming process was developed in the mid 1960s that included a system wide pavement condition survey. Thus, a pavement condition survey has been conducted on 100 percent of the state highway system every two years since 1969 (condition surveys are currently done annually).

In the late 1970s the WSPMS was developed within the WSDOT Materials Laboratory and subsequently implemented during the 1982 programming cycle. As WSPMS was developed in-house, WSDOT personnel have had the capability to upgrade and modify the software. Specifically, the original programs were improved during and after every programming cycle (every two years). In 1988, WSPMS computer programs were completely revised to fit newly developed mainframe file systems, take full advantage of personal computers and a local area network now available in the Materials Laboratory, and to better automate the WSPMS process.

Even with this evolution, however, the major functional aspects of the WSPMS has remained reasonably close to that documented in the original research report prepared by Nelson and LeClerc [3.1].

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*Portions of this section of the report were taken (or modified from) References 3.1, 3.2, 3.3, and 3.4.

3.2 WSDOT PMS STRUCTURE

3.2.1 Functional Aspects

There are four basic components of the WSPMS:

(a) file building
(b) interpreting program
(c) project level analysis
(d) network level analysis

3.2.2 File Building

The current computerized portion of the WSPMS now resides in several related, specialized, data files that are recreated from scratch each time an updated version is required.

The sources from which the WSPMS files are created include large data bases which are maintained by groups within WSDOT other than pavement management personnel. Specialized programs interrogate the mainframe data bases and capture information which is pertinent to pavement management needs.

The information captured includes roadway milepost equations, roadway configurations, pavement construction history, traffic data, and the current six-year construction (rehabilitation/major maintenance/new construction) schedule. Other PMS-specific data such as friction, ride and surface distress defects are gathered and maintained by pavement management staff using PCs and a local area network with direct access to the Department's mainframe computer.

The "Schematic File" is a small, but critical, file that is used to validate or confirm the existence of specific roadway locations. It serves as the reference for all milepost computations and comparisons, as well as documenting the existence of parallel lanes and other unique highway configurations.

The "Analysis Unit File" is a large file (11,000 records) that contains the detail information about each highway segment. Each record contains jurisdictional information, roadway configuration, and pavement type and thickness history for the most recent six layers.

The "Currently Planned Construction Program File" is created by a program that accesses one of the mainframe data bases and identifies planned projects.

A special "Multiyear Survey File" is maintained by WSPMS staff that contains the pavement condition survey data in its raw form for all surveys. The file currently contains 16 separate surveys dating from 1969 through 1993. As new surveys are completed, they will be added to this file. Location references for the whole file are maintained to ensure consistency with the configuration of the highway network and that all historic surveys are adjusted in the same manner. Maintaining the integrity of the locations of each generation of condition data is mandatory if the WSPMS is expected to function reliably!

The "PMS Projects File" establishes project beginning and end points. Data from the Schematic, Analysis Units, and Currently Planned Construction Files are used to create the PMS Projects File. This file is used for prioritizing and other references to project specific information.

3.2.3 Interpreting Program

The interpreting program takes the large array of data stored in the various data files and develops project specific performance information (pavement condition) related to time for over 3,200 project sections statewide (as of 1993). It is this feature that is unique to the WSPMS and is the most basic output of the system.

It is within the interpreting program that the pavement rating scores are calculated. Previously, an overall pavement segment rating was presented in terms of Pavement Condition Rating (PCR). The details of both the prior and current condition rating schemes are presented in Appendix E.

The primary distress type used in calculating both flexible and rigid pavement Pavement Structural Condition (PSC) is cracking (fatigue cracking for flexible pavements and slab cracking for rigid pavements). It may be interesting to note that several different pavement distress manifestations could have been used in the same manner as cracking.

Any pavement distress that is time dependent, such as rutting, roughness, etc., could have been treated in the same manner as WSPMS treats cracking. Those distresses could be tracked with time with projections to some unacceptable level being the basis for programming specific projects in a project specific pavement management system.

The WSPMS was developed giving careful consideration to why, where, and how pavement rehabilitation projects should be programmed. In Washington state, flexible pavements are placed in the rehabilitation program largely due to fatigue cracking. On the state highway system, few if any roads are so rough or rutted they take priority over the cracked pavements. If the state highway system was in poorer condition, then WSDOT would probably be forced to prioritize the projects on the roughest of the cracked roads. For fatigue cracked flexible pavements in Washington state's climate, it is clearly more efficient to rehabilitate pavements early in the first stages of fatigue cracking rather than later. WSDOT does not currently place a large emphasis on flexible pavement roughness in its PMS because programming pavement rehabilitation based on ride would eliminate many of the more efficient rehabilitation options available with early cracking determination and appropriate treatments, i.e., taking care of early flexible pavement distress such as cracking also "takes care" of roughness.

With the continued improvement in roughness and rut depth measuring equipment, WSDOT is looking toward better managing rutting in ACP projects and faulting in PCCP projects. This will be done by modifying existing PMS programs to follow these defects with time and predict when specific projects reach some unacceptable level (thus competing with cracked pavements when needed).

3.2.4 Project Level Analysis

In the original WSPMS version the project level optimizing program determined the optimum rehabilitation strategy for each specific project developed in the interpreting program. The optimizing program computed life cycle costs for an array of rehabilitation strategies for each project and ranked the output in order of life cycle costs for each project. Though this program worked reasonably well, it did not have much effect on WSDOT's decision making process. With the existing priority array process and a reasonably funded rehabilitation program, projects have been identified early in the pavement deterioration cycle so that most of the rehabilitation needs are relatively thin overlays, exactly what the optimizing program recommends. Where thicker structural overlays are indicated, additional design information is needed to analyze the project. At the present time, the project level analysis is accomplished by considerable interaction between the district program development offices, the district materials staff, and the Headquarters PMS office.

Through extensive PMS experience, it has become quite clear that the process is greatly enhanced by making as much project level information as possible available to all parties during the programming period. To this end a user friendly software package along with all of the PMS files is supplied to WSDOT managers and designers for day-to-day reference.

3.2.5 Network Level Analysis

Network level analysis has always been performed as a natural extension of the project level analysis programs in the WSPMS. When the WSPMS was first developed, the network level analysis programs consisted simply of iterating runs of the project level analysis data, given different pavement condition cutoffs or funding level constraints. Operationally, it has been found that these network programs were used only a few times for actual program studies. In both cases the exercises confirmed the level of funding already determined by funding policies.

Over the last few years WSDOT has been working towards network analysis processes that help optimize project selection within each district (to deliver the best overall pavement condition over time for fixed funding levels). WSDOT's project specific system works well enough that there is very little disagreement between the district and WSDOT Headquarters as to project definition. The most difficult programming decisions come in setting the proper timing of the projects and the level of rehabilitation to achieve the best system condition for the overall funding level.

Though WSDOT developed pavement management before most other state highway agencies (SHAs) as a result of the Priority Array Law, the agency is somewhat constrained by the interpretation of that law to do "worst first" (however, 1993 state legislation may change this somewhat). These constraints have been minimized through detailed interaction with the Districts as they develop their program. The final District programs result from many decisions, which include delaying some projects, starting others early, spending less on some and more on others depending on corridor needs as well as sizing and grouping projects (aids in efficient contracting as well as managing WSDOT's work forces).

To help better understand the impact of these decisions by looking at past trends, WSDOT has developed comprehensive summary programs. These programs are used with commercial software packages to present the information in graphical form so it can be more easily understood. The graphics are limited only by the contents of the WSPMS files and the imagination of pavement managers. Demonstrative history graphics, such as past pavement condition by pavement type, location, or functional class over time, are easily developed.

A "scenario" program has been developed that allows pavement managers to predict future conditions under various circumstances. "What if" exercises can be run into future years given changes in mileage, budget and other constraints. The results of these exercises are converted to graphics that can be understood more easily by people not familiar with the magnitudes or nuances of pavement strategies.

The flexibility of the WSPMS file structures combined with the "do-it-yourself" philosophy of pavement managers serve this dynamic environment well. Special studies and research efforts are supported using specialized, home-grown software with the

WSPMS files. There are no "black boxes." The system is managed by engineers who understand and control the details.

3.3 WSPMS PERFORMANCE EQUATIONS

3.3.1 The Basic Equation Form

Early in the development of the WSPMS, it became apparent that a step should be provided to analyze the performance of each project prior to any consideration of rehabilitation alternatives. A major objective in the development of this system was to achieve a predictive capability — something that could only be accomplished with a combined rating. Without overlooking the importance of specific types of distress, some type of combined rating was necessary to rank projects and provide a pavement condition rating versus age relationship so that time to failure might be predicted.

With this method, raw coded data indicating severity and extent of each distress type are maintained in the Multiyear Survey File. These data are then translated into a combined rating in the interpreting phase, giving this system flexibility and the utility of an analytical tool. This is an asset in calibrating weighting values for the types of distress rated, or studying any combination of distress types since weighting values can be zeroed for no influence.

An additional aspect of the interpreting phase is the potential for statistical analysis of performance trends. Since the interpreting program generates a file of performance data related to project segments, the results can be analyzed with statistical software packages. Topics of particular interest might include correlation of pavement performance to specific measures of construction quality, geographic location, pavement type, rehabilitation type, or even a specific version of construction specifications.

As previously stated, another feature of the interpreting function of WSPMS is to produce a performance curve that best represents a specific pavement's anticipated performance. Further, the performance curve can be used to predict future performance for the pavement section.

Figure 3.1 illustrates the general shape of a WSPMS performance curve. From this illustration it is seen that a pavement deteriorates with age, the rate usually increasing each year, until it reaches a state of slower deterioration. This decelerated rate of deterioration can be attributed to application of temporary fixes to hold the pavement together until a major remedy can be applied. These temporary fixes tend to cause short duration, random fluctuations in the pavement rating — probably best represented by a curve that passes through the mean value in this phase. The performance model developed for use in the interpreting program presently ignores the maintenance or temporary fix influence because it is assumed that WSDOT will initiate action prior to reaching the lower portion of the curves. A contemplated improvement in the future is to enhance the performance model by incorporating better representation in the lower range.

Figure 3.2 is an illustration of this model relating pavement condition rating to age. The general form of the performance equation adapted is

$$PSC = C - mA^P$$

where

PSC = Pavement Structural Condition rating,

A = Age which represents the time since construction or the last resurfacing (years),

C = model constant for maximum rating (~ 100),

m = slope coefficient, and

P = "selected" constant that controls the degree of curvature of the performance curve.

Figure 3.3 is an example of different shapes the curve might assume. Curves 1 and 2 are linear and demonstrate the influence of the slope, m. Curves 3, 4, 5, and 6 demonstrate the control that P exerts on the degree of curvature. Note that exponents greater than 1 indicate convex curvature, while exponents less than 1 indicate concave curvature.

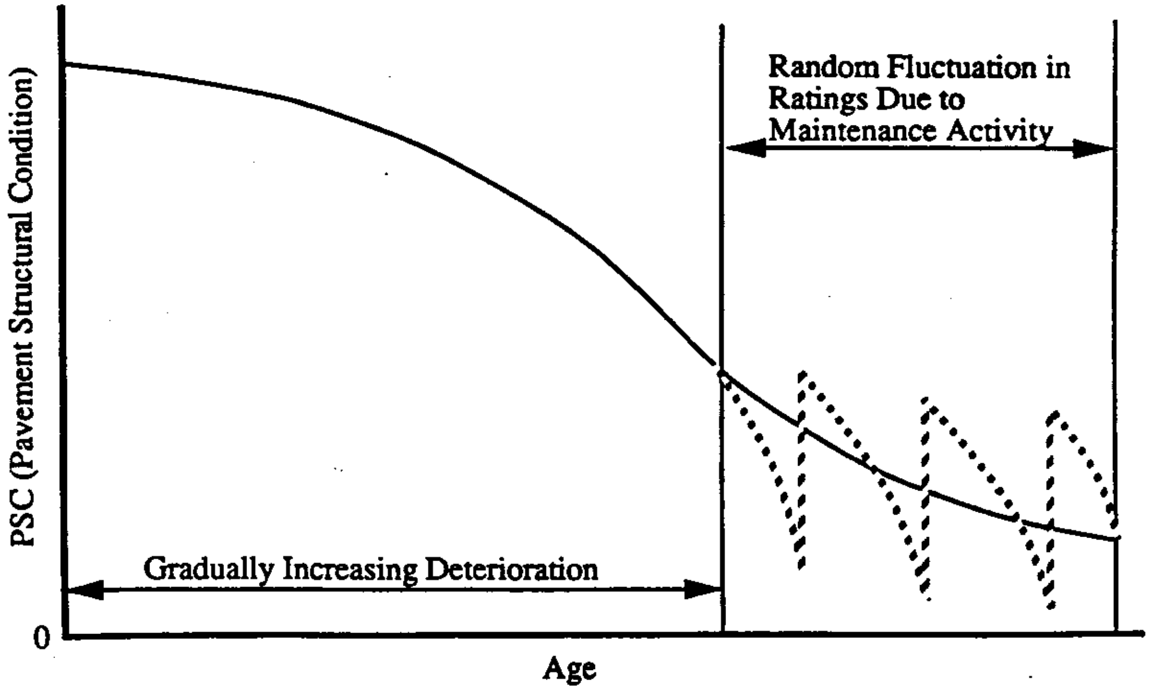

Figure 3.1. Typical Performance Curve

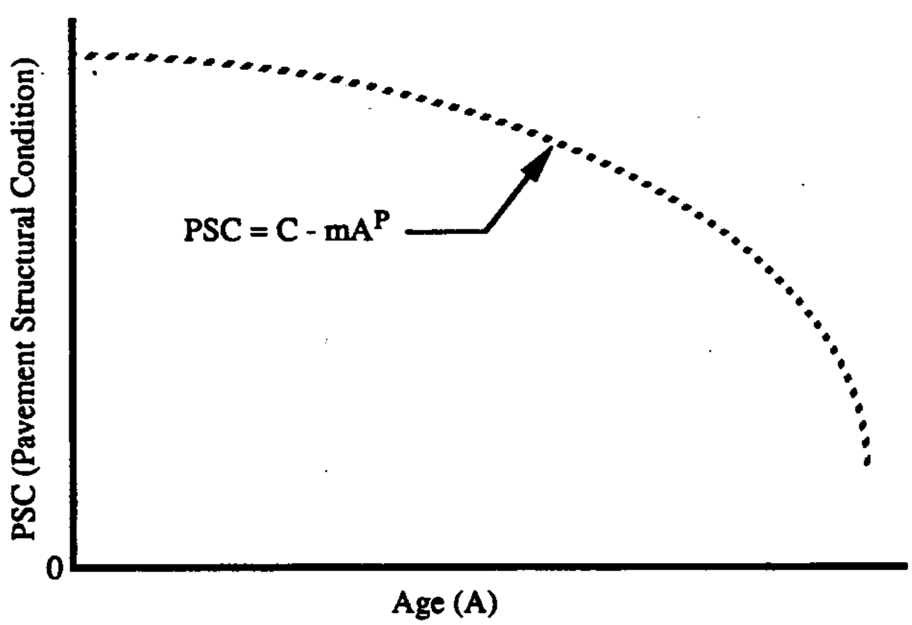

Figure 3.2. WSPMS Performance Curve Model

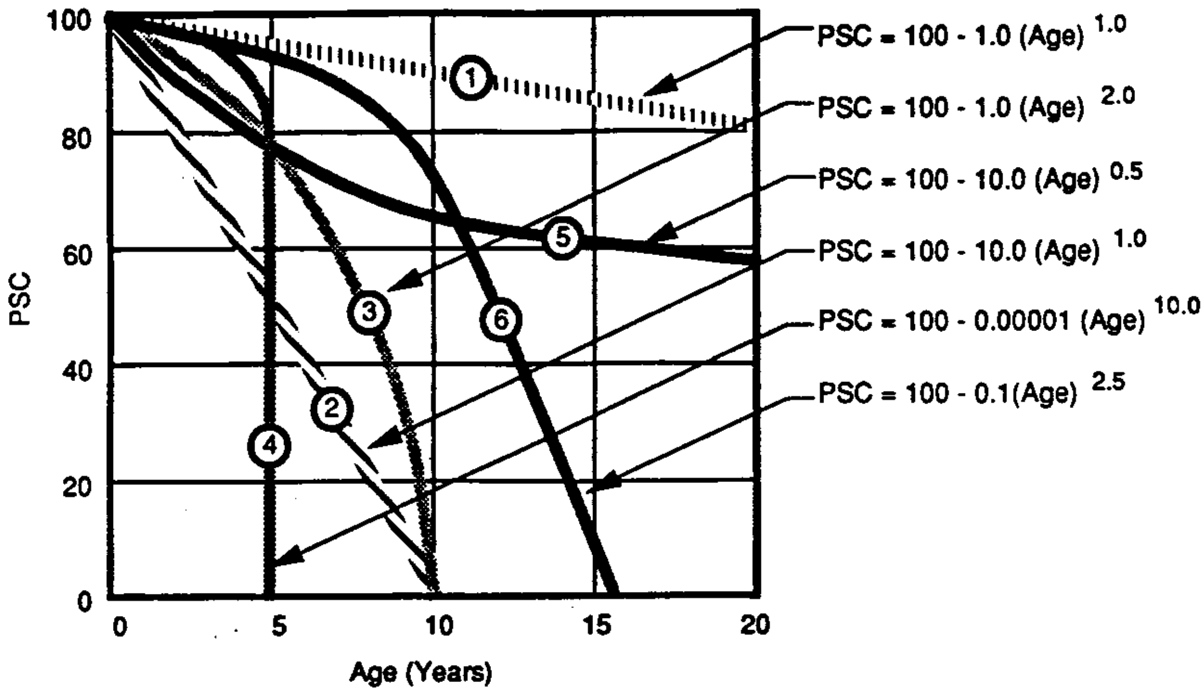

Figure 3.3. Examples of WSPMS Performance Model Curves Shapes

The plots shown in Figure 3.3 were developed using the following basic equation:

$$PSC = C - m\,(Age)^{P}$$

Different values of C, m, and P were selected to illustrate the various shapes the resulting equation can produce. Specifically, the following values were used:

Equation	C	m	P
1	100	1.0	1.0
2	100	10.0	1.0
3	100	1.0	2.0
4	100	0.00001	10.0
5	100	10.0	0.5
6	100	0.1	2.5

The above produces the following results for typical values of pavement age:

	PSC	Age (years)
Equation 1: $PSC = 100 - 1.0\,(Age)^{1.0}$	100	0
	95	5
	90	10
	85	15
	80	20
	PSC	Age (years)
Equation 2: $PSC = 100 - 10.0\,(Age)^{1.0}$	100	0
	50	5
	0	10
	PSC	Age (years)
Equation 3: $PSC = 100 - 1.0\,(Age)^{2.0}$	100	0
	94	2.5
	75	5
	44	7.5
	0	10
	PSC	Age (years)
Equation 4: $PSC = 100 - 0.00001\,(Age)^{10.0}$	100	0
	90	4
	2	5
	PSC	Age (years)
Equation 5: $PSC = 100 - 10.0\,(Age)^{0.5}$	100	0
	84	2.5
	78	5
	68	10
	61	15
	55	20

Equation	PSC	Age (years)
Equation 6: $PSC = 100 - 0.1\ (Age)^{2.5}$	100 94 68 13	0 5 10 15

Equation 6 is more typical of the performance of a thin asphalt concrete overlay.

In fitting the best curve to the pavement ratings, the program substitutes a number of different exponents (P) to transform the independent variable, age. The best fit is determined by the highest R^2 value (coefficient of determination) and lowest RMSE (root mean square error) using the least sum of squares method. The regression statistics are more fully explained in Appendix B.

Regression analysis is the initial approach employed in generating a performance equation for a specific pavement section. As one might expect, such analyses may not always produce acceptable performance equations for reasons such as:

(a) the project being analyzed may have a relatively new surfacing (or new structure), thus limiting the number of PSC versus Age points by which to develop a performance equation, or

(b) random fluctuation of condition ratings for some projects resulting in low R^2 and high RMSE values (hence a poor fit of the data).

In the original interpreting program there were two basic <u>automated</u> methods of developing performance equations:

(a) In the case of a relatively new project where there has been no more than one rating since the last action or construction work, a standard, or default, equation for the pavement type, surfacing depth, and geographical area representing average performance is used.

(b) Regression analysis is used for all the remaining projects that have at least three condition ratings (the beginning condition after last construction, and two visual ratings).

The standard regression curve building program required detailed hand editing of all project specific performance curves by PMS engineers (with extensive experience in the design and construction of Washington state pavements and knowledge of the state highway system). For the 1986 model building year, 22 percent of the project performance curves were developed using standard (default) equations, 43 percent were developed using section specific data and regression analysis, and the remainder, 35 percent, were developed or adjusted using engineering judgment.

Though the WSPMS was developed around the concept of letting the individual project "speak for itself" by developing performance (regression) curves for each project, this process can overestimate remaining life in the early stages of pavement deterioration. To better predict the most likely performance trends for each project, a third process was established that simply added the standard (default) curve to the last data point. The default curves are used to establish two artificial points that are added to the existing data points, then a regression equation is developed that best fits both actual and artificial data points (refer to Figure 3.4). This process provides a more realistic estimate of specific project performance by recognizing the past performance trends unique to each project and also incorporating knowledge of the most likely rate of future deterioration from typical pavement performance experience.

This third curve building process (characterized as a Type III equation) has almost totally eliminated the large amount of engineering edit required in the earlier system. Though there is a detailed review of all curves (equations) before publishing the biennial program, very few changes are made. As of 1990, over half the curves were developed using this "third" curve building process and this has only increased for 1993.

3.3.2 Comparisons of Measured Pavement Condition to Predicted

During the 1986 performance curve building process, a small study was conducted by WSDOT to determine how accurately the 1984 performance curve building program predicted pavement conditions in 1986 compared to the conditions measured in 1986. The condition rating at that time was based on PCR.

The mean pavement condition rating predicted for each analysis unit in 1986 was compared to the actual mean rating measured in 1986. Comparison was complicated since the number of analysis units (pavement sections) increased from less than 2000

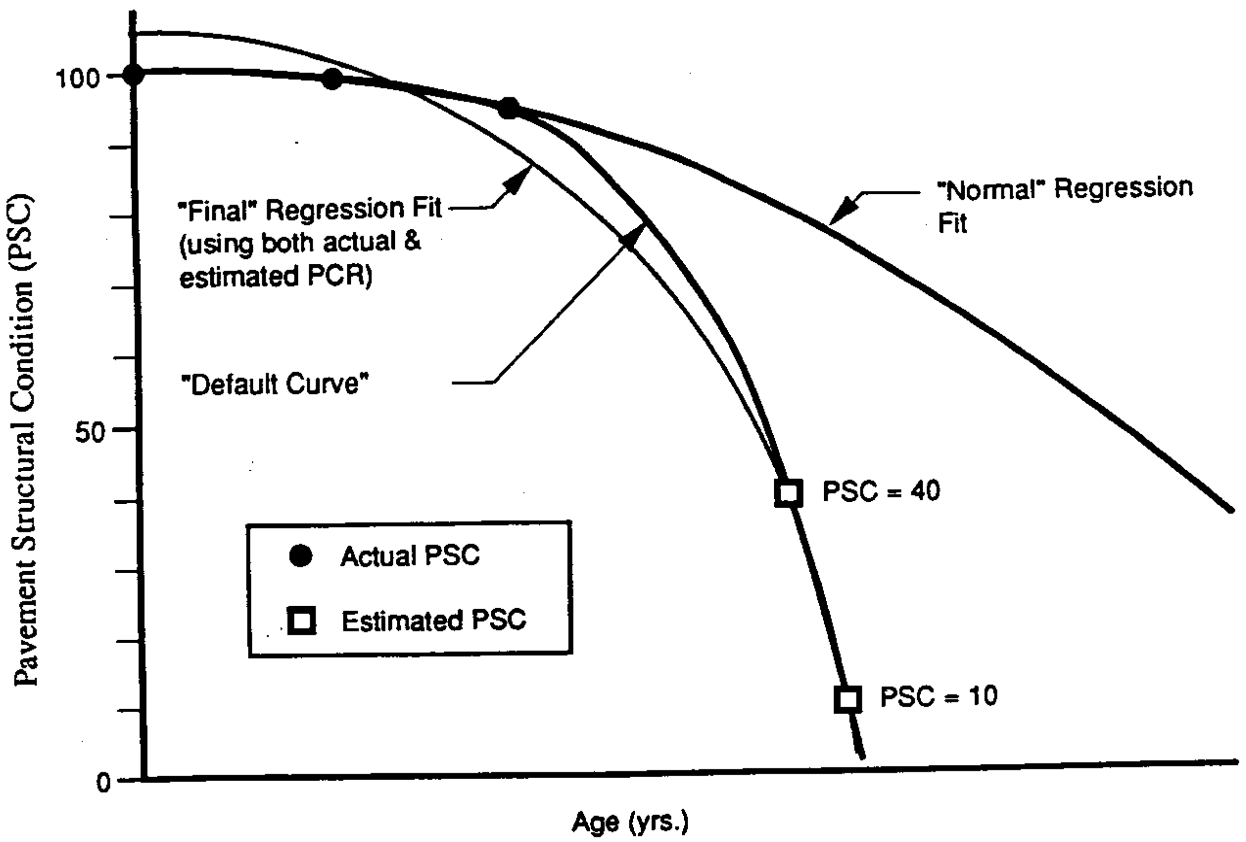

Figure 3.4. Process Used to Prevent Overestimation of Pavement Performance

used in 1984 to a little over 2600 in 1986. Thus, only the 1986 analysis units that came reasonably close to matching the 1984 analysis units were used in the comparison.

The comparison was accomplished by matching predicted pavement condition ratings for each analysis unit to measured pavement condition ratings using scatter diagrams for each pavement type and for each WSDOT District. The results of this analysis are shown in Table 3.1.

When comparing matched pairs using the scatter diagram a perfect match would result in a slope of 1.00 or 45 degrees on the diagram. The best fit of the points to the line is determined by the coefficient of the determination (R^2) approaching 1.00. As one can see from Table 3.1, most of the slopes are reasonably close to 1.0 with only a few exceptions. A slope less than 1.0 indicates the 1984 projection underestimated the actually measured condition in 1986. Similarly, a slope greater than 1.0 indicates the projected condition was overestimated.

Table 3.1. Comparison of 1984 Prediction of 1986 Pavement Condition (PCR) to Measured 1986 Pavement Condition (PCR)

Surfacing Type	Location	Number of Analysis Units	R^2	RMSE	Slope
Asphalt Concrete	District 1	389	0.64	20	0.88
	District 2	119	0.73	15	0.93
	District 3	251	0.71	18	0.95
	District 4	223	0.73	12	0.85
	District 5	135	0.55	17	0.76
	District 6	164	0.83	15	1.03
	Eastern Washington	418	0.74	16	0.94
	Western Washington	860	0.68	18	0.90
Bituminous Surface Treatments (includes seal coats)	District 2	133	0.69	16	1.02
	District 5	83	0.35	14	0.49
	District 6	93	0.50	22	0.91
	Eastern Washington	309	0.55	18	0.85
Portland Cement Concrete	District 1	91	0.66	10	0.92
	District 2	0	—	—	—
	District 3	23	0.43	11	1.18
	District 4	26	0.86	6	1.35
	District 5	47	0.80	8	1.21
	District 6	19	0.64	6	0.65
	Eastern Washington	66	0.81	8	1.02
	Western Washington	140	0.68	10	0.97

The data were separated by Districts to look somewhat at the differences by District but, more importantly, to look at the differences between eastern and western Washington, two very different environmental regions. Western Washington has a mild marine climate and is represented by Districts 1, 3, and 4. Eastern Washington is semi-arid, as it lies in the rain shadow of the Cascade Mountain Range, and is represented by Districts 2, 5, and 6. In general, normal pavement service life is about 10 to 30 percent longer in western Washington compared to pavement performance in eastern Washington. The effect of the climate difference can also be seen in the accuracy of the predictions.

3.3.3 Standard ("Default") Performance Equations

As previously stated, standard performance equations must be used in some cases for specific pavement sections (reasons such as recent repaving, etc.). It is interesting to see what these "standard" equations look like; however, please keep in mind that the equations are updated periodically. Presented in Tables 3.2 and 3.3 are the 1986 standard equations along with the number of sections used to develop each equation and its predicted life (years) to a PCR = 40. The term "analysis units" shown in Tables 3.2 and 3.3 implies a uniform (same construction) section of pavement. The method used (described below) to develop these equations produces an artificially high R^2 and low RMSE (thus, these values are not presented in the tables).

The 1986 equations were developed using pavement sections (analysis units) that had "production" regression fitted equations with a $R^2 \geq 0.8$ and a RMSE ≤ 9. Upon selecting the pavement sections that fit the criteria, each equation so selected was used to predict the ages at which the PCRs would be 85, 70, 40, and 0 (including an "artificial" PCR = 100 at Age = 0). Then the 10 percent of the equations that had the longest and the 10 percent with the shortest age to a PCR = 0 were excluded from the sample. Following this, the ages for each of the selected PCR levels were averaged and an

Table 3.2. Standard "Default" Performance Equations — WSPMS — 1986 — Western Washington

Location	Type of Construction/ Pavement Surfacing	Number of Analysis Units	Performance Equation	Age to PCR = 40
Western Washington	New or Reconstructed/ Bituminous Surface Treatment	2	$PCR = 100 - 0.086 (Age)^{2.50}$	13.7
	New or Reconstructed/ Asphalt Concrete	26	$PCR = 100 - 0.22 (Age)^{2.00}$	16.5
	New or Reconstructed/ Portland Cement Concrete	19	$PCR = 100 - 0.85 (Age)^{1.25}$	30.1
	Resurfacing/BST over AC	5	$PCR = 100 - 8.50 (Age)^{1.25}$	4.8
	Resurfacing/BST over BST	6	$PCR = 100 - 3.42 (Age)^{1.50}$	6.8
	Resurfacing/AC Overlay (under 1.2 inches)	75	$PCR = 100 - 0.58 (Age)^{2.00}$	10.2
	Resurfacing/AC Overlay (1.2 inches to 2.4 inches)	126	$PCR = 100 - 0.76 (Age)^{1.75}$	12.1
	Resurfacing/AC Overlay (over 2.4 inches)	19	$PCR = 100 - 0.54 (Age)^{1.75}$	14.8

Table 3.3. Standard "Default" Performance Equations — WSPMS — 1986 — Eastern Washington

Location	Type of Construction/ Pavement Surfacing	Number of Analysis Units	Performance Equation	Age to PCR = 40
Eastern Washington	New or Reconstructed/ Bituminous Surface Treatment	4	$PCR = 100 - 0.094 (Age)^{2.50}$	13.2
	New or Reconstructed/ Asphalt Concrete	15	$PCR = 100 - 0.07 (Age)^{2.50}$	14.9
	New or Reconstructed/ Portland Cement Concrete	19	$PCR = 100 - 0.85 (Age)^{1.25}$	30.1
	Resurfacing/BST over AC	11	$PCR = 100 - 6.24 (Age)^{1.25}$	6.1
	Resurfacing/BST over BST	80	$PCR = 100 - 2.93 (Age)^{1.50}$	7.5
	Resurfacing/AC Overlay (under 1.2 inches)	15	$PCR = 100 - 1.63 (Age)^{1.75}$	7.8
	Resurfacing/AC Overlay (1.2 inches to 2.4 inches)	75	$PCR = 100 - 0.45 (Age)^{2.00}$	11.6
	Resurfacing/AC Overlay (over 2.4 inches)	26	$PCR = 100 - 0.44 (Age)^{2.00}$	11.6

equation fitted through the points. The equation was "forced" through PCR = 100 at Age = 0.

The 1993 equations are shown in Tables 3.4 through 3.7, with each table featuring a different highway functional classification (Table 3.4, Interstate; Table 3.5, Principal Arterial; Table 3.6, Minor Arterial; Table 3.7, Major Collector). These equations do not distinguish between "new" and "rehabilitation" pavement performance since there is little "all new" pavement mileage on the WSDOT system (as of 1993). The equations were developed in a similar way to those produced for 1986 conditions; however, PCR has changed to PSC and the associated predicted life is to a PSC = 50 (the condition at which rehabilitation is preferred). Further, the equations are listed by district and pavement surface. Of the 72 equations (models) listed, 38 were developed for projects within the listed district and pavement type (model code = 1). The remaining 34 equations (model code = 2) are default models based on regression analysis of statewide projects. The need for use of statewide default models was due to causes such as too few condition surveys (hence PSCs) to evaluate, inadequate regression model statistics, or unreasonable predictive results.

The 1993 default equations were based on "production" equations which had the following characteristics:

- Most recent survey PSC $\leq$ 75
- RMSE $\leq$ 9
- Upper and lower 10 percent of equations with longest and shortest age to PSC = 0 were excluded
- Intercept ("C") $\geq$ 80
- Length of individual analysis units $\geq$ 0.10 mile
- Production equations restricted to Type III or traditional regression equations

The decision whether to use a Type III or traditional, project-specific regression equation in the default building process is based on the time required to reach a PSC = 0. If there

Table 3.4. Pavement Performance Equations for the Interstate Functional Classification — WSPMS — 1993

District	Pavement Surface	Performance Equation	Age to PSC = 50	Model
1 (Seattle)	AC	$PSC = 100 - 0.196 (Age)^{2.00}$	16.0	2
	BST	$PSC = 100 - 0.809 (Age)^{2.00}$	7.9	2
	PCC	$PSC = 100 - 0.018 (Age)^{2.25}$	33.5	1
2 (Wenatchee)	AC	$PSC = 100 - 0.166 (Age)^{2.25}$	12.6	1
	BST	$PSC = 100 - 0.809 (Age)^{2.00}$	7.9	2
	PCC	$PSC = 100 - 0.034 (Age)^{2.00}$	38.1	2
3 (Tumwater)	AC	$PSC = 100 - 0.009 (Age)^{3.00}$	17.5	1
	BST	$PSC = 100 - 0.809 (Age)^{2.00}$	7.9	2
	PCC	$PSC = 100 - 0.109 (Age)^{1.75}$	33.2	1
4 (Vancouver)	AC	$PSC = 100 - 0.0018 (Age)^{3.50}$	18.6	1
	BST	$PSC = 100 - 0.809 (Age)^{2.00}$	7.9	2
	PCC	$PSC = 100 - 0.0055 (Age)^{2.75}$	27.5	1
5 (Yakima)	AC	$PSC = 100 - 0.029 (Age)^{2.75}$	15.1	1
	BST	$PSC = 100 - 0.809 (Age)^{2.00}$	7.9	2
	PCC	$PSC = 100 - 0.112 (Age)^{1.75}$	32.7	1
6 (Spokane)	AC	$PSC = 100 - 0.574 (Age)^{1.75}$	12.8	1
	BST	$PSC = 100 - 0.809 (Age)^{2.00}$	7.9	2
	PCC	$PSC = 100 - 0.034 (Age)^{2.00}$	38.1	2

Model Code

1 = Model based on <u>actual</u> projects for listed conditions
2 = Default model based on <u>statewide</u> projects

Table 3.5. Pavement Performance Equations for the Principal Arterial Functional Classification — WSPMS — 1993

District	Pavement Surface	Performance Equation	Age to PSC = 50	Model
1 (Seattle)	AC	PSC = 100 - 0.196 $(Age)^{2.00}$	16.0	1
	BST	PSC = 100 - 0.809 $(Age)^{2.00}$	7.9	2
	PCC	PSC = 100 - 0.025 $(Age)^{2.00}$	44.7	1
2 (Wenatchee)	AC	PSC = 100 - 0.239 $(Age)^{2.25}$	10.7	1
	BST	PSC = 100 - 0.987 $(Age)^{2.00}$	7.1	1
	PCC	PSC = 100 - 0.034 $(Age)^{2.00}$	38.1	2
3 (Tumwater)	AC	PSC = 100 - 0.063 $(Age)^{2.50}$	14.5	1
	BST	PSC = 100 - 0.809 $(Age)^{2.00}$	7.9	2
	PCC	PSC = 100 - 0.011 $(Age)^{2.25}$	42.1	1
4 (Vancouver)	AC	PSC = 100 - 0.023 $(Age)^{2.75}$	16.3	1
	BST	PSC = 100 - 7.050 $(Age)^{1.00}$	7.1	1
	PCC	PSC = 100 - 0.486 $(Age)^{1.50}$	22.0	1
5 (Yakima)	AC	PSC = 100 - 0.202 $(Age)^{2.50}$	9.1	1
	BST	PSC = 100 - 1.80 $(Age)^{1.75}$	6.7	1
	PCC	PSC = 100 - 0.145 $(Age)^{1.75}$	28.2	1
6 (Spokane)	AC	PSC = 100 - 1.740 $(Age)^{1.50}$	9.4	1
	BST	PSC = 100 - 0.809 $(Age)^{2.00}$	7.9	2
	PCC	PSC = 100 - 0.034 $(Age)^{2.00}$	38.1	2

Model Code

1 = Model based on actual projects for listed conditions
2 = Default model based on statewide projects

Table 3.6. Pavement Performance Equations for the Minor Arterial Functional Classification — WSPMS — 1993

District	Pavement Surface	Performance Equation	Age to PSC = 50	Model
1 (Seattle)	AC	PSC = 100 - 0.109 $(Age)^{2.25}$	15.2	1
	BST	PSC = 100 - 0.188 $(Age)^{2.50}$	9.3	1
	PCC	Not Shown		
2 (Wenatchee)	AC	PSC = 100 - 0.419 $(Age)^{2.00}$	10.9	1
	BST	PSC = 100 - 0.155 $(Age)^{2.50}$	10.1	1
	PCC	PSC = 100 - 0.034 $(Age)^{2.00}$	38.1	2
3 (Tumwater)	AC	PSC = 100 - 0.172 $(Age)^{2.25}$	12.4	1
	BST	PSC = 100 - 1.050 $(Age)^{2.00}$	6.9	1
	PCC	Not Shown		
4 (Vancouver)	AC	PSC = 100 - 0.036 $(Age)^{2.50}$	18.1	1
	BST	PSC = 100 - 0.809 $(Age)^{2.00}$	7.9	2
	PCC	PSC = 100 - 0.034 $(Age)^{2.00}$	38.1	2
5 (Yakima)	AC	PSC = 100 - 0.099 $(Age)^{2.50}$	12.1	1
	BST	PSC = 100 - 0.206 $(Age)^{2.50}$	9.0	1
	PCC	PSC = 100 - 0.034 $(Age)^{2.00}$	38.1	2
6 (Spokane)	AC	PSC = 100 - 0.916 $(Age)^{1.75}$	9.8	1
	BST	PSC = 100 - 0.809 $(Age)^{2.00}$	7.9	2
	PCC	PSC = 100 - 0.034 $(Age)^{2.00}$	38.1	2

- Model Code

  1 = Model based on <u>actual</u> projects for listed conditions
  2 = Default model based on <u>statewide</u> projects

- Models "Not Shown" due to small sample size

Table 3.7. Pavement Performance Equations for the Major Collector Functional Classification — WSPMS — 1993

District	Pavement Surface	Performance Equation	Age to PSC = 50	Model
1 (Seattle)	AC	$PSC = 100 - 0.234 (Age)^{2.00}$	14.6	1
	BST	$PSC = 100 - 3.430 (Age)^{1.50}$	6.0	1
	PCC	Not Shown		
2 (Wenatchee)	AC	$PSC = 100 - 0.129 (Age)^{2.25}$	14.1	2
	BST	$PSC = 100 - 0.170 (Age)^{2.50}$	9.7	1
	PCC	$PSC = 100 - 0.034 (Age)^{2.00}$	38.1	2
3 (Tumwater)	AC	$PSC = 100 - 0.136 (Age)^{2.25}$	13.8	1
	BST	$PSC = 100 - 0.728 (Age)^{1.75}$	11.2	1
	PCC	Not Shown		
4 (Vancouver)	AC	$PSC = 100 - 0.0096 (Age)^{3.00}$	17.3	1
	BST	$PSC = 100 - 0.196 (Age)^{3.00}$	6.3	1
	PCC	$PSC = 100 - 0.034 (Age)^{2.00}$	38.1	2
5 (Yakima)	AC	$PSC = 100 - 0.074 (Age)^{2.50}$	13.6	1
	BST	$PSC = 100 - 2.04 (Age)^{1.75}$	6.2	1
	PCC	$PSC = 100 - 0.034 (Age)^{2.00}$	38.1	2
6 (Spokane)	AC	$PSC = 100 - 1.82 (Age)^{1.50}$	9.1	1
	BST	$PSC = 100 - 2.65 (Age)^{2.00}$	4.3	1
	PCC	$PSC = 100 - 0.034 (Age)^{2.00}$	38.1	2

- Model Code

  1 = Model based on actual projects for listed conditions
  2 = Default model based on statewide projects

- Models "Not Shown" due to small sample size is ± 15 percent difference in time (years) to a PSC = 0 between the traditional regression equation and the Type III equation, then the Type III model is used.

3.4 PMS DATA PRESENTATION

Pavement management systems by their very nature deal with a very large amount of information in numeric or special code. One of the first problems WSDOT had in developing and using the WSPMS was the presentation of the information in a form that is easily understood and used. The original programs presented the data in book after book of computer listings. There was an attempt to present some of the material in graphic form by developing books with all the district construction, traffic data, and plotted curves on one sheet for each project. There was also a separate listing made that provided the last pavement condition information for the entire state highway system. The latter was probably the most used document because it was easily understood.

To provide a more user friendly window to see and make use of the data contained in the WSPMS, a program was developed to provide WSDOT managers and design engineers most of the data in a more visual form. This is the Management Information Data Link (MIDAL), a 12 megabyte program (as of 1993) that contains complete statewide construction history, traffic information, ride and friction information, the last set of pavement condition ratings, all the pavement performance curves, and the programming information for the biennial construction program. The program is built to be used on personal computers. Access through the program is straightforward and user friendly, with all information presented in words with a minimum of numbers, and few tables and no spreadsheets. Some of the more complex information is presented in performance curves or bar graphics. A picture is often worth more than a thousand words. This program has gained wide use and is now being used by those not involved in PMS because it provides easier access to some of the corporate file information than the corporate file systems themselves.

SECTION 4.0

WSPMS RESULTS

4.1 TYPES OF RESULTS

The WSPMS can be used to develop numerous types of output (or "results" or "products"). These products can range from straightforward statistics on pavement age, condition, etc. to historical presentations of statewide or district condition trends. A few of these results will be illustrated in the following sections.

4.2 BASIC STATISTICS

4.2.1 Background

WSDOT Research Report 143.1 [4.1] was prepared in response to FHWA Demonstration Project No. 302, "Pavement Performance Curves." The basic issue addressed in the report was an attempt to see what kinds of performance models could be developed on a network basis from the WSPMS database. Further, basic statistical measures, such as mean and standard deviation, were calculated for various pavement surface types (bituminous surface treatment (BST), asphalt concrete (AC), and portland cement concrete (PCC)). The following subsections will overview only these basic statistics.

4.2.2 The Data

The WSPMS data files contained 2,616 separate pavement sections (separate sections of pavement with relatively uniform construction and performance) at the time of this analysis, which represented over 7,000 centerline miles of state maintained highways. The total number of pavement sections was initially separated into eight [illegible]

the table is a subset of the total in WSPMS and represent about 20 percent of the mileage

Table 4.1. Basic Pavement Categories Used for Developing General Statistics

Surfacing Type	Construction Type	Number of Pavement Sections
Bituminous Surface Treatment	New or Reconstruction	6
	Age ≥ 5 years	5
Asphalt Concrete	New or Reconstruction	58
	New or Reconstruction, Age ≥ 10 years	40
	Overlays	383
	Overlays, Age ≥ 5 years	341
Portland Cement Concrete	New or Reconstruction	31
	New or Reconstruction, Age ≥ 15 years	29

on the route system. These subsets were created to include only pavement sections that exhibited a systematic (or classic) performance curve. Specific criteria used to develop these subsets include the following:

(a) The pavement section performance curve (PCR) versus age was based on actual performance data and exhibited an R^2 of no less than 0.75 (75 percent).

(b) The RMSE of the performance curve was no larger than 10.

The primary variables used in the analysis are as follows:

(a) Pavement Condition Rating (PCR): This is a measure of the observed pavement surface distress and ranges from 100 (no distress) to 0 or below (extensive surface distress). PCR is primarily determined by measures of the extent and severity of pavement surface cracking.

(b) Age: Pavement age is determined from the time of construction, reconstruction or overlay to time of the last PCR.

(c) Accumulated 18,000 lb. equivalent single axle loads (ESAL): The number of ESALs estimated for the age of the pavement section.

(d) Pavement thickness (THICK): The thickness of the pavement surface course (for either BST, AC, or PCC surfaces).

4.2.3 General Statistics

Tables 4.2 through 4.5 contain general statistical measures for the various pavement section subsets. These tables contain the number of pavement sections, the mean, median, standard deviation, and the minimum and maximum values.

4.2.3.1 Bituminous Surface Treatment

The general statistical measures for two bituminous surface treatment data subsets are shown in Table 4.2. In general, few pavement sections were available for analysis (a maximum of six). The ESALs accumulated until the last PCR rating averaged about 258,000 at an age of about eight years. Thus, these sections met the AASHTO's definition of a "low volume road" [4.2].

All bituminous surface treatment categories were for new or reconstructed pavement structures.[1] It was also examined how a minimum survival time of five years would influence the results. As one can see in Table 4.2, the average age increased slightly, but otherwise the two categories showed little difference.

4.2.3.2 Asphalt Concrete

The general statistical measures for the eight asphalt concrete data subsets are shown in Tables 4.3 and 4.4. Table 4.3 is for new or reconstructed pavement structures and Table 4.4 for asphalt concrete overlays.

Table 4.3 shows that the average new asphalt concrete surfacing layer was 5.3 inches thick and the average PCR was 58 at an age of about 12.7 years. The ACP depths were not evenly distributed but fell into two distinct groups, at about 4 inches and 8 to 9 inches. The accumulated ESALs at these average conditions were a bit less than 1,500,000.

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[1]This means that the project was either to completely rebuild the existing roadway with 1.0 to 2.0 feet of gravel and crushed bases surfaced with a BST, or an existing roadway was covered with 4 to 6 inches of crushed base and resurfaced with a BST.

Table 4.2. General Statistics for Bituminous Surface Treatments

Construction Type	Variable	Number of Pavement Sections	Mean ($\bar{x}$)	Median	Standard Deviation (s)	Minimum	Maximum
New or Reconstruction	PCR	6	69	75	31	32	98
	AGE	6	8.2	6.5	4.8	3.0	15.0
	ESAL	6	258,000	185,000	236,000	45,000	603,000
	THICK	6	1.1	0.7	0.9	0.5	3.0
New or Reconstruction Age ≥ 5 years	PCR	5	63	55	31	32	96
	AGE	5	9.2	7.0	4.5	5.0	15.0
	ESAL	5	291,000	277,000	248,000	45,000	603,000
	THICK	5	1.1	0.7	1.1	0.5	3.0

Table 4.3. General Statistics for Asphalt Concrete.— New or Reconstruction

Construction Type	Variable	Number of Pavement Sections	Mean ($\bar{x}$)	Median	Standard Deviation (s)	Minimum	Maximum
New or Reconstruction	PCR	58	58	62	21	5	96
	AGE	58	12.7	13.0	4.5	4.0	24.0
	ESAL	58	1,439,000	802,000	1,679,000	20,000	6,925,000
	THICK	58	5.3	4.2	2.3	1.8	10.2
New or Reconstruction Age ≥ 10 Years	PCR	40	50	57	21	5	74
	AGE	40	15.0	14.0	3.5	10.0	24.0
	ESAL	40	1,856,000	1,091,000	1,864,000	90,000	6,925,000
	THICK	40	5.4	4.2	2.4	2.4	10.2

PCR = Pavement Condition Rating

AGE = Age (years)

ESAL = Accumulated 18,000 lb. equivalent single axle loads

THICK = Surface course thickness (inches)

Table 4.4. General Statistics for Asphalt Concrete – Overlays

Construction Type	Variable	Number of Pavement Sections	Mean ($\bar{x}$)	Median	Standard Deviation (s)	Minimum	Maximum
Overlay	PCR	383	62	65	25	-45	98
	AGE	383	8.2	8.0	3.0	3.0	21.0
	ESAL	383	712,000	429,000	903,000	13,000	5,662,000
	THICK	383	1.7	1.8	0.9	0.2	5.4
Overlay Age ≥ 5 years	PCR	341	61	63	25	-45	97
	AGE	341	8.8	8.0	2.7	5.0	21.0
	ESAL	341	748,000	458,000	940,000	13,000	5,662,000
	THICK	341	1.8	1.8	0.8	0.2	5.0

Table 4.5. General Statistics for Portland Cement Concrete

Construction Type	Variable	Number of Pavement Sections	Mean ($\bar{x}$)	Median	Standard Deviation (s)	Minimum	Maximum
New or Reconstruction	PCR	31	60	59	15	29	95
	AGE	31	26.4	21.0	14.4	5.0	69.0
	ESAL	31	9,933,000	9,448,000	5,342,000	1,722,000	22,191,000
	THICK	31	8.4	9.0	1.0	5.0	9.0
New or Reconstruction Age ≥ 15 years	PCR	29	58	58	12	29	79
	AGE	29	27.6	21.0	14.0	15.0	69.0
	ESAL	29	10,386,000	9,701,000	5,221,000	1,722,000	22,191,000
	THICK	29	8.4	9.0	1.0	5.0	9.0

PCR = Pavement Condition Rating

AGE = Age (years)

ESAL = Accumulated 18,000 lb. equivalent single axle loads

THICK = Surface course thickness (inches)

For asphalt concrete overlays, Table 4.4 illustrates notable differences between the typical overlays used by WSDOT and new asphalt concrete surface courses. The overlays were thinner (1.7 versus 5.3), newer (8.2 versus 12.7), had fewer accumulated ESALs (712,000 versus 1,439,000), but were in about the same overall condition (average PCR of 62 for overlays versus 58 for new asphalt concrete surface courses). Further, there were more overlays in the WSPMS database. The overlays included thin "maintenance" type seals (0.75 to 1.0 inch) as well as structural overlays (1.75 to 3.0 inches).

Minimum survival times of ten years for new or reconstructed asphalt concrete surface courses and five years for asphalt concrete overlays were also examined. The summary statistics are shown in Tables 4.3 and 4.4, respectively.

4.2.3.3 Portland Cement Concrete

The general statistical measures for the two portland cement concrete data subsets are shown in Table 4.5. This information shows that, when compared to new asphalt concrete surface courses, portland cement concrete surfaces were older (26.4 versus 12.7 years) and thicker (8.4 versus 5.3 inches), had experienced substantially more ESALs 9,933,000 versus 1,439,000), but were in about the same overall condition, as measured by PCR.

4.3 TYPICAL DISTRICT PRIORITY ARRAY

The district priority array project listing which results from the WSPMS is based on the "worst first" concept. More specifically, up to 1988, this meant that those projects with the worst pavement condition were listed first (had the highest priority). From 1988 to 1993, this was changed to reflect those projects with the earliest due date to a PSC = 50 (PCR = 40 prior to 1992) had the highest priority. The overall goal was (and is) to program those projects for work which have the highest need.

The actual priority array listing can be illustrated for the April 12, 1993, rank order run for District 2. For example, the first listed project is identified as:

- SR: 97
- MP: 201.23 to 201.57 (increasing)
- Project Identification Number: 209720A
- Ad. Date: March 1995
- Project Title: OHME GARDEN ROAD To DOT STOCKPILE
- Project Status: Approved
- Length: 0.68 lane-mile
- Ideal Programming Date: 1986

The above project information is self-explanatory with the possible exception of the ideal programming date. This date is simply the original date the project reached a PSC = 50. For the SR97 project in District 2, this occurred in 1986 (or nine years beyond the planned advertisement date for the contract). Generally, there are few projects for which the "ideal date" and "ad date" differ by so much time. For example, the fourth project listed for District 2 has an ideal date of 1990 and an ad date of March 1993 as follows:

- SR: 2
- MP: 174.10 to 174.37 (increasing)
- Project Identification Number: 200261A
- Ad. Date: March 1993
- Project Title: ROAD NW TO SHRP TEST SECTION
- Project Status: Approved
- Length: 0.54 lane-mile
- Ideal Programming Date: 1990

The first project on the District 2 priority array listing where the PSC = 50 ideal year and the ad. date year are the same is the 38th project listed (out of a total of 263 paving projects listed):

- SR: 2
- MP: 119.12 to 119.92 (increasing)
- Project Identification Number: 200233A
- Ad. Date: March 1993
- Project Title: Easy St. Vic. to SR 28
- Project Status: Approved
- Length: 2.07 lane-miles
- Ideal Programming Date: 1993

4.4 PAVEMENT CONDITION — TIME TRENDS

Figures 4.1 through 4.5 illustrate another type of data summary available through WSPMS source data. The bars are plots of lane miles versus the condition ranges of good (PSC = 75 to 100), fair (PSC = 50 to 74), poor (PSC = 25 to 49) and very poor (PSC = 0 to 24). Figure 4.1 is for all pavements, statewide; Figure 4.2 Interstate ACP pavements, statewide; Figure 4.3 Interstate PCCP pavements, statewide; Figure 4.4 Principal Arterials, ACP and BST combined, statewide; and Figure 4.5 Principal Arterials, PCCP, statewide. From these figures, the following trends are evident:

- Overall pavement condition (Figure 4.1) improved up to 1989 and has subsequently varied within a small range.
- The Interstate ACP (Figure 4.2) reached its "best" condition in 1986.
- The Interstate PCCP (Figure 4.3) shows a trend of increased deterioration (low PSC) in 1988, well-illustrated by the poor category (PSC = 25 to 49). The true condition is even worse than shown because slab faulting is not, as yet, accurately measured. The slab faulting distress is, unfortunately, increasing rapidly statewide based on subjective observations.
- The principal arterials for ACP and BST pavements combined (Figure 4.4) reveal reduced mileage in the very poor category (PSC = 0 to 24) but increasing mileage in the fair category (PSC = 50 to 74).
- The principal arterials for PCC pavements show a large variation in condition but more so over the last five years (1988 to 1992). Note that the total lane miles are relatively small compared to the other functional classifications.

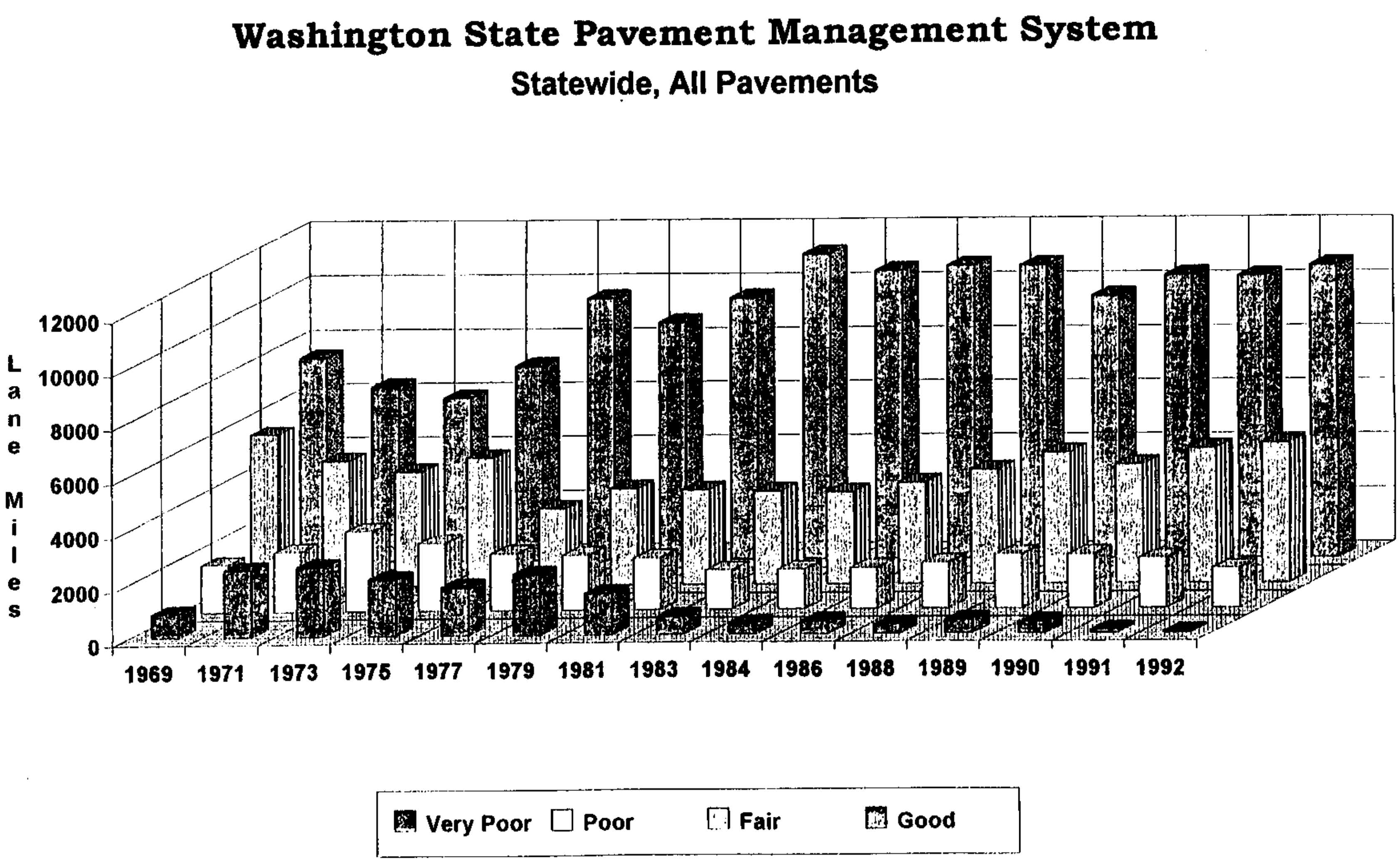

Figure 4.1. Pavement Condition — Time Trends for All Functional Classes of Pavements — Statewide

2/10/93

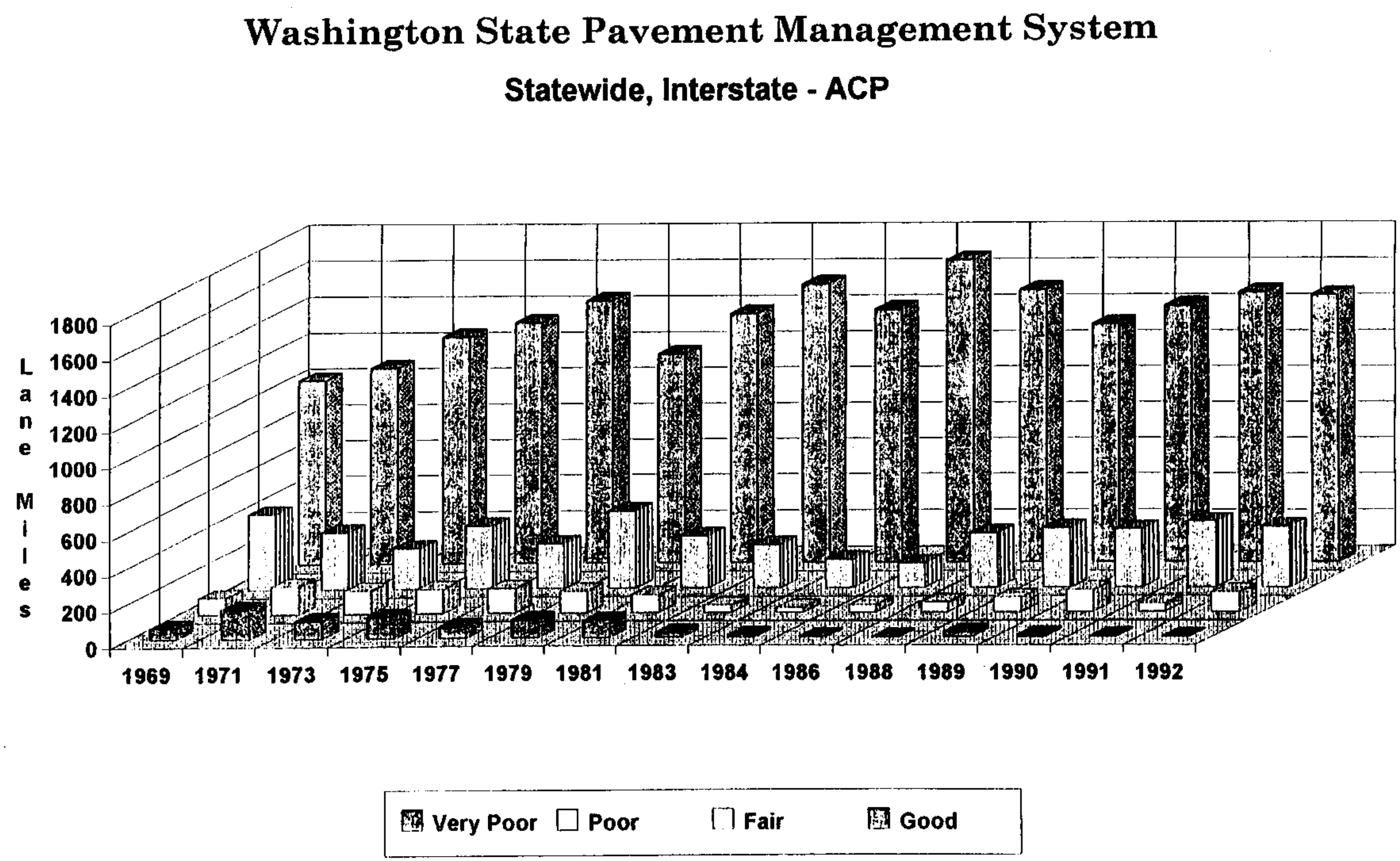

Figure 4.2. Pavement Condition — Time Trends for Interstate AC Pavements — Statewide

Washington State Pavement Management System

Statewide, Interstate - PCCP

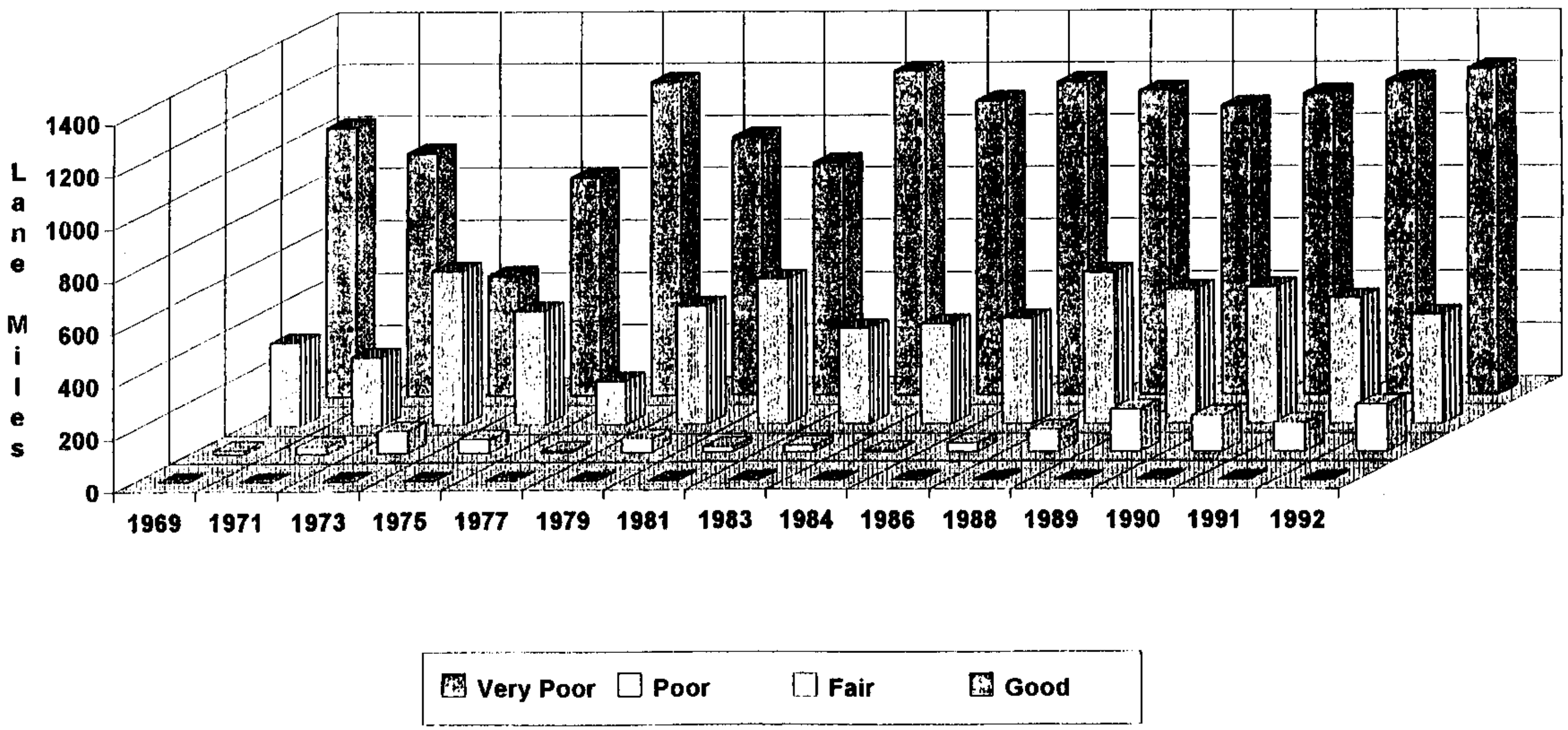

Figure 4.3. Pavement Condition — Time Trends for Interstate PCC Pavements — Statewide

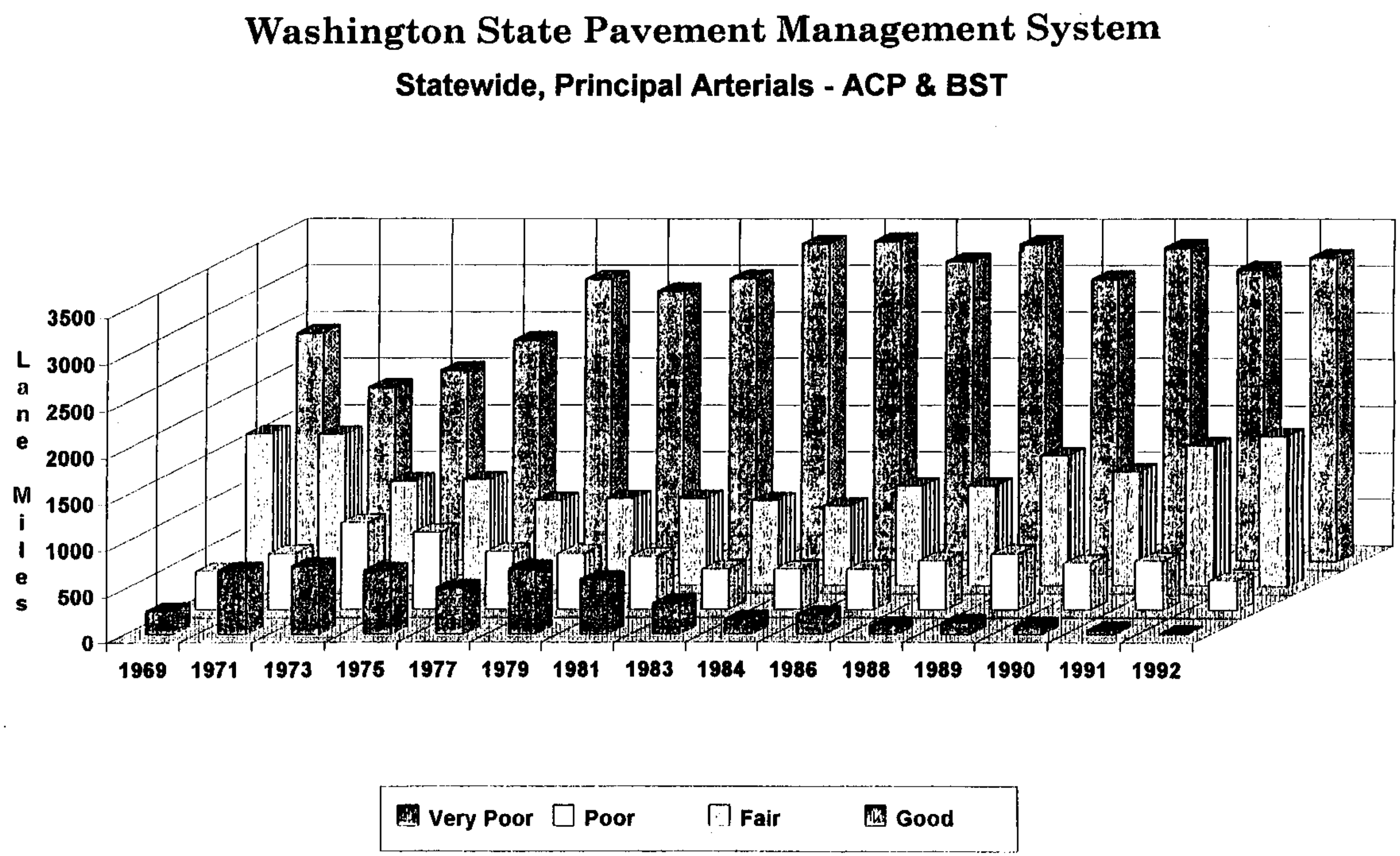

Figure 4.4. Pavement Condition — Time Trends for Principal Arterial ACP and BST Pavements — Statewide

Washington State Pavement Management System

Statewide, Principal Arterials - PCCP

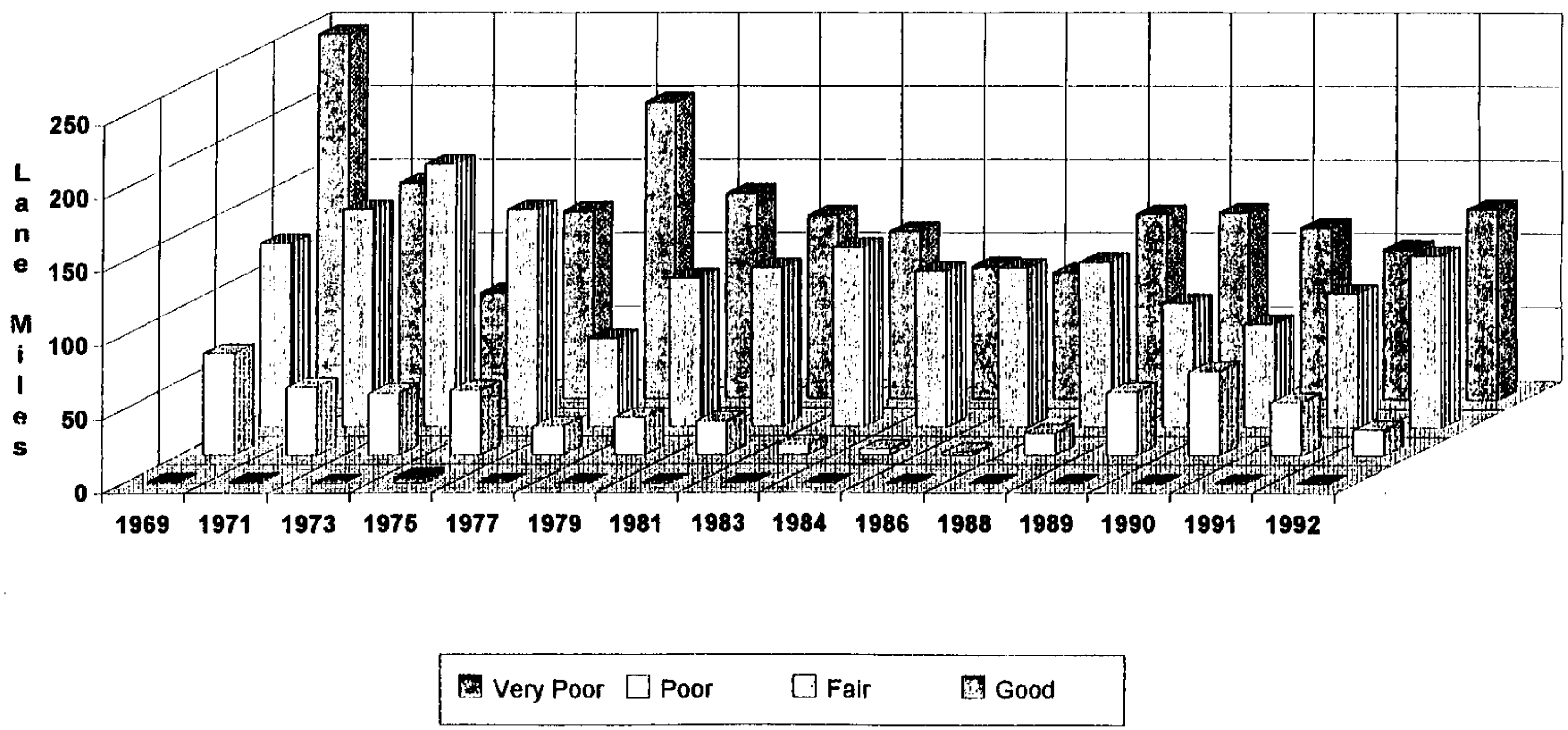

Figure 4.5 Pavement Condition — Time Trends for Principal Arterial PCC Pavements — Statewide

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SECTION 5.0

SUMMARY

This report is an attempt to update some of the WSPMS features and provide documentation of those updates. Further, based on the interviews conducted in each of the six WSDOT districts, a PMS overview is provided in SECTION 2.0 (OVERVIEW OF PAVEMENT MANAGEMENT SYSTEMS). SECTION 3.0 (WASHINGTON STATE PAVEMENT MANAGEMENT SYSTEM) is used to provide a current, general overview of the WSPMS file structure and performance equation concept. SECTION 4.0 (WSPMS RESULTS) is used to provide a selection of WSPMS results such as general pavement statistics, selected examples from a district priority array (which is a WSPMS product), and a selection of pavement condition-time trends.

The bulk of the report is represented by six appendices. Briefly, these are

- Appendix A: Contains documentation on the rehabilitation project scoping technique contained in the WSPMS which was developed during the study. The scoping technique is fully implemented within WSPMS.
- Appendix B: Contains background information requested by District personnel about pavement prediction models (performance curves). The information is general but provides the requested background material.
- Appendix C: Contains the significant state legislation which mandates priority programming (hence the original primary need for the WSPMS).
- Appendix D: Contains the most recent version of the FHWA Pavement Policy which includes the national mandate for PMS.
- Appendix E: Contains the documentation on calculation of pavement condition indices (these were substantially modified during this study).
- Appendix F: Contains summaries of interviews conducted in each District relative to pros and cons of the then current WSPMS and recommended changes. Most of the changes requested by the Districts have been made and incorporated in the current WSPMS or will be following completion of the subsequent Phase II portion of the study.

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1.1 Nelson, T. L., and LeClerc, R. V., "Development and Implementation of Washington State's Pavement Management System," Research Report WA-RD 50.1, Washington State Department of Transportation, Olympia, Washington, September 1982.

1.2 Nelson, T. L., and LeClerc, R. V., "Development and Implementation of Washington State's Pavement Management System—Executive Summary," Research Report WA-RD 50.3, Washington State Department of Transportation, Olympia, Washington, February 1983.

2.1 AASHTO, "AASHTO Guidelines for Pavement Management Systems, " American Association of State Highway and Transportation Officials, Washington, D.C., July 1990.

2.2 FHWA, "Federal-Aid Highway Program Manual," Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., March 6, 1989.

3.1 Nelson, T. L., and LeClerc, R.V., "Development and Implementation of Washington State's Pavement Management System," Research Report WA-RD 50.1, Washington State Department of Transportation, Olympia, Washington, September 1982.

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3.3 Jackson, N. C., Kay, K. R., and Peters, A. J., "Predictive Pavement Condition Program in the Washington State Pavement Management System," Proceedings, Vol. 2, Second North American Conference on Managing Pavements, Toronto, Canada, November 2-6, 1987.

3.4 Mahoney, J. P., and Jackson, N. C., "Performance Prediction," Shortcourse Module, Advanced Pavement Management System Course, National Highway Institute, Federal Highway Administration, 1990.

4.1 Mahoney, J.P., Kay, R.K. and Jackson, N.C. "Pavement Performance Equations," Research Report WA-RD 143.1, Washington State Department of Transportation, Olympia, Washington, March 1988.

4.2 American Association of State Highway and Transportation Officials, "AASHTO Guide for Design of Pavement Structures — 1986," American Association of State Highway and Transportation Officials, Washington, D.C., 1986.

APPENDIX A

AN OVERVIEW OF THE WSDOT PAVEMENT MANAGEMENT SYSTEM OVERLAY SCOPING TECHNIQUE

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WSDOT PAVEMENT MANAGEMENT SYSTEM
OVERLAY SCOPING TECHNIQUE

1. WHY?

Until the advent of the technique described in this appendix, the WSPMS did not "scope" project specific pavement rehabilitation. What was done instead was to "apply" a "standard fix" to each pavement segment requiring rehabilitation (based on a preselected minimum Pavement Condition Rating (PCR) level). The goal of the scoping technique is to incorporate into WSPMS an asphalt concrete overlay thickness estimate for each pavement segment requiring rehabilitation (or BST requirement). This will provide, hopefully, more realistic, initial rehabilitation estimates from WSPMS.

2. HOW?

The approach taken is to use a technique quite similar to The Asphalt Institute component analysis method [A-1]. This method was further modified by Ritchie and Mahoney [A-2] and used in the computer program OVERDRIVE. The Asphalt Institute component analysis overlay design method and the modifications thereto will be presented in the following sections.

3. THE ASPHALT INSTITUTE COMPONENT ANALYSIS METHOD

The component analysis approach to overlay design essentially requires that the total pavement structure be developed as a new design for the specified service conditions and then compared to the existing pavement structure (taking into account both pavement condition, type, and thickness of the pavement layers). A review of all current component design procedures quickly reveals that substantial judgment is required to effectively use them. This judgment is mainly associated with selection of "weighting factors" or "conversion factors" to use in evaluating the structural adequacy of the existing pavement layers.

The Asphalt Institute component analysis design approach (termed "effective thickness") uses relationships between subgrade strength, pavement structure, and traffic. The existing structural integrity of the pavement is converted to an equivalent thickness of asphalt concrete which is then compared to that required for a new design. The structural evaluation procedure developed by The Asphalt Institute allows for determining the required thickness of asphalt concrete overlay or to estimate the length of time until an overlay is required.

The three essential parts of this overlay design procedure will be briefly described and include

- subgrade analysis,
- pavement structure thickness analysis, and
- traffic analysis.

3.1 Subgrade Analysis

Testing of the subgrade materials is encouraged even if original design records are available. Use of resilient modulus (M_r), soaked CBR, or R-value tests appear to be the easiest to use with this procedure. For actual design, the design stiffness of the subgrade must be characterized in terms of resilient modulus. Associated correlations for CBR and R-value are

$$M_r\ (\text{psi}) = 1500\ (\text{CBR}) \qquad \text{(Eq. 1)}$$

$$= 1155 + 555\ (\text{R-value}) \qquad \text{(Eq. 2)}$$

If test data in terms of M_r, CBR, or R-value are not available, subgrades can be placed into one of three classes for design purposes as follows:

(a) Poor soils. Soft and plastic when wet, generally composed of silts or clays. Typical properties: M_r = 4,500 psi, CBR = 3, R-value = 6.

(b) Medium soils. Include soils such as loams, silty sands, and sand-gravels which contain moderate amounts of clay and silt. These soils can be expected to lose only a moderate amount of strength when wet. Typical properties: M_r = 12,000 psi, CBR = 8, R-value = 20.

(c) Good soils. These soils can be expected to retain a substantial amount of their strength when wet and include clean sands and sand-gravels. Typical properties: M_r = 25,000 psi, CBR = 17, R-value = 43.

3.2 Pavement Structure Thickness Analysis

The goal of this portion of the design method is to determine the "Effective Thickness (TE)" of the existing pavement structure. The Asphalt Institute has two approaches which can be used, only one will be illustrated in this report. First, the significant pavement layers are identified and their condition determined. Second, "Conversion Factors" are selected for each layer (judgment by the designer is very important at this point). Third, the Effective Thickness for each layer is determined by multiplying the actual layer thickness by the appropriate Conversion Factor. The Effective Thickness of the complete pavement structure is the sum of the individual Effective Thicknesses. Typical layer thickness Conversion Factors are shown in Table A-1.

3.3 Traffic Analysis

The Asphalt Institute pavement design procedures require the use of 18,000 lb (80 kN) equivalent single axle loads (ESALs) to characterize the traffic loading input. A variety of techniques can be used to estimate ESALs, and The Asphalt Institute provides information which is helpful; however, the ESAL related information which follows is based on WSDOT data sources. For example, in general terms, Table A-2 shows "typical" ESALs per year for various WSDOT routes. If a ten year overlay design life was required, then ESALs ranging from 250,000 (SR21) to 20,000,000 (SR5) would be used. Naturally, values such as those shown in Table A-2 are too general to be of much value for specific project locations.

Table A-1. Example of The Asphalt Institute Conversion Factors for Estimating Thickness of Existing Pavement Components to Effective Thickness (after Ref. A-1)

Description of Layer Material		Conversion Factor[1]
1.	Native subgrade	0.0
2.	a. Improved subgrade — predominantly granular materials	
	b. Lime modified subgrade of high PI soils	
3.	a. Granular subbase or base — CBR not less than 20	0.1-0.3
	b. Cement modified subbases and bases constructed from low PI soils	
4.	a. Cement or lime-fly ash bases with pattern cracking b. Emulsified or cutback asphalt surfaces and bases with extensive cracking, rutting, etc. c. PCC pavement broken into small pieces	0.3-0.5
5.	a. Asphalt concrete surface and base that exhibit extensive cracking	0.5-0.7
6.	a. Asphalt concrete — generally uncracked b. PCC pavement — stable, undersealed and generally uncracked pavement	0.9-1.0
7.	Other categories of pavement layers listed in Ref. A-1	

[1] Equivalent thickness of new asphalt concrete

Table A-2. Approximate ESAL Estimates for Various WSDOT Routes

Highway Type and Route	Estimated 18,000 lb ESALs per Year
Interstate	
• SR5 (North Seattle)	2,000,000
• SR5 (Centralia)	2,000,000
• SR90 (Moses Lake)	750,000
• SR90 (Spokane)	1,000,000
US	
• SR2 (Stevens Pass)	150,000
• SR97 (Swauk Pass)	125,000
• SR195 (Pullman South)	175,000
State	
• SR17 (Leahy South)	50,000
• SR20 (Washington Pass)	50,000
• SR21 (Republic South)	25,000

An alternative approach for estimating ESALs is to multiply ESAL factors by specific classifications of trucks and buses and sum the results. Such ESAL factors have been compiled by the FHWA (Table A-3a) and for WSDOT conditions (Table A-3b). This approach can accommodate a wide variety of truck information ranging from only an estimate of the percent of the Average Daily Traffic (ADT) which constitutes trucks to estimates of trucks broken into categories of single and multi-units as illustrated in Table A-3b.

The term "truck factor" or "ESAL factor" represents the average ESAL per truck (or axle). The truck factors shown in Table A-3b suggest an overall ESAL per truck of about 1.2 (this represents both loaded and unloaded trucks). Thus, if a project was expected to have 1,000,000 "trucks" during the design period, the resulting ESALs would be about 1,200,000.

Specifically, the WSPMS "imports" truck classification data in terms of single units (two axles), combination units (tractor-semi-trailer), and tractor-multi-trailer units. The associated ESAL factors are 0.25 ESAL per single unit, 1.0 ESAL per combination unit (assumes four axles), and 1.75 ESALs per multi-trailer unit (assumes seven axles). Further, an annual growth rate of 1.6 percent is used for all cases.

3.4 Example of the Unmodified Asphalt Institute Procedure

A two-lane highway has the following characteristics and resulting overlay requirement.

1. **Traffic**

    (a) Average Daily Traffic = 4,000

    (b) Percent trucks (total all units) = 10%

    (c) Traffic growth rate = 4%

Table A-3a. Average Truck Factors Compiled from FHWA Data (after Ref. A-1)

Vehicle Types	Truck Factors (ESALs/truck)				
	Rural Highways			Urban Highways	Combined
	Interstate	Other	All	All	All
1. Single-units					
(a) 2-axle, 4-tire	0.02	0.02	0.03	0.03	0.02
(b) 2-axle, 6-tire	0.19	0.21	0.20	0.26	0.21
(c) 3-axles or more	0.56	0.73	0.67	1.03	0.73
(d) All single-units	0.07	0.07	0.07	0.09	0.07
2. Tractor semi-trailers					
(a) 3-axle	0.51	0.47	0.48	0.47	0.48
(b) 4-axle	0.62	0.83	0.70	0.89	0.73
(c) 5-axles or more	0.94	0.98	0.95	1.00	0.95
(d) All multiple units	0.93	0.97	0.94	1.00	0.95
3. All trucks	0.49	0.31	0.42	0.30	0.40

Table A-3b. Summary of ESAL Factors [from Ref. A-5]

Highway System	ESAL Factors				
	Single Units	Combination Units	Buses	Individual Axle	Overall Truck*
Interstate	0.30	1.25	1.60	0.25	1.20
Non-Interstate Rural	0.50	1.50	1.60	0.25	1.40
Non-Interstate Urban	0.25	1.20	1.60	0.25	1.00

*Excludes buses

2. **Existing pavement structure and condition**

(a) Asphalt concrete = 0.35 ft (4.2 in.)

(b) Crushed stone base = 0.80 ft (9.6 in.)

(c) Subgrade design strength value: CBR = 8 or M_r = 12, 000 psi

(d) Overall, the pavement structure is in poor condition with asphalt concrete exhibiting well defined crack patterns

3. **Determine overlay thickness for a 10-year period**

(a) 18,000 lb. equivalent single axle loads

(i) Number of trucks in the design lane per day = (4,000) (0.50) (0.10) = 200

(ii) ESALs/day = 200 (1.4 ESALs/truck) = 280/day

(iii) If annual ESAL growth rate = 1.6 percent for 10 years, then

$$\frac{(1 + 0.016)^{10} - 1}{0.016} = 10.8$$

(iv) ESALs for design period =- (280 ESALs/day) (365 days/yr) (10.8) = 1,100,000 after adjustment for design period and traffic growth rate

(b) Effective pavement thickness

Layer Thickness (in.)		Conversion Factor (Table A-1)		Effective Thickness (in.)
4.2	x	0.5	=	2.1
9.6	x	0.2	=	1.9
		Total Te	=	4.0

(c) Required new "Full-Depth" asphalt concrete pavement thickness (Tn) = 8.0 in. (refer to Figure A-1).

(d) Thickness of asphalt concrete overlay = Tn - Te = 8.0 - 4.0 in. = 4.0 in.

4. WSDOT OVERLAY SCOPE METHOD

The following subsections will overview three of the needed parameters to estimate AC overlay thickness: conversion factors for existing pavements, subgrade modulus, and full-depth AC thickness.

FULL-DEPTH ASPHALT CONCRETE

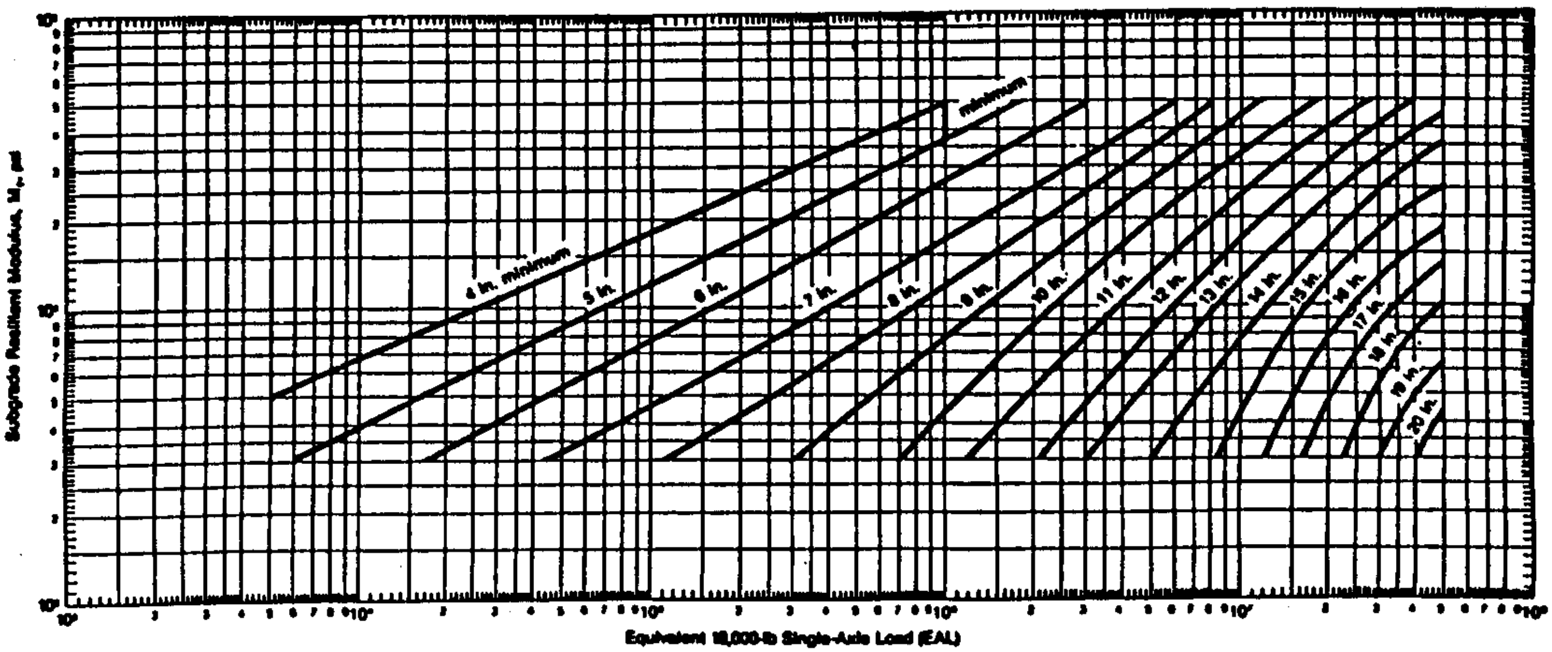

Figure A-1. The Asphalt Institute Design Chart for Full-Depth Asphalt Concrete Pavement (from Ref. A-1)

4.1 Conversion Factors

There are several elements from The Asphalt Institute component analysis method that have been modified to better conform to WSDOT conditions and practice. The primary modification is the layer conversion factors used to convert existing layers into equivalent new asphalt concrete thicknesses. These "initial" conversion factors ("C") were made a function of surface distress (both extent and severity). These factors are shown in Table A-4 (Asphalt Concrete Surface Courses and Asphalt Treated Bases (ATB)), Table A-5 (Emulsified or Cutback Asphalt Surface Courses and Bases), and Table A-6 (Base and Subbase Courses Other than ATB).

The initial implementation of the scoping technique resulted in numerous enhancements and refinements. A major enhancement was the development of the Pavement Structural Condition (PSC) value which replaces the Pavement Condition Rating (PCR). The PSC can be used as a direct predictor of past, current, or future conversion factors ("C") for ACP or BST wearing courses. (Note: the details associated with the calculation of PSC are contained in the main body of the report). The relationship between the conversion factors and PSC are:

(a) ACP Wearing Course

$$\text{"C"} = 0.3 + [(PSC)(0.007)]$$

whereby if PSC = 0 then C = 0.3

PSC = 100 then C = 1.0

(b) BST Wearing Course

$$\text{"C"} = 0.3 + [(PSC)(0.005)]$$

whereby if PSC = 0 the C = 0.3

PSC = 100 then C = 0.8

These equations are simply linear functions scaled between the maximum and minimum values.

Table A-4. Initially Used Conversion Factors for Determining Equivalent Thickness of Asphalt Concrete for Asphalt Concrete Surface Courses and Asphalt Treated Bases

Type of Distress			Conversion Factor (C)
Fatigue Cracking		Rutting	
Extent (%)[1]	Severity[2]		
0	—	0	1.0
0	—	<1/4"	0.9
0	—	≥ 1/4", < 1/2"	0.8
0	—	≥ 1/2", < 3/4"	0.7
0	—	≥ 3/4", < 1-1/2"	0.6
0	—	≥ 1-1/2"	Reconst or Mill and Overlay
< 10%	H	0, < 1/2"	0.7
< 10%	S	0, < 1/2"	0.5
≥ 10%, < 25%	H	0, < 1/2"	0.6
≥ 10%, < 25%	S	0, < 1/2"	0.4
≥ 25%	H	0, < 1/2"	0.5
≥ 25%	S	0, < 1/2"	0.3
< 10%	H or S	≥ 1/2", < 3/4"	0.5
< 10%	H or S	≥ 3/4", < 1-1/2"	0.4
< 10%	H or S	≥ 1-1/2"	Reconst or Mill and Overlay
≥ 10%, < 25%	H or S	≥ 1/2", < 3/4"	0.4
≥ 10%, < 25%	H or S	≥ 3/4", < 1-1/2"	Reconst or Mill and Overlay
≥ 10%, < 25%	H or S	≥ 1-1/2"	Reconst or Mill and Overlay
≥ 25%	H or S	≥ 1/2", < 3/4"	0.3
≥ 25%	H or S	≥ 3/4", < 1-1/2"	Reconst or Mill and Overlay
≥ 25%	H or S	≥ 1-1/2"	Reconst or Mill and Overlay

[1]Percentage of wheel track per station
[2]H = hairline; S = spalling

Table A-5. Initially Used Conversion Factors for Determining Equivalent Thickness of Asphalt Concrete for Emulsified or Cutback Asphalt Mixtures (Surfaces and Bases)[1]

Type of Distress			Conversion Factor (C)
Fatigue Cracking		Rutting	
Extent (%)[2]	Severity[3]		
0	—	0, < 1/2"	0.8
0	—	≥ 1/2", < 3/4"	0.6
0	—	≥ 3/4", < 1-1/2"	0.5
0	—	≥ 1-1/2"	Reconst or Mill and Overlay
< 10	H	0, < 1/2"	0.6
< 10	S	0, < 1/2"	0.4
≥ 10, < 25	H	0, < 1/2"	0.5
≥ 10, < 25	S	0, < 1/2"	0.3
≥ 25	H	0, < 1/2"	0.4
≥ 25	S	0, < 1/2"	0.2
< 10	H	≥ 1/2", < 3/4"	0.55
< 10	H	≥ 3/4", < 1-1/2"	0.4
< 10	H	≥ 1-1/2"	Reconst or Mill and Overlay
< 10	S	≥ 1/2", < 3/4"	0.3
< 10	S	≥ 3/4", < 1-1/2"	0.25
< 10	S	≥ 1-1/2	Reconst or Mill and Overlay
≥ 10, < 25	H	≥ 1/2", < 3/4"	0.4
≥ 10, < 25	H	≥ 3/4", < 1-1/2"	0.3
≥ 10, < 25	H	≥ 1-1/2"	Reconst or Mill and Overlay
≥ 10, < 25	S	≥ 1/2", < 3/4"	0.3
≥ 10, < 25	S	≥ 3/4", < 1-1/2"	0.2
≥ 10, < 25	S	≥ 1-1/2"	Reconst or Mill and Overlay
≥ 25	H	≥ 1/2", < 3/4"	0.3
≥ 25	H	≥ 3/4", < 1-1/2"	0.2
≥ 25	H	≥ 1-1/2"	Reconst or Mill and Overlay
≥ 25	S	≥ 1/2", < 3/4"	0.25
≥ 25	S	≥ 3/4", < 1-1/2"	Reconst or Mill and Overlay
≥ 25	S	≥ 1-1/2"	Reconst or Mill and Overlay

[1] This includes "built-up" BST/seal coat combinations
[2] Percentage of wheel track per station
[3] H = hairline; S = spalling

Table A-6. Initially Used Conversion Factors for Determining Equivalent Thickness of Asphalt Concrete for Base and Subbase Courses Other than ATB

	Type of Material	Conversion Factor (C)
•	Portland Cement Concrete (overlaid by ACP)	0.50
•	Cement Stabilized Granular Material	0.4
•	Cement stabilized, low PI soil	0.2
•	Lime or lime-flyash stabilized crushed stone or gravel	0.3
•	Other lime stabilized layer excluding high PI subgrade soils	0.15
•	Crushed stone - Crushed Surfacing Top Course - Crushed Surfacing Base	 0.35 0.30
•	Any other granular material with CBR ≥ 20	0.2
•	Sand	0.1

Table A-7. Subgrade Classes (after Ref. A-1)

Soil Class	Characteristics	Design Modulus
Poor	Soft and plastic when wet, generally composed of silts and clays	4,500 psi
Medium	Includes loams, silty sands, and sand-gravels which contain moderate amounts of clay and silt. Can be expected to lose only a moderate amount of strength when wet.	12,500 psi
Good	Expected to retain substantial amount of strength when wet. Includes clean sands and sand-gravels.	25,000 psi

For ACP or BST layers below the wearing course, the conversion factors fall into ranges as follows:

(a) "Buried" ACP Wearing Course: "C" = 0.65 (max) to 0.30 (min)

(b) "Buried" BST: "C" = 0.55 (max.) to 0.30 (min)

The maximum "C" assumes a PSC = 50 when "buried" ("buried" implies being overlaid or resurfaced). The minimum "C" assumes a PSC = 0. The exception to this is that the "buried" ACP and BST "C" reverts to the wearing course "C" if the wearing course value is less than the maximum limits (ACP = 0.65, BST = 0.55) for the buried layers.

4.2 Subgrade Modulus

The subgrade modulus is required to obtain a thickness for a "new" full-depth asphalt concrete pavement (along with the design ESALs). There are at least three options for estimating this modulus value.

4.2.1 Deflection Data

The WSDOT FWD deflection data can be used along with the following equation to estimate the subgrade modulus (equation from a recent NCHRP study [A-6] which will be used to revise Part III of the AASHTO Pavement Guide [A-7]):

$$M_R = P\,(1 - \mu^2)/(\pi)(D_r)(r) \qquad \text{(Eq. 3)}$$

where M_R = backcalculated subgrade resilient modulus (psi),

P = applied load (lbs),

D_r = pavement surface deflection a distance r from the center of the load plate (inches),

μ = Poisson's ratio for the subgrade (usually fixed at 0.45), and

r = distance from center of load plate to D_r (inches).

An earlier version of the WSDOT scoping technique used the equations developed by Newcomb [A-3].

4.2.2 Subgrade Classes

The general subgrade classes can be used as shown in Table A-7 (also described in Paragraph 3.1). In other words, one can select the basic subgrade class for each specific pavement segment. In lieu of this, the single best category to choose in Table A-7 is 12,500 psi. This recommendation is based on review of extensive amounts of backcalculated layer moduli throughout the state and WSDOT triaxial laboratory tests. Actually, use of 12,500 psi is somewhat conservative since 13 subgrade samples tested by WSDOT averaged 19,300 psi with a standard deviation of 8,600 psi. Thus, 12,500 psi is about the average of the samples tested minus one standard deviation. This range of subgrade moduli undoubtedly appear somewhat "high." Most of the WSDOT triaxial testing to date on "subgrades" are borrow materials used to create the roadway embankment.

4.2.3 Performance Based

If one assumes that the PSC - Age relationship for each pavement segment is primarily influenced by subgrade modulus, then it is possible to develop a "rule of thumb" from this relationship to estimate subgrade modulus. One must caution that the following can at best be only approximately correct and at worst very wrong.

An examination of Figure A-1 shows that for various levels of design ESALs, halving or doubling the subgrade modulus from some nomial value increases or decreases the required AC depth by about 1.5 inches. For example:

Subgrade Modulus (psi)	AC Thicknesses Design ESALs 100,000	 1,000,000	 10,000,000
6,250	6.3"	9.3"	14.3"
12,500 (nomial)	4.9"	7.9"	12.9"
25,000	—	6.1"	10.9"

Further, if one assumes a nomial subgrade modulus of 12,500 psi for a design ESALs of 1,000,000, then the range of ESALs is 2,400,000 (+1.5 inch AC) to 350,000 (-1.5 inch AC). Dividing the range of subgrade moduli (25,000 - 6,250 psi) by the associated ESAL range (2,400,000 - 350,000) results in 9.1 psi per 1,000 ESALs (or round off to 10 psi per 1,000 ESALs).

The way the above rule of thumb can be used is illustrated as follows:

- If normal Age to PSC = 50 is, say, 12.5 years (from standard (default) equation), but actual Age at PSC = 50 is 10 years, then ΔAge = 2.5 years (12.5 - 10). Multiply ΔAge x ESALs/year = ESALs. This provides an estimate of the "reduced" ESALs. If ESALs/year = 100,000, then

  ΔAge x ESALs/year = 2.5 year x 100,000/year

  = 250,000 ESALs (or 250 1,000 ESALs).

  Thus, estimated subgrade modulus

  $$= \text{nomial modulus} - \left(\frac{10 \text{ psi}}{1{,}000 \text{ ESALs}}\right)(250\ 1{,}000 \text{ ESALs})$$

  $$= 12{,}500 \text{ psi} - 2{,}500 \text{ psi} = 10{,}000 \text{ psi}.$$

  Thus, M_r = 10,000 psi for the purpose of obtaining a full-depth, new AC thickness from Figure A-1.

The above calculations, again, assumes any <u>loss</u> in performance is associated with a <u>lower</u> than <u>nomial</u> subgrade modulus. This assumption is, of course, overly simplistic; however, some attempt must be made to account for less than nomial pavement performance. Further, this method of estimating subgrade resilient modulus need only be considered until such time as all WSDOT pavements have representative FWD deflection data and, hence, improved estimates of subgrade modulus.

4.3 Calculation of Full-Depth Asphalt Concrete Pavement

O'Neil [A-4] developed the following regression equation which can be used to estimate full-depth AC as a function of subgrade modulus and ESALs:

$$\text{Asphalt Thickness (inches)} = -3.845 + 5.672 (\ln (M_r)) - 0.4390 (\ln (M_r))^2 - 2.197 (\ln (\text{ESAL})) + 0.1455 (\ln (\text{ESAL}))^2 \quad \text{(Eq. 5)}$$

$R^2 = 0.996$
RMSE = 0.299 inch
n = 67 points taken from Figure A-1.

For example, from Figure A-1, for ESALs = 1,000,000 and M_r = 12,500 psi, the full-depth AC thickness is about 7.9 inches. Inserting these ESALs and M_r into Equation 5:

$$
\begin{aligned}
\text{AC (inches)} = \; & -3.845 + 5.672 (\ln (12{,}500)) \\
& - 0.4390 (\ln (12{,}500))^2 \\
& -2.197 (\ln (1{,}000{,}000)) \\
& +0.1455 (\ln (1{,}000{,}000))^2 \\
= \; & 8.0 \text{ inches}
\end{aligned}
$$

A 0.1 inch difference is only 0.0083 ft of AC overlay, an acceptable variation.

4.4 Illustration of Method

For a pavement segment that requires an overlay,

- Design ESALs = 1,000,000 (assumed)
- Subgrade resilient modulus = 12,500 psi (known or calculated)
- Full-depth new AC = 8.0 inches (calculated from Equation 5)
- Existing pavement structure
  - 4.2 inches AC (PSC = 60; thus "C" = 0.72)
  - 9.6 inches crushed stone base (CSTC/CSB)
  - Subgrade (nomial)
- Convert existing to full-depth AC

- AC:	4.2 inches x 0.72	=	3.0 inches
- Base:	9.6 inches x 0.30 (Table A-6)	=	2.9 inches
			5.9 inches

- "Scoped" overlay thickness

  8.0 inches - 5.9 inches = 2.1 inches (or about 0.18 ft)

4.5 Discussion

To initially evaluate the overlay scoping technique, three separate pavement sections were evaluated at different ESAL, subgrade moduli, and distress levels. The ESAL levels were set at 1 x 10^5, 1 x 10^6, and 1 x 10^7; the subgrade moduli at 4,500 psi, 12,500 psi, and 25,000 psi; the distress levels were a function of fatigue cracking only (none, less than 10 percent hairline cracking, greater than 10 percent but less than 25 percent hairline cracking, and greater than 25 percent spalling cracks). The distress levels were used along with Tables A-4 and A-6 (conversion factors) to calculate the "existing" full-depth AC thickness (t_x). The new AC full-depth thickness (t_n) was calculated by use of Equation 5 (recall that this equation was developed from Figure A-1). The difference between t_n and t_x is the required overlay thickness (t_o). These results are shown in Tables A-8, A-9, and A-10.

The overlay thicknesses appear to be somewhat typical. However, one interesting observation is the influence of extensive pavement distress (as illustrated by the $\geq$ 25 percent fatigue cracking) on the required overlay. The overlay thickness is nearly independent of the original pavement structure if extensive distress is allowed to accumulate (based on t_o values in Tables A-8, A-9, and A-10). This tends to reconfirm what the authors have previously observed on a few, prior, relatively thick overlay designs for the WSDOT route system.

5. FUTURE ENHANCEMENTS

The scoping technique does not have any type of reliability to account for project uncertainties (and hence uncertainty relative to pavement performance). The addition of reliability can be added to the technique if desired.

6. SUMMARY

The previously described overlay scoping method can only be considered as approximate; however, prior experience with OVERDRIVE (and limited comparisons to other design methods) has shown the resulting overlay thicknesses to be reasonable. Only experience with the proposed approach will prove its value or show that further modifications are required.

Table A-8. Overlay Thicknesses for Various Levels of ESALs, Pavement Thicknesses, and Distress Levels (Subgrade M_r = 4,500 psi)

Existing Pavement Structure	Distress Level[1]	ESALs								
		100,000			1,000,000			10,000,000		
		Calculated Thicknesses			Calculated Thicknesses			Calculated Thicknesses		
		t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)	t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)	t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)
1.5" AC	None	5.1	6.8	1.7	5.1	10.2	5.1	5.1	15.2	10.1
	< 10% H	4.6	6.8	2.2	4.6	10.2	5.6	4.6	15.2	10.6
12.0" BASE	≥ 10 < 25% H	4.5	6.8	2.3	4.5	10.2	5.7	4.5	15.2	10.7
(CSTC)	≥ 25% S	4.0	6.8	2.8	4.0	10.2	6.2	4.0	15.2	11.2
3.0" AC	None	5.4	6.8	1.4	5.4	10.2	4.8	5.4	15.2	9.8
	< 10% H	4.5	6.8	2.3	4.5	10.2	5.7	4.5	15.2	10.7
8.0" BASE	≥ 10 < 25% H	4.2	6.8	2.6	4.2	10.2	6.0	4.2	15.2	11.0
(CSTC)	≥ 25% S	3.3	6.8	3.5	3.3	10.2	6.9	3.3	15.2	11.9
6.0" AC	None	8.4	6.8	0.0	8.4	10.2	1.8	8.4	15.2	6.8
	< 10% H	6.6	6.8	0.2	6.6	10.2	3.6	6.6	15.2	8.6
8.0" BASE	≥ 10 < 25% H	6.0	6.8	0.8	6.0	10.2	4.2	6.0	15.2	9.2
(CSTC)	≥ 25% S	4.2	6.8	2.6	4.2	10.2	6.0	4.2	15.2	11.0

[1] Distress levels for fatigue cracking only

(2) t_x: Equivalent thickness of new AC based on "C" factors from Tables A-4 and A-6

(3) t_n: From Equation 5 (fixed M_r = 4,500 psi)

(4) $t_o = t_n - t_x$

Table A-9. Overlay Thicknesses for Various Levels of ESALs, Pavement Thicknesses, and Distress Levels (Subgrade M_r = 12,500 psi)

Existing Pavement Structure	Distress Level[1]	ESALs								
		100,000			1,000,000			10,000,000		
		Calculated Thicknesses			Calculated Thicknesses			Calculated Thicknesses		
		t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)	t_x (2) (in.)	t_n (3) (in.)	t_o (4) (in.)	t_x (2) (in.)	t_n (3) (in.)	t_o (4) (in.)
1.5" AC	None	5.1	4.6	0.0	5.1	8.0	2.9	5.1	13.0	7.9
	< 10% H	4.6	4.6	0.0	4.6	8.0	3.4	4.6	13.0	8.4
12.0" BASE	≥ 10 < 25% H	4.5	4.6	0.1	4.5	8.0	3.5	4.5	13.0	8.5
(CSTC)	≥ 25% S	4.0	4.6	0.6	4.0	8.0	4.0	4.0	13.0	9.0
3.0" AC	None	5.4	4.6	0.0	5.4	8.0	2.6	5.4	13.0	7.6
	< 10% H	4.5	4.6	0.1	4.5	8.0	3.5	4.5	13.0	8.5
8.0" BASE	≥ 10 < 25% H	4.2	4.6	0.4	4.2	8.0	3.8	4.2	13.0	8.8
(CSTC)	≥ 25% S	3.3	4.6	1.3	3.3	8.0	4.7	3.3	13.0	9.7
6.0" AC	None	8.4	4.6	0.0	8.4	8.0	0.0	8.4	13.0	4.6
	< 10% H	6.6	4.6	0.0	6.6	8.0	1.4	6.6	13.0	6.4
8.0" BASE	≥ 10 < 25% H	6.0	4.6	0.0	6.0	8.0	2.0	6.0	13.0	7.0
(CSTC)	≥ 25% S	4.2	4.6	0.4	4.2	8.0	3.8	4.2	13.0	8.8

1 Distress levels for fatigue cracking only

(2) t_x: Equivalent thickness of new AC based on "C" factors from Tables A-4 and A-6

(3) t_n: From Equation 5 (fixed M_r = 12,500 psi)

(4) $t_o = t_n - t_x$

Table A-10. Overlay Thicknesses for Various Levels of ESALs, Pavement Thicknesses, and Distress Levels (Subgrade M_r = 25,000 psi)

Existing Pavement Structure	Distress Level[1]	ESALs								
		100,000			1,000,000			10,000,000		
		Calculated Thicknesses			Calculated Thicknesses			Calculated Thicknesses		
		t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)	t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)	t_x(2) (in.)	t_n(3) (in.)	t_o(4) (in.)
1.5" AC	None	5.1	4.0(5)	0.0	5.1	6.0	0.9	5.1	11.0	5.9
	< 10% H	4.6	4.0	0.0	4.6	6.0	1.4	4.6	11.0	6.4
12.0" BASE	≥ 10 < 25% H	4.5	4.0	0.0	4.5	6.0	1.5	4.5	11.0	6.5
(CSTC)	≥ 25% S	4.0	4.0	0.0	4.0	6.0	2.0	4.0	11.0	7.0
3.0" AC	None	5.4	4.0	0.0	5.4	6.0	0.6	5.4	11.0	5.6
	< 10% H	4.5	4.0	0.0	4.5	6.0	1.5	4.5	11.0	6.5
8.0" BASE	≥ 10 < 25% H	4.2	4.0	0.0	4.2	6.0	1.8	4.2	11.0	6.8
(CSTC)	≥ 25% S	3.3	4.0	0.7	3.3	6.0	2.7	3.3	11.0	7.7
6.0" AC	None	8.4	4.0	0.0	8.4	6.0	0.0	8.4	11.0	2.6
	< 10% H	6.6	4.0	0.0	6.6	6.0	0.0	6.6	11.0	4.4
8.0" BASE	≥ 10 < 25% H	6.0	4.0	0.0	6.0	6.0	0.0	6.0	11.0	5.0
(CSTC)	≥ 25% S	4.2	4.0	0.0	4.2	6.0	1.8	4.2	11.0	6.8

---

[1] Distress levels for fatigue cracking only

(2) t_x: Equivalent thickness of new AC based on "C" factors from Tables A-4 and A-6

(3) t_n: From Equation 5 (fixed M_r = 25,000 psi)

(4) $t_o = t_n - t_x$

(5) The Asphalt Institute recommends 4.0 inches of AC as a minimum (Equation 5 indicates 2.6 inches)

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APPENDIX B

INTRODUCTION TO PREDICTION MODELS AND PERFORMANCE CURVES

APPENDIX B

INTRODUCTION TO PREDICTION MODELS AND PERFORMANCE CURVES

1. WHY USE PREDICTION MODELS?

Of the various ways in which pavement prediction models can be developed, the fundamental reasons for developing such models can include

(a) to predict future pavement condition for specific highway segments (often to some lower limit of "acceptability"),

(b) to estimate the type and timing of maintenance and/or rehabilitation for specific highway segments,

(c) to optimize the pavement condition for a complete highway network,

(d) to use as a "feedback" loop to the pavement design process, or

(e) to use in pavement life-cycle cost analyses.

Undoubtedly, other reasons could be added to the above list.

Modeling of pavement performance is essential to pavement management regardless of whether it is the project or network levels [B-1].

The terms "prediction models" and "performance curves" will be rolled into one term, "pavement models," henceforth in this appendix. Such models can take numerous forms. For example, one might want to predict some measure of pavement condition as a function of equivalent single axle loads (ESALs) or pavement age. In a more complicated manner, one might attempt to predict pavement condition as a function of material properties, traffic, and climate parameters. This would require significantly more data and, hence, effort and expense. In fact, the current AASHO Road Test performance equation is a good illustration of this, as follows:

$$\log_{10}W_{18} = (z_R)(S_0) + (9.36)(\log(SN+1)) - 0.20 + \frac{\log\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + (2.32)((\log_{10}M_R) - 8.07)$$

where

W_{18} = predicted future traffic (18,000 lb single axle loads) for the performance period,

z_R = z statistic for a specific level of reliability,

S_0 = overall standard deviation,

SN = structural number,

ΔPSI = $p_0 - p_t$ = design serviceability loss, and

M_r = effective roadbed soil resilient modulus.

2. BUILDING PERFORMANCE MODELS

2.1 Types of Models

Pavement performance models, broadly speaking, can be developed by use of techniques such as

- regression analysis (least squares),
- Markov transition probabilities, or
- Bayesian methodology.

As stated by Lytton [B-1],

> "There are several types of performance and, correspondingly, several types of performance models. Performance, in its broadest sense, is predicted by deterministic and probabilistic models. The deterministic models include those for predicting primary response, structural, functional, and damage performance of pavements. The probabilistic models include survivor curves, Markov and semi-Markov transition processes."

Lytton further pointed out the following items as significant in performance prediction and modeling [B-1]:

(a) principles underlying each type of model,

(b) selection of the model mathematical form,

(c) role of statistics and mechanics in developing an efficient model,

(d) data needed for a specific model,

(e) modification of each model to represent the effects of maintenance, and

(f) limitations and uses of specific models.

Darter [B-2] noted four basic criteria to use in developing reliable pavement models. These criteria include

(a) an adequate database built from in-service pavements,

(b) the inclusion of all variables that significantly affect pavement performance,

(c) an adequate functional form of the model, and

(d) a model that meets the proper statistical criteria for precision and accuracy (error of prediction, coefficient of determination (R^2), etc.).

As one can see, both Lytton and Darter suggest the same kinds of things as being important in pavement model building.

Lytton [B-1] developed a table that illustrated the types of performance models that may be used at various levels of pavement management (Table B-1). The types of models are separated into two broad categories:

(a) deterministic and

(b) probabilistic.

Deterministic models are generally "classic" regression models and can predict a <u>single</u> value of <u>something</u> versus probabilistic models that can predict a <u>range</u> of values of <u>something</u>.

2.1.1 Regression Analysis

Regression is a statistical tool that is used to "relate" two or more variables. Such "relationships" are rarely perfect in that one variable (for example, <u>pavement age</u>) cannot be consistently used to "perfectly" predict another variable (for example, <u>pavement condition</u>).

Table B-1. Types of Performance Models Used in Pavement Management (modified after Lytton [A-1])

Levels of Pavement Management	Types of Performance Models						
	Deterministic				Probabilistic		
	Primary Response	Structural	Functional	Damage	Survivor Curves	Transition Process Models	
	• Deflection • Stress • Strain • etc.	• Distress • Pavement Condition	• PSI • Safety • etc.	• Load Equivalent		Markov	Semi-Markov
• National Network				•	•	•	•
• State Network		•	•	•	•	•	•
• District Network		•	•	•	•	•	•
• Project	•	•	•	•			

The variable being predicted is often designated as "y" and the variable used to predict "y" is designated as "x." Thus, y is termed the dependent variable and x is the independent variable. The best relationship (equation, actually) to use to predict some from x is one that minimizes the differences between the regression line (or curve) and the actual data. The term "least squares fit" comes from the minimization of the squared differences between the actual data points and their corresponding points on the fitted line (or curve). Important parameters that can be used to judge how well an equation "fits" the actual data include:

(a) Coefficient of determination (R^2): Explains how much of the total variation in the data is explained by the regression equation (or curve).

(b) Root mean square error (RMSE): This is the standard deviation of the predicted "y" values for a specific value of x.

(c) Number of data points (n): Generally, the more data points used to develop a regression equation, the better.

(d) Hypothesis tests on regression constants (generally based on the t-statistic).

The most basic form of a regression equation would be:

$$\hat{y} = b_0 + b_1 (x)$$

where $\hat{y}$ = predicted y,

x = independent variable, and

b_0, b_1 = regression constants (b_0 = intercept and b_1 = slope).

Illustration of some deterministic models can be found in Figure B-1. The types of performance models shown in Figure B-1 is in accordance with those described in Table B-1.

As one can see, the basic straight line regression equation ($y = b_0 + b_1(x)$) is only appropriate for one of the four models shown in the figure.

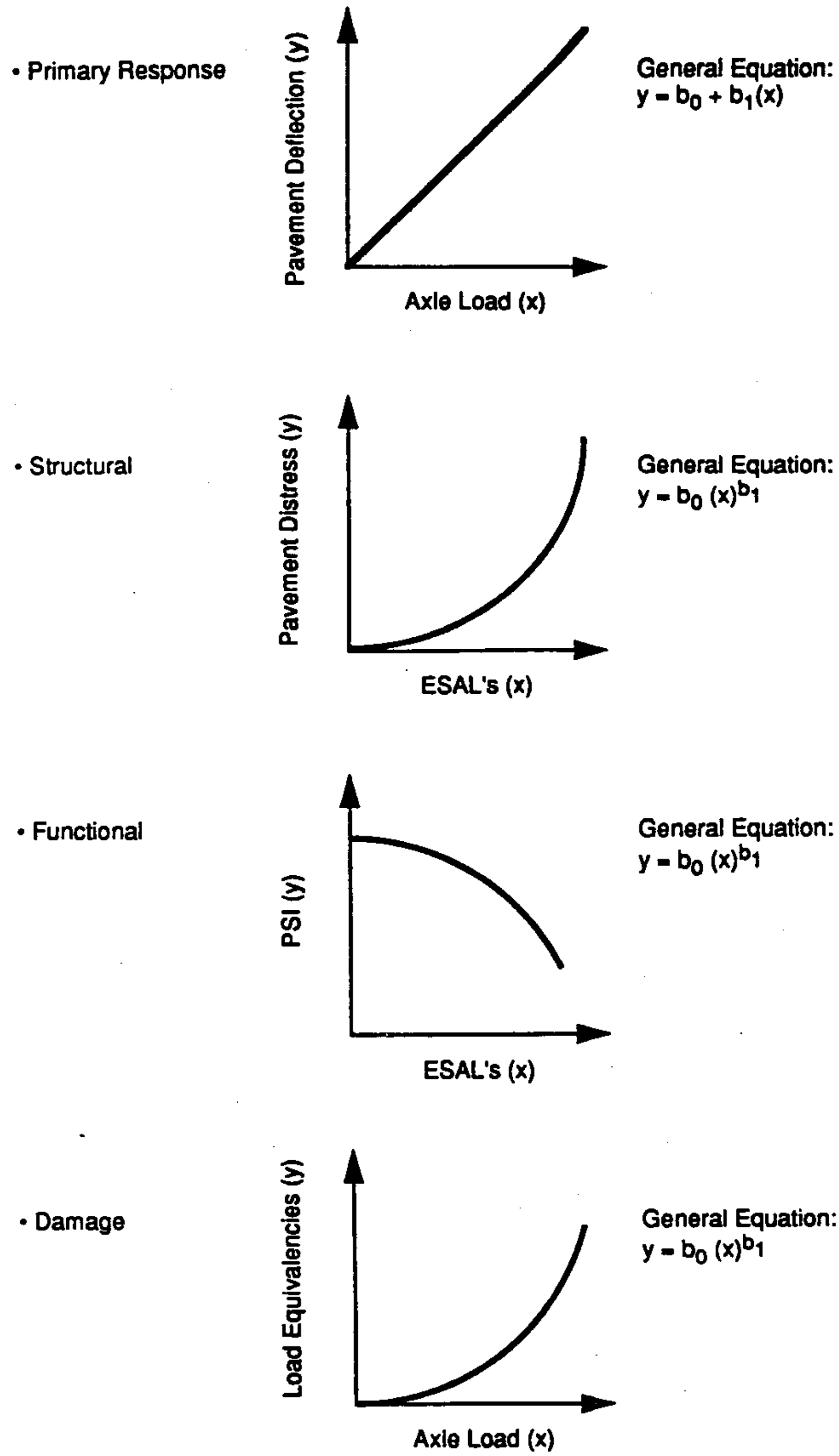

Figure B-1. Types of Performance Models

2.1.2 Markov Transition Probabilities

The basic Markov assumption is that current pavement condition, for example, is only dependent on its preceding prior condition. Further, future pavement condition is dependent only on the preceding current pavement condition. A straightforward illustration of this is shown in Figure B-2 (from Cook and Lytton [B-3]). Thus, given a pavement whose current state is a PSC = 70, then next year there is a 1 in 10 chance the PSC will be either 70, 69, or 66, a 3 in 10 chance the PSC will be 67, and a 4 in 10 chance the PSC will be 68. The probabilities are transition probabilities ("transitioning" the PSC from one PSC state to the next). Further, the Markov assumption implies that the next year PSC is independent of how the pavement acquired a current year PSC = 70.

An illustration of a probability transition matrix developed for WSDOT in the early 1970s is shown in Figure B-3. The probability states (from-to) are based on two-year intervals. The probabilities in the matrix show, for example, that when a pavement is in condition state 9 (PCR of 100 to 90), there is a 90 percent chance that it will remain in condition state 9 after two years and a 10 percent chance that it will move "down" to condition state 8 (PCR of 89 to 80). Further, there is no chance such a pavement will be in a lower condition state (zero probability). (PCR is used since the referenced information was developed for that method of calculating a condition rating.)

From such probability transition matrices, one can obtain performance prediction models. Figure B-4 shows the most likely expected performance for the probabilities shown in Figure B-3. The calculation of the plotted points shown in Figure B-4 are based on matrix multiplication, the specifics of which will not be shown in these notes. It suffices that the prediction of pavement performance at any future time is possible if one knows the initial condition state (a vector quantity) for a specific pavement and the one step (or one time period) transition matrix (also a vector).

The major advantages and disadvantages of using a probability transition matrix to obtain pavement performance prediction models [as stated in Ref. B-6]:

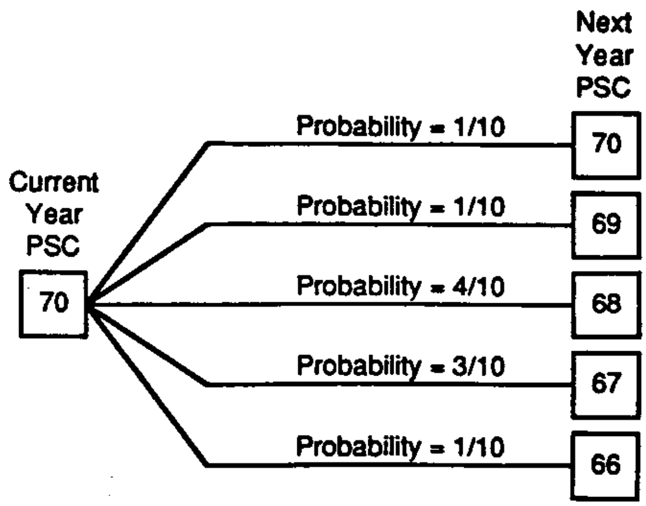

Figure B-2. Illustration of Markov Transition Probabilities by Use of Pavement Condition Rating (after Cook and Lytton [B-3])

Matrix for flexible pavement original construction with only routine maintenance

TO PCR State

		9 100-90	8 89-80	7 79-70	6 69-60	5 59-50	4 49-40	3 39-30	2 29-20	1 19-10
	9 100-90	0.90	0.10							
	8 89-80	0.05	0.65	0.30						
FROM	7 79-70		0.05	0.60	0.25	0.10				
PCR State	6 69-60			0.05	0.45	0.25	0.20	0.05		
	5 59-50				0.05	0.25	0.40	0.30		
	4 49-40					0.05	0.20	0.75		
	3 39-30						0.05	0.65	0.30	
	2 29-20							0.10	0.80	0.10
	1 19-10								0.05	0.95

Figure B-3. An Example of a Probability Transition Matrix [modified after Ref. B-6]

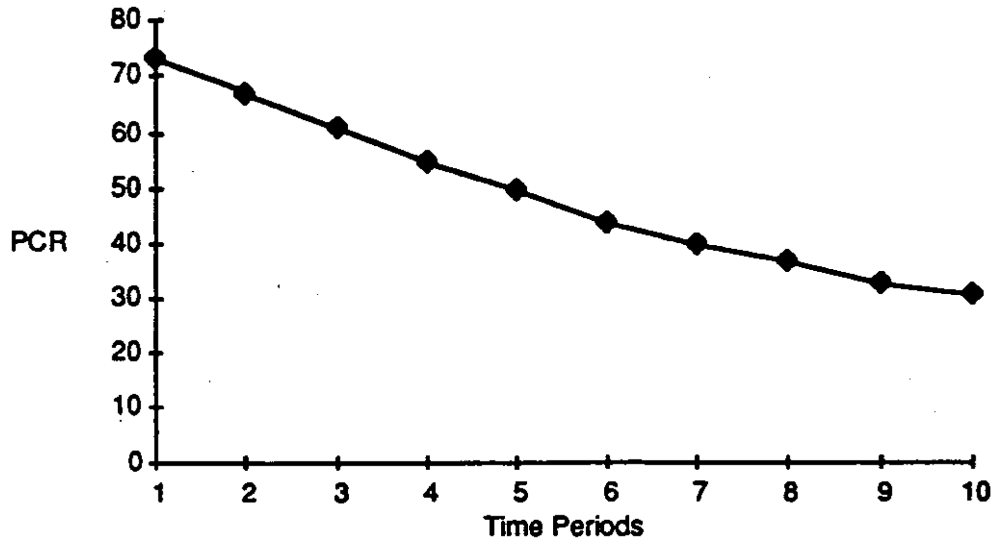

Figure B-4. Performance Prediction Obtained from Probability Transition Matrix [modified after Ref. B-6]

Advantages

(a) "It provides a convenient way to incorporate data feedback (field measurements) into a prediction model.

(b) It lends itself to subjective (experience) inputs. That is, in the absence of data to use in developing the needed matrices, the judgment of experienced personnel can be used to fill in the probabilities such as shown in Figure B-3.

(c) It provides a mathematical means for obtaining performance predictions.

(d) It provides a probabilistic distribution of the expected value of [PCR] with time which will be required to identify those sections performing significantly differently than would be expected.

(e) It will reflect performance trends obtained from field observations regardless of non-linear trends with time."

Disadvantages

(a) "It does not provide any guidance as to the physical factors which contribute to the change in [PCR].

(b) It is time independent, that is, the probability of changing from one condition state to a lower condition state is not influenced by the age of the pavement ..."

To date, it appears that Markov pavement models primarily have been used for network level PMS activities in SHAs such as Arizona, Alaska, and Kansas.

2.1.3 Bayesian Methodology

Bayesian statistic decision theory was named after Thomas Bayes, an English mathematician who published a paper in 1763 that introduced the basic concepts [B-4]. Essentially, the Bayesian methodology allows both subjectively and objectively obtained data to be combined and predictive (regression) equations developed. In fact, the approach can be used to produce regression equations exclusively developed from subjective information. One example of this was done in NCHRP Project 9-4 by obtaining opinions from engineers in several SHAs in order to develop predictive equations (Smith et al [B-5]).

In NCHRP Project 9-4, a principal model of interest was to relate pavement performance (e.g., fatigue life in years, "y") to various pavement designer-controller variables ("x's"), such as asphalt consistency (penetration), asphalt content (percent asphalt by weight of mix), asphaltic concrete proportion (percent thickness of the pavement materials above the subgrade consisting of asphalt concrete), and base course density (relative compaction based on AASHTO T-180). By using both subjective data (opinions) and objective data (generated from mechanistic models), a typical equation (for a specific SHA) appeared as follows:

General Equation Form:

$$y = b_0 + b_1 (PEN) + b_2 (AC) + b_3 (TAC) + b_4 (DEN)$$

Specific Equation:

$$y = -27.07 + 0.1114 (PEN) + 0.4313 (AC) + 0.1158 (TAC) + 0.2775 (DEN)$$

where

y = fatigue life (years),

x's = PEN, AC, TAC, DEN,

PEN = recovered penetration after three to five years of service,

AC = percent asphalt content (by weight of mix),

TAC = percent asphalt concrete thickness in structural section above subgrade, and

DEN = relative compaction of base course material using AASHTO T-180 maximum density.

For example, if PEN = 30, AC = 5.5%, TAC = 30%, and DEN = 95% (all fairly "typical" values), then the predicted asphalt concrete fatigue life would be estimated as y = 8.5 years.

In traditional regression analysis, the unknown regression (b's) are based on the observed data and assumed to have a unique value. In Bayesian regression analysis, the regression parameters are assumed to be random variables with associated probability distributions (analogous to a mean and standard deviation).

2.2 Project vs. Network Level Regression Models

The development and, to some extent, the use of pavement performance regression based models is a function of whether the models are used at the project or network levels. This section will outline some of the model development considerations you may need to be aware of.

First, the availability of appropriate data to develop a pavement model is critical. At the project level, this often is not a major problem as project specific information, such as annual condition ratings, age, ESALs, layer thickness, etc., are available. For the manner in which WSDOT models its projects, only PSC and Age are needed for each unique pavement segment. A network model requires the same kind of information, but often is impaired by what one might call the "on-the-diagonal problem" (illustrated in Figure B-5). This stems from obtaining and attempting to model network level pavement performance data for "designed" pavement structures. Because most SHA pavements are designed for local traffic, material, and climate conditions, it should be no surprise that these effects are difficult to "observe" in the data. Figure B-5 shows that thicker pavements are observed for higher traffic levels (i.e., designed). Thus, if you would like a model to reflect how traffic (ESALs) should influence pavement performance (such as PSC), then you need a wide range of PSCs, ESALs, and thicknesses; however, for pavements with equal design periods, the variation of PSC with ESALs is often "hidden," i.e., the pavements will have about the same level of condition (approximately the same PSC for equal age) regardless of ESAL level, because the thickness is a related factor. This issue suggests why network level performance models often have several independent variables and further why test tracks overcome some of these modeling problems for the performance data obtained (whereby a wide range of pavement thicknesses are subjected to equal traffic).

A second consideration in the development of project and network level PMS models is the model form. The basic WSDOT project level model is quite straightforward

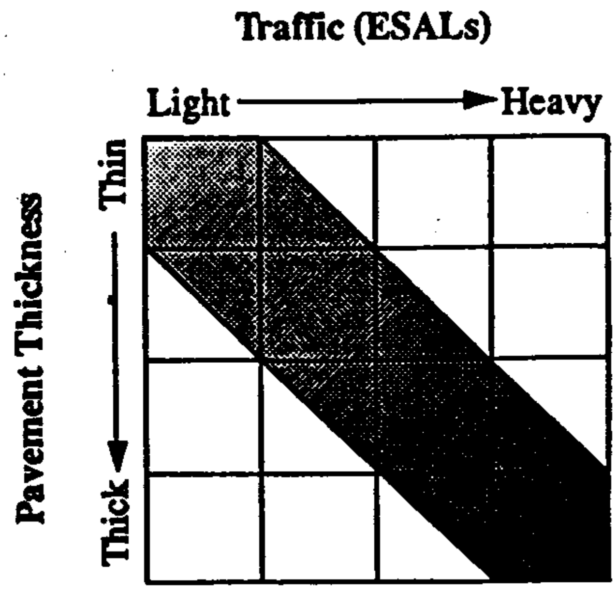

Figure B-5. Illustration of the "On-the-Diagonal" Performance "Problem" for Pavement Structures (as shown in Table B-2). This is due to the fact that each unique pavement segment on the WSDOT route system is modeled and generally well represented by PSC (dependent variable) and Age (independent variable), keeping in mind that WSDOT wants to predict when each pavement segment will reach an "unacceptable" condition. On the other hand, a network level model may need to be somewhat more complicated (as shown in Table B-2).

One's expectations as to how to evaluate a model, once developed, in terms of R^2, RMSE, sample size, and the number of independent variables, is a function of PMS levels (shown in Table B-3). In other words, how one models and one's expectations for how well the model predicts is very much a function of the type of model (project level or network level). For example, WSDOT project level models typically have R^2 values of 0.9 or better, RMSE of 5 or less PSC points, sample sizes of about 3 to 6 data points (PCR and Age pairs) and, of course, one independent variable (Age). Network level models will often have R^2 values of less than 0.9 (often much lower), the RMSE will be higher, the sample size substantially larger (hopefully 20 or more data points — depends somewhat on the number of independent variables), and the number of independent variables will be greater. Also, it must be added that the best model "shape" (straight line, curve, S-shape, etc.) is important, as well.

Finally, Table B-4 is used to illustrate a few considerations about the independent variables used in pavement performance modeling. Usually, network models will require independent variable transformations (to logs, square roots, etc.) to become adequate predictors of the dependent variable.

These transformations are often selected based on theoretical concepts, but, undoubtedly, their final selection will involve a process of trial-and-error (try something — see if it works). Further, one must be concerned about correlation among the independent variables. For example, if you have both AC thickness and ESALs in the

Table B-2. General Model Forms for Prediction of PCR

PMS Model Type	Model Form
WSDOT Project Specific	$PSC = b_0 - b_1(Age)^{Power}$
Network (an example)	$PSC = b_0 - b_1\,(ESALs) + b_2\,(AC\ Thick)$

Table B-3. PMS Regression Parameter Expectations as a Function of Model Type

	Regression Parameter Expectations			
PMS Model Type	R^2	RMSE	Sample Size (n)	Number of Independent Variables (x's)
WSDOT Project Specific	High Value	Low Value	Small Sample	1
Network (an example)	Medium to Low Values	Medium to High Values	Large Sample	More than 1

Table B-4. PMS Models and Independent Variable Considerations

PMS Model Type	Need for Independent Variable Transformation?	Correlation Among Independent Variables?	Test Independent Variable(s) for Significance (t-test)?
WSDOT Project Specific	Yes	No (only 1 independent used, which is Age)	No
Network (an example)	Most Likely	Can be a problem	Very Important

same equation, you should expect the two variables to be related (i.e., AC thickness increases as ESALs increase). This correlation among independent variables diminishes the predictive capability of the overall model. Lastly, one should check whether the regression coefficients ("b's") are "significant." This is done with hypothesis tests. If the regression coefficients test as "insignificant" (a statistical way of saying that a regression coefficient is no different than 0, a formal way of saying it's essentially worthless), then the independent variable, as used, has little or no predictive capability for the dependent variable. Such independent variables should be dropped from the model or transformed in some fashion and evaluated again.

An example of a very straightforward "network" model developed from WSDOT's PMS database was for predicting PCR (dependent variable) as a function of the following independent variables: Age, ESALs, and surface course thickness (or overlay thickness). (PCR is used since this information was developed prior to the adoption of either PSC or PCI.)

The "best" equation from the database without using variable transformations was:

$$PCR = 95.1 - 4.51\,(AGE) + 2.69\,(THICK)$$

$R^2 = 65\%$
RMSE = 15 PCR points
n = 383 pavement sections

where PCR = Pavement Structural Condition

= 100 - Σ (Distress Deduct Points),

AGE = Pavement age (years) determined from the time of construction of the overlay to the time of the last condition survey (hence last PCR),

THICK = Thickness (inches) of asphalt concrete overlay, and

n = number of overlaid sections used in developing the regression equation.

One can contrast the above equation to a "typical" WSDOT project specific equation such as:

$$PCR = 100 - 0.7\,(AGE)^{1.75}$$

$R^2 > 90\%$
RMSE < 5 PCR points
$n \cong 5$ data points

This equation is typical of an asphalt concrete overlaid pavement section in western Washington.

This appendix will be concluded by noting that multiple independent variable models always have an increasing R^2 as the number of independent variables increases. If an added independent variable is a poor predictor of the dependent variable, then it will increase the R^2 very little (but the R^2 will increase all the same). Needless to say, we want independent variables in the model which substantially contribute to the overall predictive capability of the model.

3. REFERENCES

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APPENDIX C

REVISED CODE OF WASHINGTON CHAPTER 47.05 PRIORITY PROGRAMMING FOR HIGHWAY DEVELOPMENT

SECTIONS

State highway improvement projects in urban areas, priority programming to be accorded: RCW 47.26.070

47.05.010 Declaration of purpose. The legislature finds that anticipated revenues available for state highways for the foreseeable future will fall substantially short of the amount required to satisfy all of the state highway needs. It is the purpose of this chapter to 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. [1969 ex.s. c 39 § 1; 1963 c 173 § 1.]

47.05.021 Functional classification of highways. (1) The transportation commission if hereby directed to conduct periodic analyses of the entire state highway system, report thereon to the chairs of the transportation committees of the senate and house of representatives including one copy to the staff of each of the committees, biennially and based thereon, to subdivide, classify, and subclassify according to their function and importance all designated state highways and those added from time to time and periodically review and revise the classifications into the following three functional classes:

(a) The "principal arterial system" shall consist of a connected network of rural arterial routes with appropriate extensions into and through urban areas, including all routes designated as part of the interstate system, which serve corridor movements having travel characteristics indicative of substantial state-wide and interstate travel;

(b) The "minor arterial system" shall, in conjunction with the principal arterial system, form a rural network of arterial routes linking cities and other activity centers which generate long distance travel, and, with appropriate extensions into and through urban areas, form an integrated network providing interstate and interregional service; and

(c) The "collector system" shall consist of routes which primarily serve the more important intercounty, intracounty, and intraurban travel corridors, collect traffic from the system of local access roads and convey it to the arterial system, and on which, regardless of traffic volume, the predominant travel distances are shorter than on arterial routes.

(2) Those state highways which perform no arterial or collector function, which serve only local access functions, and which lack essential state highway characteristics shall be designated "local access" highways.

(3) In making the functional classification the transportation commission shall adopt and give consideration to criteria consistent with this section and federal regulations relating to the functional classification of highways, including but not limited to the following:

(a) Urban population centers within and without the state stratified and ranked according to size;

(b) Important traffic generating economic activities, including but not limited to recreation, agriculture, government, business and industry;

(c) Feasibility of the route, including availability of alternate routes within and without the state;

(d) Directness of travel and distance between points of economic importance;

(e) Length of trips;

(f) Character and volume of traffic;

(g) Preferential consideration for multiple service which shall include public transportation;

(h) Reasonable spacing depending upon population density; and

(i) System continuity. [1987 c 505 § 50; 1979 ex.s. c 122 § 1; 1977 ex.s. c 130 § 1.]

Severability—1979 ex.s. c 122: "If any provision of this act or its application to any person or circumstance is held invalid, the remainder of the act or the application of the provision to other persons or circumstances is not affected." [1979 ex.s. c 122 § 10.]

Effective dates—1977 ex.s. c 130: "Section 1 of this 1977 act modifying the functional classification of state highways shall apply to the long range plan for highway improvements and to the six year program for highway construction commencing July 1, 1979 and to the preparation thereof and shall take effect July 1, 1977. Section 2 of this 1977 act shall take effect July 1, 1979." [1977 ex.s. c 130 § 3.] "Section 1 of this 1977 act" is codified as RCW 47.05.021; "Section 2 of this 1977 act" repealed RCW 47.05.020.

47.05.030 Six-year program and financial plan for improvements—Objectives—Categories—Allocation of funds. The transportation commission shall adopt and periodically revise, after consultation with the legislative transportation committee, a comprehensive six-year program and financial plan for highway improvements specifying program objectives for each of the highway categories, "A," "B," "C," and "H," defined in this section, and within the framework of estimated funds for such period. The program and plan shall be based upon the improvement needs for state highways as determined by the department from time to time.

With such reasonable deviations as may be required to effectively utilize the estimated funds and to adjust to unanticipated delays in programmed projects, the commission shall allocate the estimated funds among the following described categories of highway improvements, so as to carry out the commission's program objectives:

(1) Category A shall consist of those improvements necessary to sustain the structural, safety, and operational integrity of the existing state highway system (other than improvements to the interstate system to be funded with federal aid at the regular interstate rate under federal law and regulations, and improvements designated in subsections (2) through (4) of this section).

(2) Category B shall consist of improvements for the continued development of the interstate system to be funded with federal aid at the regular interstate rate under federal law and regulations.

(3) Category C shall consist of the development of major transportation improvements (other than improvements to the interstate system to be funded with federal aid at the regular interstate rate under federal law and regulations) including designated but unconstructed highways which are vital to the statewide transportation network.

(4) Category H shall consist of those improvements necessary to sustain the structural and operational integrity of existing bridges on the highway system (other than bridges on the interstate system or bridge work included in another category because of its association with a highway project in such category).

Projects which are financed one hundred percent by federal funds or other agency funds shall, if the commission determines that such work will improve the state highway system, be managed separately from the above categories. [1987 c 179 § 2; 1979 ex.s. c 122 § 2; 1977 ex.s. c 151 § 44, 1975 1st ex.s. c 143 § 1; 1973 2nd ex.s. c 12 § 4; 1969 ex.s. c 39 § 3; 1965 ex.s. c 170§ 33; 1963 c 173 § 3.]

Severability—1979 ex.s. c 122: See note following RCW 47.05.021.

47.05.035 Allocation of funds, factors—Program objectives. (1) The transportation commission, in preparing the comprehensive six-year program and financial plan for highway improvements, shall allocate the estimated funds among categories A, B, C, and H giving primary consideration to the following factors:

(a) The relative needs in each of the categories of improvements;

(b) The need to provide adequate funding for category A improvements to protect the state's investment in its existing highway system;

(c) the continuity of future highway development of all categories of improvements with those previously programmed; and

(d) The availability of special categories of federal funds for specific work.

(2) The commission in preparing the comprehensive six-year program and financial plan shall establish program objectives for each of the highway categories, A, B,.C, and H. [1987 c 179 § 3; 1979 ex.s. c 122 § 3; 1975 1st ex.s. c 143 § 2.]

Severability—1979 ex.s. c 122: See note following RCW 47.05.021.

47.05.040 Six- year comprehensive highway improvement program and financial plan—Adoption—Biennial revision—Apportionment. (1) Prior to October 1st of each even-numbered year, the transportation commission as provided in subsections (2), (3), (4), and (5) of this section shall adopt and thereafter shall biennially revise, after consultation with the legislative transportation committee, the comprehensive six-year program and financial plan for highway improvements, including program objectives, as specified in RCW 47.05.030 as now or hereafter amended.

(2) The commission shall first allocate to category A improvements as a whole the estimated construction funds as will be necessary to accomplish the commission's program objectives for category A highway improvements throughout the state. The commission shall then apportion the allocated category A Construction funds among the several transportation districts considering the improvement needs of each district in relation to such needs in all districts.

(3) The commission shall next allocate to category B improvements the estimated federal aid interstate funds and state matching funds as necessary to accomplish the commission's program objectives for category B highway improvements throughout the state.

(4) The commission shall next allocate to category H the federal bridge replacement funds and required state funds necessary to accomplish the commission's objectives for category H throughout the state.

(5) The commission shall then allocate to category C improvements the remaining estimated construction funds to accomplish the commission's program objectives for category C highway improvements throughout the state. [1987 c 179 § 4; 1979 ex.s. c 122 § 4; 1977 ex.s. c 235 § 15; 1975 1st ex.s. c 143 § 3; 1973 2nd ex.s. c 12 § 5; 1969 ex.s. c 39 § 4; 1963 c 173 § 4.]

Severability—1979 ex.s. c 122: See note following RCW 47.05.021.

47.05.051 Six-year comprehensive highway improvement program and financial plan—Priority selection criteria—Departure from criteria—Biennial revision. (1) The comprehensive six-year program and financial plan for each category of highway improvements shall be based upon a priority selection system within the program objectives established for each category. The commission using the criteria set forth in RCW 47.05.030, as now or hereafter amended, shall determine the category of each highway improvement.

(2) Selection of specific category A and H projects for the six-year program shall take into account the criteria set forth in subsection (4) of this section.

(3) Selection of specific category B projects for the six-year program shall be based on commission established priorities for completion and preservation of the interstate system.

(4) In selecting each category A and H project as provided in subsection (2) of this section, the following criteria (not necessarily in order of importance) shall be taken into consideration:

(a) Its structural ability to carry loads imposed upon it;

(b) Its capacity to move traffic at reasonable speeds without undue congestion;

(c) Its adequacy of alignment and related geometrics;

(d) Its accident experience; and

(e) Its fatal accident experience.

(5) The transportation commission in carrying out the provisions of this section may delegate to the department of transportation the authority to select category A, B, and H improvements to be included in the six-year program.

(6) Selection of specific category C projects for the six-year program shall be based on the priority of each highway section proposed to be improved in relation to other highway sections within the state with full regard to the structural, geometric, safety, and operational adequacy of the existing highway section taking into account the following:

(a) Continuity of development of the highway transportation network;

(b) Coordination with the development of other modes of transportation;

(c) The stated long range goals of the local area and its transportation plan;

(d) Its potential social, economic, and environmental impacts;

(e) Public views concerning proposed improvements;

(f) The conservation of energy resources and the capacity of the transportation corridor to move people and goods safely and at reasonable speeds; and

(g) Feasibility of financing the full proposed improvement.

(7) The commission in selecting any project for improvement in categories A, B, C, or H may depart from the priority of projects so established (a) to the extent that otherwise funds cannot be utilized feasibly within the program, (b) as may be required by a court judgement, legally binding agreement, or state and federal laws and regulations, (c) as may be required to coordinate with federal, local, or other state agency construction projects, (d) to take advantage of some substantial financial benefit that may be available, (e) for continuity of route development, or (f) because of changed financial of physical conditions of an unforeseen or emergent nature. The commission shall maintain in its files information sufficient to show the extent to which the commission has departed from the established priority of projects.

(8) The comprehensive six-year program and financial plan for highway improvements shall be revised biennially pursuant to RCW 47.05.040 as now or hereafter amended. The adopted program and plan shall be extended for an additional tow year, to six years in the future, effective on July 1st of each odd-numbered year. [1987 c 179 § 5; 1979 ex.s. c 122 § 5; 1975 1st ex.s. c 143 § 4.]

Severability—1979 ex.s. c 122: See note following RCW 47.05.021.

47.05.055 Application of chapter 122, Laws of 1979 ex. sess.—Deviations from plans. The provisions of *this 1979 amendatory act modifying existing procedures for priority programming for highway development as set forth in chapter 47.05 RCW, shall first apply to the comprehensive six-year program and financial plan for highway improvements for the period 1981 to 1987. For the biennia ending June 30, 1979, and

June 30, 1981, the commission may deviate from the existing long range plan and the six-year program to accommodate the modified procedures prescribed by *this 1979 amendatory act. [1979 ex.s. c 122 § 6; 1975 1st ex.s. c 143 § 6.]

***Reviser's note:** This 1979 amendatory act [1979 ex.s. c 122] consisted of amendments to RCW 47.05.021, 47.05.030, 47.05.035. 47/05/040, 47.05.051, 47.05.055, 47.05.070, and 47.26.180 and the repeal of RCW 47.05.020.

Severability—1979 ex.s. c 122: See note following RCW 47.05.021.

47.05.070 Budget recommendation to be presented to governor and legislature—Contents. The transportation commission shall approve and present to the government and to the legislature prior to its convening, a recommended budget for the ensuing biennium. The biennial budget shall include details of proposed expenditures, and performance and public service criteria for construction, maintenance, and planning activities in consonance with the comprehensive six-year program and financial plan adopted under provisions of RCW 44.40.070 and 47.05.040. [1983 1st ex.s. c 53 § 31; 1979 ex.s. c 122 § 7; 1977 ex.s. c 151§ 45; 1973 2nd ex.s. c 12 § 7; 1963 c 173 § 7.]

Severability—1983 1st ex.s. c 53: See note following RCW 47.10.802.

Severability—1979 ex.s. c 122: See note following RCW 47.05.021.

47.05.085 Delay of project for coordination with county-funded improvements. The department may delay a highway improvement at the request of a county of service district to enable the county or district to develop local funding necessary to pay for additional highway improvements over and above those planned by the department so that the highway improvements may be done at the same time. [1985 c 400 § 4.]

APPENDIX D

COPY OF FHWA PAVEMENT POLICY FOR HIGHWAYS

This document is from the Code of Federal Regulations (CFR) and the Federal-Aid Policy Guide (dated December 9, 1991).

SUBCHAPTER G - ENGINEERING AND TRAFFIC OPERATIONS

PART 626 - PAVEMENT DESIGN POLICY

Sec.

Authority: 23 U.S.C. 101(e), 109, and 315; 49 CFR 1.48(b).

Source: 54 FR 1357, Jan. 13, 1988, unless otherwise noted.

Sec. 626.1 Purpose.

To set forth a policy to select, design, and manage Federal-aid highway pavements in a cost-effective manner and identify pavement work eligible for Federal-aid funding.

Sec. 626.3 Definitions.

(a) "Analysis period." The period of time for which the economic analysis is to be made.

(b) "Pavement maintenance." All routine actions, both responsive and preventative, which are taken by the State or other parties to preserve the pavement structure, including joints, drainage, surface, and shoulders, as necessary for its safe and efficient utilization.

(c) "Pavement management system." A set of tools or methods that assist decisionmakers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition.

(d) "Pavement performance period." The period of time that a newly constructed, rehabilitated or reconstructed pavement will perform before reaching its terminal serviceability. This may also be referred to as service life.

(e) "Pavement reconstruction." Construction of the equivalent of a new pavement structure which usually involves complete removal and replacement of the existing pavement structure including new and/or recycled materials.

(f) "Pavement rehabilitation." Resurfacing, restoration, and rehabilitation (3R) work undertaken to restore serviceability and to extend the service life of an existing facility. This may include partial recycling of the existing pavement, placement of additional surface materials or other work necessary to return an existing pavement, including shoulders, to a condition of structural or functional adequacy.

(g) "Pavement structure." A combination of a subbase, base course, and surface course placed on a subgrade to support the traffic load and distribute it to the roadbed.

Sec. 626.5 Policy.

(a) Pavement Management System. Each State highway agency (SHA) shall have a pavement management system (PMS) that is acceptable to the FHWA and is based on concepts described in American Association of State Highway and Transportation Officials publications including its 1985 "Guidelines on Pavement Management." The SHA's PMS shall cover all Rural Arterial (Interstate, other Principal Arterials and Minor Arterials) and Urban Principal Arterial (Interstate, other Freeways and Expressways, and Other Principal Arterials) routes under its jurisdiction. The expansion of a SHA's PMS to include all rural and urban arterials, regardless of jurisdiction, is desirable. The development of a local PMS for pavements under local jurisdiction is also desirable. The SHA's PMS shall be operational within a reasonable period of time, not to exceed 4 years from January 13, 1989.

(b) Pavement Design - New and Reconstructed Pavements. Each SHA shall have a process that is acceptable to the FHWA for the type selection and design of new and reconstructed pavement structures. The type selection process shall include an engineering and economic analysis for alternate designs. The analysis period selected shall be the same for all alternates being considered.

(c) Pavement Design - Rehabilitated Pavements. Each SHA shall have a pavement rehabilitation selection process that is acceptable to the FHWA and that includes identification of candidate solutions and a methodology for structural design. For pavements approaching terminal serviceability and exhibiting significant structural deficiencies, the process shall include procedures for making an engineering and economic analysis of alternative rehabilitation strategies. These alternative rehabilitation strategies should include both reconstruction and rehabilitation alternatives.

(d) Safety. Each project involving construction of a pavement shall have a skid resistant surface. Pavement rehabilitation and reconstruction projects shall also incorporate other cost-effective opportunities to enhance safety as required by 23 CFR 625.2.

Sec. 626.7 Eligibility

(a) New and Reconstructed Pavements. To be eligible for Federal-aid funding, the design of new and reconstructed pavement structures shall be a cost-effective solution based on the State's pavement type selection and pavement design processes.

(b) Rehabilitated (3R) Pavements. To be eligible for Federal-aid funding, the design of rehabilitation pavement projects on routes classified as Interstate, Other Principal Arterials (rural and urban), and Other Freeways and Expressways, regardless of jurisdiction, shall provide for a performance period of at least 8 years. The FHWA may approve exceptions to the 8-year performance requirement when the State's historical performance data indicate that a lesser period would be appropriate. A minimum performance period of 5 years may be approved for all other Federal-aid pavement rehabilitation projects.

(c) Pavement Maintenance. Pavement maintenance as defined under 23 CFR 626.3(b) is not eligible for Federal-aid funding.

NON-REGULATORY SUPPLEMENT

OPI: HNG-42

1. POLICY (23 CFR 626.5)

a. Pavement Management System

(1) Background. For many years SHAs have been providing well-designed and constructed pavements, proper maintenance, and timely rehabilitation. Managing these activities in the past was difficult but did not involve many of the acute problems that now prevail. Rising costs, reduced resources, increased utilization of the system, needs that far exceed revenues, and a changing emphasis from system expansion to system preservation and rehabilitation are issues which highway administrators and engineers must address. A systematic approach to managing pavements is needed if the tremendous investment in today's highway network is to be protected and if every available highway dollar is to be maximized. A PMS provides the data, analysis capability, and products which give SHA decisionmakers key information with which to address these needs.

(2) Scope and Purpose. A PMS is a systematic approach to providing highway administrators and engineers with the types of information needed to effectively and efficiently manage their highway pavements. It includes the collection, processing, analysis, and reporting of data on pavement sections. The analysis and reporting capabilities of a PMS are directed towards identifying current and future needs, developing rehabilitation programs, priority programming of projects and funds, and providing feedback on the performance of pavement designs,

materials, rehabilitation techniques, and maintenance levels.

(3) Coverage

(a) Maximum benefits can be achieved from a PMS when it includes all roadways under the jurisdiction of an agency. This provides for full network-level performance and trend information which would not otherwise be available. It is feasible to design various levels of sophistication and complexity into a PMS based on the relative level of management commitment and importance of the roadway section. For example, certain data may be collected visually for lower-order systems, but require some degree of objective measurement for higher-level systems.

(4) Content

(a) Certain key elements are in all effective PMSs. These elements must be tailored to address the characteristics of the organizational structure, available resources, decisionmaking process, pavement network, and environment within the State. These key elements include:

1 Inventory - An accounting of the physical features of the roadway network is essential as a framework for the collection, storage, and retrieval of pavement information. Basic data items typically include lengths, number of lanes, widths, surface type, functional classification, shoulder information, etc. Expanded information on pavement structure material types and

thicknesses, construction quality, and dates of major work including maintenance activities (i.e., project history data) can also be a valuable feature of an inventory since significant additional analysis and performance feedback data is possible.

2 Condition Survey - A measurement of the condition of the PMS roadway network from which the change over time can be determined. The four major measurements which are typically included in a PMS survey are: (a) ride (or roughness), (b) distress, (c) structural adequacy, and (d) surface friction. Ride and distress are often the two major parameters in a calculated "condition index" used in many PMSs, while structural adequacy and surface friction can be used as priority modifiers and aids to first-cut strategy selection for budgeting purposes. Distress data collection is usually separated by roadway type into at least two classes: asphalt and concrete. A number of different distress types have been used in PMSs, including various types of cracking, rutting, patching, joint condition, spalling, pumping, etc. The details and extent of distress data collection will be highly dependant on PMS scope and the characteristics of the State's roadways, environment, etc.

3 Traffic Data - Pavement loading data are a key element of a PMS which enters into analysis of pavement performance, deterioration rates, etc. Traffic data, necessary to calculate cumulative loads, is discussed more fully in paragraph 4b(1).

4 Database System - An effective, automated system for the storage and retrieval of roadway inventory, condition, and traffic data is a critical feature of successful PMSs. The PMS database can be considered as a resource for all functional elements of an SHA dealing with pavements, and is the source of data used in analyses and production of PMS products. A means of linking data to physical locations should be integral to the design of a database system, as this can provide for significant additional capabilities through correlations to other data sources maintained by an SHA; such as accidents, bridges, railroad crossings, etc. The SHA is encouraged to incorporate its maintenance management system into the PMS.

5 Highway Performance Monitoring System (HPMS)- Due to the similar data needs, coordination should be encouraged between a SHA's PMS and HPMS activities as they relate to pavement data items in the "HPMS Field Manual."

6 Data Analysis Capability -

Effective manipulation of the information in the PMS database to produce useful input to decisionmakers is probably the most important of the PMS components. Capabilities in the areas of traffic analysis, network trends, project programming, project ranking and project strategy selection are useful ingredients. These procedures provide key information to SHA top management and is therefore a valuable resource to all types of pavement-related decision processes.

(5) Products. Products and benefits from a PMS can be realized by many different types of groups both within and outside of the SHA. Examining the products of a PMS is one of the best measures of the benefits of the system. Some of the products that should be part of an acceptable PMS are:

(a) For outside groups such as legislators and the public:

1 Status reports on overall trends and conditions; and

2 Analysis of future performance given specified budgets; and needed funds for desired performance levels (i.e., objective answers to the implications of lower funding levels and/or lower standards).

(b) For SHA Management:

1 Comprehensive, comparative assessment of current and expected future network condition and needs;

2 Proposed single- and multi-year programs (i.e., prioritized listings) for meeting rehabilitation/reconstruction needs;

3 Reports on relative needs among different systems, areas of the State, etc.;

4 More accurate assessment of the cost effectiveness of various rehabilitation and reconstruction strategies; and

5 Impacts and costs of different program scenarios.

(c) For SHA Technical/Engineering Staff:

1 Improved communication among planning, design, construction, maintenance, materials, and research on pavement issues through the consistent PMS database;

2 More accurate and complete information on "what's out there" when initiating project strategy selection and pavement design; and

3 More extensive pavement performance records over a period of years, which can be used to conduct evaluations of materials, designs, etc.

(6) Implementation and Monitoring

(a) It is envisioned that many States will have to implement a PMS on a staged basis, putting the components of the system into operation as each is developed. It is not expected that analysis capabilities which require detailed historic pavement performance information, such as multi-year programming, be operational within this timeframe since the necessary data may not be sufficient. These capabilities will develop and improve as the condition database grows.

(b) The FHWA field offices will monitor the States' implementation and assess progress and adequacy on the basis of periodic reviews. The reviews will assess the PMS primarily on the quality of the data collected, the products being produced and their use in strengthening the State's pavement program.

2. GENERAL PAVEMENT DESIGN CONSIDERATIONS (23 CFR 626.5)

The SHA's pavement design procedures should include consideration of traffic, roadbed soils, reliability analysis, drainage, shoulder structure, environment, economic analysis, pavement performance, and materials of construction. Based on recent research efforts and noted pavement design weaknesses, SHAs are encouraged to give special attention to the following six items in designing new, reconstructed, or rehabilitated pavements.

a. Traffic

(1) Accurate cumulative load (normally expressed as 18 kip equivalent single axle loads or ESALs) estimates are extremely important to structural pavement design. Load estimates should be based on representative current vehicle classification and truck weight data and anticipated growth in heavy truck volumes and truck weights. Representative current traffic data should be obtained using a statistically valid procedure for obtaining count,

classification, and weight data comparable to the procedure recommended in the FHWA "Traffic Monitoring Guide." Vehicle classification data on the number and types of trucks is essential to the estimation of cumulative loads during the design period and should be given special emphasis. Weight information should be obtained using weigh-in-motion (WIM) equipment since this data is more representative than data obtained using static scales. States should purchase and implement the use of automatic vehicle classification and WIM systems as soon as possible to improve the current base traffic data from which to forecast future truck volumes and loads.

(2) When forecasting future loadings, SHA's should, at a minimum, make forecasts for two truck classes: trucks up to 4-axle combination and trucks with 5-axles or more. Changes in load factors should also be monitored and forecasted. The forecasting procedures should consider past trends and future economic activity in the area. A traffic data collection and forecasting program that identifies the most important truck types and the changes in numbers and weights of these truck types during the design period should provide realistic load estimates.

b. Reliability Analysis. The use of the reliability concept provides a rational approach for evaluating the probability that a pavement section will perform as designed over the performance period. A reliability analysis should include a method for accounting for chance deviation in performance caused by variation in construction, environment, traffic estimates, and lack of fit errors in the design equations. Ideally, estimation of the components of chance variations should be based on design, construction, and environmental conditions similar to the project site. Pavement performance probability distributions are generally normal. As a result, the incremental cost of achieving increased reliability significantly increases as the reliability level goes up. Therefore, the selection of an appropriate level of reliability should be based on a careful weighing of the incremental cost against the risk associated with premature distress. The SHAs are encouraged to become familiar with the reliability concept and how it can be applied in the design of pavement structures.

c. Drainage. Free water that enters and collects within undrained pavements is a primary cause of premature and continuing pavement damage. A number of recently completed research efforts that included evaluation of performance and maintenance costs confirm that providing adequate pavement drainage is highly cost-effective over the long term. The SHAs are encouraged to perform a drainage analysis for each new, rehabilitated, or reconstructed pavement structure. Designs should provide for methods to minimize the potential for reduced service life due to saturated structural layers. Methods include subsurface drainage, joint and crack sealing, roadside drainage and the use of moisture insensitive materials.

d. Shoulder Structure. Recent studies demonstrate that structurally adequate shoulders improve both mainline pavement and shoulder performance. The SHAs are encouraged to use paved shoulders where conditions warrant. Shoulders should be structurally capable of withstanding wheel loadings from encroaching truck traffic. On urban freeways or expressways, strong consideration should be given to constructing the shoulder to the same structural section as the mainline pavement. This will allow the shoulder to be used as a temporary detour lane during rehabilitation or reconstruction. The SHAs are also encouraged on new and reconstructed pavement projects to investigate the advantage of specifying that the shoulder be of the same materials as the mainline, particularly for high-volume roadways. Constructing shoulders of the same materials as the mainline facilitates construction, reduces maintenance costs, and improves mainline pavement performance.

e. Economic Analysis (Life Cycle Cost). The concept of life cycle costing is an important pavement management and design tool. Selection of a pavement design only because it has the lowest initial cost can lead to serious future pavement problems. Since pavements are long term public investments, it is appropriate to consider all the costs that occur throughout their lives. While the analysis will identify the alternative with the least life cycle cost, available funding may not permit its selection. The selection of an alternative should take into account the results of the life cycle cost analysis, but these results must be weighed against the needs of the entire system. While the least cost alternative for one highway section may be total reconstruction, it might be so expensive that other sections could not receive timely rehabilitation and thus might require more costly repairs in the future.

f. Material Properties. Material properties have a major impact on pavement design and performance. The design process should consider the following: the properties and related performance characteristics of available materials; new materials and practices which may be available that can contribute to extended pavement life; and the constuctability and maintainability of the specified materials or processes.

(1) Quality Assurance/Quality Control. Increased truck weights, axle loads, and tire pressures, as well as stiffer truck suspension systems and new axle configurations, have created the need for emphasis on the design and construction of high quality pavements to prevent premature rutting and stripping of asphalt pavements and

pumping of concrete pavements. Appropriate mix design, specifications, and construction procedures need to be established for materials, construction, and maintenance, so that design parameters and assumptions will be met. Quality Assurance/Quality Control processes need to be established for the processing and production of materials, construction inspection, and maintenance operations to assure that the assumed pavement performance period will be attained.

(2) Resilient Modulus (M_R). The resilient modulus (M_R) has been used by many highway engineers and researchers and was included in the 1986 "AASHTO Guide for Design of Pavement Structures" (1986 Guide) as the definitive property to characterize materials for pavement design. It is a measure of a material's modulus of elasticity under repeated loading increments. It closely represents the pavement behavior when subjected to a moving wheel load and can be used in mechanistic analysis of multi-layer systems for predicting pavement distress and performance. The SHAs are encouraged to become familiar with procedures for determining resilient modulus and how it can be applied in the design of pavement structures.

3. <u>PAVEMENT DESIGN (23 CFR 626.5)</u>

A. Pavement Type Selection

(1) Each SHA shall have a pavement type selection process for the design of new or reconstructed pavements. The analysis period selected should include an initial pavement structure performance period, plus at least one rehabilitation operation. Appendix B of the 1986 Guide provides excellent guidance on the content of a pavement type selection process. The SHAs are

encouraged to include in the pavement type selection process those principal and secondary factors listed in Appendix B. The selection of pavement type is not an exact science, but a process in which engineering judgments are made on both the type of factors included and the values assigned to each. The FHWA field offices will determine the adequacy of the SHA pavement type selection procedures through periodic reviews.

(2) The FHWA does not encourage the use of alternate bids to determine the pavement type. In those rare instances where the use of alternate bids is considered, the SHA's engineering and economic analysis of the pavement type selection process should clearly demonstrate that there is no clear cut choice between two or more alternatives having equivalent designs. Equivalent design implies that each alternative will be designed to perform equally over the same performance period without subsequent rehabilitation during this period. The use of planned rehabilitation is not allowed when evaluating alternate bids. Equal performance is intended to include similar life-cycle costs. For example, a 12-year design requiring frequent maintenance is not considered equal in performance to a 12-year design requiring very little maintenance, even though initial costs are identical.

b. Methods of Pavement Design. Each SHA shall have procedures for the design of new or reconstructed pavements. The SHA may use the design procedures outlined in the 1986 Guide or they may use other pavement design procedures that by past performance or supported by research are satisfactory for the pertinent conditions. The FHWA field offices will conduct periodic reviews to determine the acceptability of the SHA's pavement design procedures. Project-by-project pavement design checks will not be required. However, using the SHA's accepted procedures, the FHWA should review a number of project pavement designs each year to ensure that the SHA is following these procedures.

c. Pavement Design. It is essential that rehabilitation projects be properly engineered in order to obtain the goal of achieving the best return possible for the money expended. It is recognized that it may not be necessary to provide alternatives or a detailed economic analysis of alternatives for all rehabilitation projects. If an existing pavement structure is sound and the cost to restore serviceability is minor when compared to the cost of a new pavement structure or major rehabilitation, an engineering and economic analysis of alternative actions may not be necessary. In general, for all major rehabilitation projects, each of the following steps should be followed to properly analyze and design the project.

(1) Project Evaluation

(a) Obtain the necessary available information to evaluate the performance and establish the condition of the in-place pavement with regard to traffic loading, environmental conditions, and material strength. A pavement's historical condition data, obtained from the PMS, can provide good initial information.

(b) Before developing appropriate rehabilitation alternatives, it is important that the type of pavement distress be identified and the factors causing the distress determined. This need is often overlooked when considering rehabilitation strategies. The tools to perform project failure analysis such as coring, trenching, and measuring deflection are well known, but need to be emphasized.

(c) Feasible alternatives should address the causes of the deterioration, be effective in repairing the existing distress, and prevent the premature reoccurrence of the distress.

(2) Project Analysis

(a) Perform an engineering and economic analysis on candidate strategies. The engineering analysis should consider the traffic loads, climate, materials, construction practices, and expected performance. The economic analysis should consider service life, initial cost, maintenance costs, and future rehabilitation requirements, including maintenance of traffic costs.

(b) Select the best rehabilitation alternative. Although the economic analysis results are important in selecting the preferred alternatives, budget constraints and engineering judgment should also be considered in selecting the best alternative for a particular project.

(3) Project Design

(a) Sufficient testing, both destructive and non-destructive, should be conducted to verify the assumptions made during the alternative comparison. A new distress survey should be considered if the original survey was not 100 percent of the project, or was not completed within a year of the time the project is scheduled to go to contract.

(b) In addition to the surface indicators, it is essential that the final design consider and address all factors causing the distress. Such factors as structural capacity, subgrade support, surface and subsurface drainage characteristics need to be considered and provided for in the final design.

(c) Once a rehabilitation alternative is selected, the project should be designed using appropriate engineering techniques. There are a number of publications available to guide the selection of these engineering techniques. The FHWA's "Pavement Rehabilitation Manual," and training course "Techniques for Pavement Rehabilitation" provide excellent guidelines. There are also a number of excellent guides available from the asphalt and concrete industries.

(4) Project Implementation. It is important that the intent of the design be well documented in the project plans and specifications so as to provide both the contractor and the construction engineering personnel a clear and concise project proposal. In addition, adequate communication should be maintained between the design and construction engineers to reinforce the intent of the design and provide feedback on project constructability and performance so that timely evaluation can be made of the selected rehabilitation alternative and its appropriateness. The performance information should also be included as a part of the SHA's PMS. The lack of good performance data on pavement rehabilitation techniques has been one of the weaker points in the rehabilitation process. Increased emphasis should be placed on developing

basic performance data that is not presently available on a rehabilitation technique.

4. SAFETY (23 CFR 626.5)

a. The SHAs should be encouraged to provide for skid resistant surfaces on all projects, regardless of funding source. New pavement surfaces constructed with Federal funds shall have skid resistant properties suitable for the needs of the traffic. New pavement surfaces which are financed by others on projects where a skid resistant surface was previously constructed with Federal funds are expected to have skid resistant properties suitable for the needs of the traffic. Pavement performance histories and existing skid data should be analyzed to ensure that the materials, mix designs, and construction techniques used are capable of providing a satisfactory skid resistant surface over the expected performance period of the pavement. Each SHA's skid accident reduction program should include a systematic process to identify, analyze, and correct hazardous skid locations. The same procedures and quality standards used in construction should be used in maintenance operations.

b. Pavement rehabilitation and reconstruction projects are to be developed and accomplished in a manner which considers and includes appropriate safety improvements. The scope of the needed pavement improvement should be considered when determining the type of improvements that are feasible, prudent, and practical. Minor safety improvements may be appropriate for pavement rehabilitation projects while significant geometric upgrading may be appropriate for pavement reconstruction projects.

c. Even though pavement resurfacing typically enhances safety by addressing problem areas such as rough pavements, poor surface drainage, low skid resistant qualities, etc., resurfacing alone does not fulfill the congressional intent that 3R/4R projects enhance highway safety. Other cost-effective roadway safety improvements must also be considered.

d. Plans and specifications for proposed pavement rehabilitation and reconstruction projects should include items to minimize disruption and ensure adequate protection of the motorists and workers within the construction work zone, in accordance with the provisions of 23 CFR 630, Subpart J and 23 CFR 635.125.

5. ELIGIBILITY (23 CFR 626.7)

a. New and Reconstructed Pavements. The cost-effective solution should include an economic analysis based on life-cycle costs. It is essential that each SHA have sufficient data to document the life-cycle costs and performance of each pavement type. Total reconstruction should be considered as an option when evaluating the rehabilitation of existing pavements. The SHA's PMS, pavement type selection, and pavement design processes should indicate when pavement reconstruction should be considered a feasible alternative.

b. Rehabilitated (3R) Pavements.

(1) Long term improvements are the preferred option for all pavement rehabilitation projects. However,it is recognized that network needs and budget limitations may sometimes affect the final selection process.

(2) The consideration of exceptions to the 8-year performance period should be given on a project-by-project basis only when the SHA's proposed rehabilitation technique is cost-effective based on historical performance data, and the economic analysis indicates that a lesser performance period would be more appropriate. Exceptions to the 8-year performance requirement should only be considered when the engineering analysis clearly indicates that no structural

improvements are needed within 5 years of project construction. There is no specific provision for exception to the 5-year performance period. Shorter term strategies on these types of roadways are generally considered maintenance.

(3) Many types of pavement and shoulder rehabilitation work, including concrete pavement restoration (CPR), chip seals and seal coats used to provide all-weather skid resistant surfaces may be eligible if the SHA can provide historical performance data that demonstrates the proposed rehabilitation meets performance period requirements and is cost-effective. Pavement and shoulders must be structurally adequate for the projected traffic during the performance period.

(4) Some rehabilitation techniques may be warranted even though they may not always provide the required 8-year performance period. In such cases, an exception may be granted. Examples of rehabilitation techniques which may warrant an exception include open-graded asphalt friction courses and grinding of concrete pavements. Open-graded asphalt friction courses utilizing high quality, polish resistant aggregates are known to have an outstanding capability for maintaining good frictional characteristics over the operating range of speeds on high-speed highways. Grinding of concrete pavements, particularly when hard aggregates are present, has the potential to improve ride, restore the surface profile and cross-slope, and improve skid resistance through a rougher surface macrotexture.

(5) The importance of properly sealed joints in concrete pavements can not be overstated. Sealing of longitudinal lane/shoulder joints is considered equally as important as the sealing of transverse joints. Properly sealed

joints increase the life of the pavement by preventing the infiltration of incompressibles into the joint and by reducing the amount of moisture entering the pavement structure.

(a) Replacement of existing joint sealant material may be eligible for Federal-aid funds if the replacement material has the potential to provide the required performance period, the SHA's maintenance of the joints has been satisfactory, and the useful life of the existing sealant material has been reached.

(b) Sealant material that provides a long service life can be expected to be cost-effective. It will be necessary for the SHA to properly construct and maintain this sealant material in order to achieve the maximum service life. Maintenance of joints should be on a frequent or continuous rather than periodic basis and is not eligible for Federal-aid funding.

(c) When determined to be eligible, replacement of joint sealant material shall be performed on a project-wide basis rather than on a spot location or short section basis.

c. Pavement Maintenance. The importance of adequate and timely maintenance of the pavement structure and shoulders, including incidental items, is recognized as essential to satisfactory pavement performance. Each SHA is expected to perform satisfactory maintenance with State funds. It is considered inappropriate for the SHA to let maintenance of an item lapse in order to obtain Federal-aid funds for the rehabilitation or replacement of that item. Such practices will result in this work being determined ineligible.

APPENDIX E

THE DEVELOPMENT AND COMPARISON OF CONDITION RATINGS

APPENDIX E

THE DEVELOPMENT AND COMPARISON OF CONDITION RATINGS

1. INTRODUCTION

From the late 1960s to 1992, the overall measure of pavement condition as used by WSDOT was the Pavement Condition Rating (PCR) scheme. During 1992, WSDOT began the process of changing to a new overall distress measure: Pavement Structural Condition (PSC).

Each of these rating schemes (old and new) will be described, then compared.

2. PAVEMENT CONDITION RATING (PCR)

The PCR was used by WSDOT to provide an overall measure of pavement condition for both flexible and rigid pavements up to 1992. Essentially, it was a function of four distress types for flexible pavements and three for rigid pavements. The weighting values for flexible pavements are shown in Table E-1 and are applied to the following distress types:

(a) fatigue (alligator) cracking,
(b) longitudinal cracking,
(c) transverse cracking, and
(d) patching.

The weighting values for rigid pavements are shown in Table E-2 and are applied to the following distress types:

(a) slab cracking,
(b) spalling at joints and cracks, and
(c) faulting, settlement.

WSDOT currently surveys additional types of distress, as illustrated in Figure E-1, but used only those listed in Tables E-1 and E-2 for PMS purposes. The final Pavement Condition Rating (PCR) was a combination of the visual rating and ride rating:

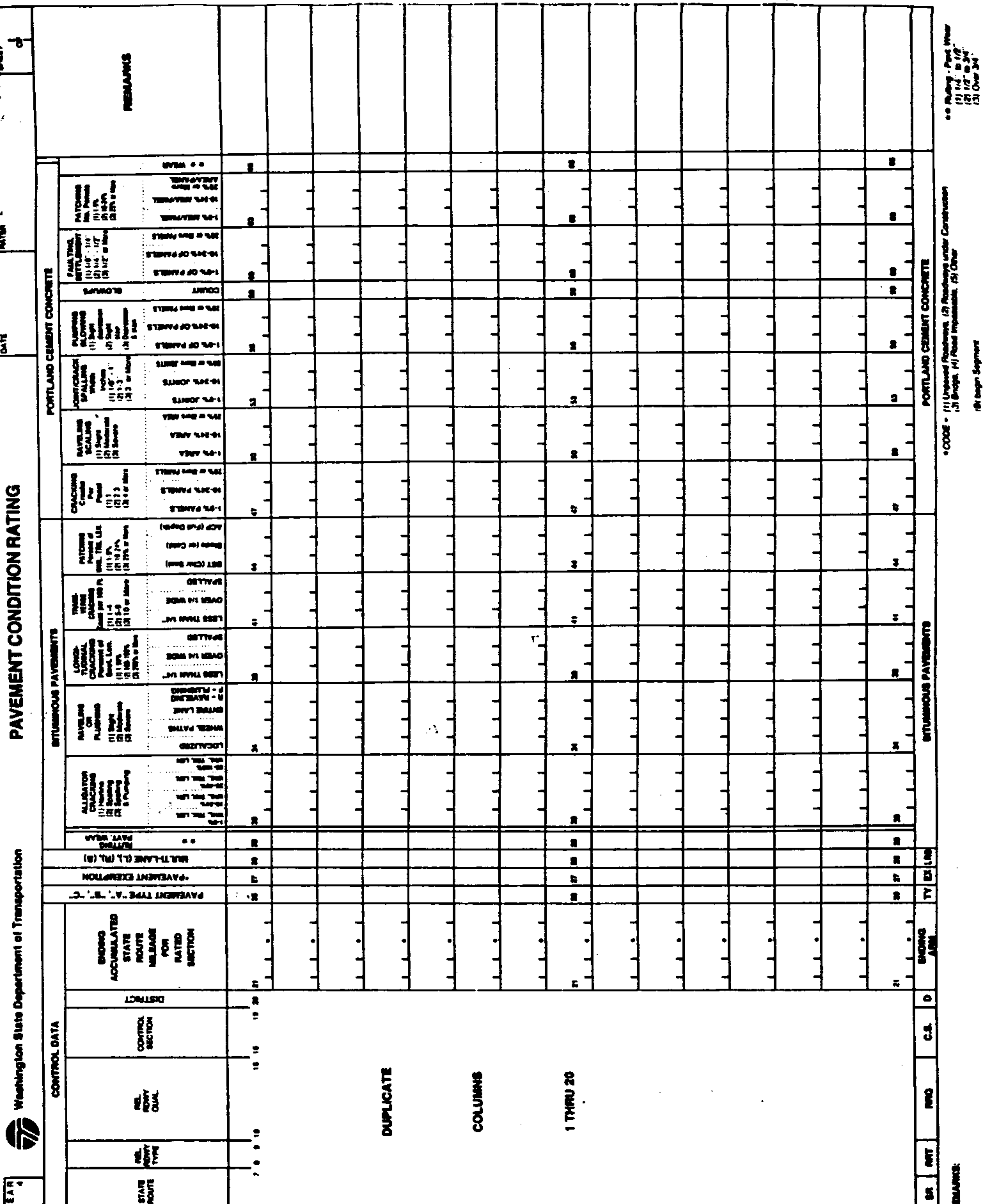


Figure E-1. WSDOT Pavement Distress Recording Form

Table E-1. Flexible Pavement Defect Deductions for PMS

				Percent of Wheel Track Length			
				1-24	25-49	50-74	75+
Alligator Cracking		(1)	Hairline	20	25	30	35
		(2)	Spalling	35	40	45	50
		(3)	Spalling & Pumping	50	55	60	65
				Average Width in Inches			
				1/8-1/4	1/4+	Spalled	
Longitudinal Cracking	Lineal Feet per 100 feet	(1)	1-99	5	15	30	
		(2)	100-199	15	30	45	
		(3)	200+	30	45	60	
				Average Width in Inches			
				1/8-1/4	1/4+	Spalled	
Transverse Cracking	Number per 100 feet	(1)	1-4	5	10	15	
		(2)	5-9	10	15	20	
		(3)	10+	15	20	25	
				Type of Patch			
				BST	Blade	AC	
Patching	Percent Area per 100 feet	(1)	1-5	20	25	30	
		(2)	6-25	25	30	35	
		(3)	25+	30	40	50	

Table E-2. Portland Cement Concrete Defect Deductions for PMS

				Percent of Panels		
				1-25	26-50	51+
Cracking Averaging 1/8+	Units per Panel Length	(1)	1-2	5	10	20
		(2)	3-4	10	20	35
		(3)	4+	15	30	50
				Percent of Joints		
				1-15	16-50	51+
Spalling at Joints and Cracks	Average Width in Inches	(1)	1/4-1	5	10	15
		(2)	1-3	10	20	30
		(3)	3+	15	30	50
				Percent of Panels		
				1-15	16-35	36+
Faulting, Settlement	Average Displacement in Inches	(1)	1/8-1/4	5	10	20
		(2)	1/4-1/2	10	20	30
		(3)	1/2+	15	30	40

$$PCR = [100-\Sigma D]\left[1.0 - .3\left(\frac{CPM}{5000}\right)^2\right]$$

where ΣD = sum of the defect values (Tables E-1 and E-2) and
CPM = counts per mile from a Cox Road Rater.

The ride input in the equation had little effect except for the worst conditions. As can be seen by the relative defect values, the PCR was largely a measure of fatigue cracking for flexible pavements and cracking for PCC slabs. The first stages of fatigue cracking for flexible pavements was evident at a PCR of about 40 (this assumes other distress will generally be present). Service lives were generally estimated at a PCR of 40 which is close to a Pavement Serviceability Index (PSI) of 3.0. Normally, there was (or is) no significant roughness from distressed pavement at this stage.

Though the PCR scheme worked well, it had deficiencies that were largely corrected by PSC.

3. PAVEMENT STRUCTURAL CONDITION (PSC) — FLEXIBLE

3.1 Introduction

The PSC replaces the PCR previously described. Some of the reasons for changing the flexible pavement condition rating scheme include:

(a) Improve the assessment of the structural value of the surfacing material (either asphalt concrete (AC) or bituminous surface treatment (BST)) for the rehabilitation scoping process (refer to Appendix A). More specifically, it is an attempt to estimate, in an analogous sense, the "conversion factor" as illustrated in various overlay design methods.

(b) Improve the manner in which various pavement distress types are combined to represent a specific pavement segment.

(c) Use essentially the same WSDOT distress survey results. The specific distress types and associated extents and severities are described in Reference E-1.

(d) The PSC ranges from 100 (best) to 0 (worst). The prior PCR scale had an open-ended lower scale (potentially a negative PCR of -100 was possible for flexible pavements and -40 for rigid pavements).

(e) The PSC produces an improved performance curve (PSC vs. Age). Specifically, the influence of longitudinal and transverse cracking is better incorporated into the PSC.

(f) Alligator cracking, as incorporated into the PSC score, can more easily "force" a pavement segment into the rehabilitation mode. The logic for this is straightforward in that rehabilitation is least expensive if the project is programmed early in the fatigue cracking cycle.

(g) The PSC scheme will better accommodate automated distress survey techniques which will likely provide "continuous" measures of pavement distress.

3.2 Calculation of PSC — Flexible

3.2.1 Overall Rating

The PSC is calculated as follows:

$$PSC = 100 - \text{deduct points} \quad \text{(Eq. 1)}$$

$$= 100 - 15.8\,(EC)^{0.5}$$

where PSC = Pavement Structural Condition Flexible

EC = equivalent cracking, which is a composite of alligator, longitudinal, transverse cracking, and patching.

The EC is an additive function as follows:

$$EC = ACEC + LCEC + TCEC + PTEC \quad \text{(Eq. 2)}$$

where EC = total equivalent cracking,

ACEC = alligator cracking component of equivalent cracking,

LCEC = longitudinal cracking component of equivalent cracking,

TCEC = transverse cracking component of equivalent cracking, and

PTEC = patching cracking component of equivalent cracking.

Equation 1 was obtained from the following data:

PSC	Percent Alligator Cracking (Spalling and Pumping, AC3)
100	0
50	10
0	40

The equation was obtained by "selecting" various "powers" and obtaining the b_1 intercept by regression. The power and b_1 which produced the least error were selected. The resulting equation was

$$PSC = 100.0 - 15.8114\,(AC3)^{0.5}$$

or

$$PSC = 100.0 - 15.8\,(AC3)^{0.5}$$

$R^2 \simeq 100.0\%$
SEE $\simeq 0.0$
$n = 3$

All other forms of cracking are in terms of AC3, thus the term EC is substituted for AC3.

3.2.2 Alligator Cracking Component

The alligator (or fatigue) cracking component of equivalent cracking is estimated as follows:

$$ACEC = AC3 + 0.445\,(AC2)^{1.15} + 0.13\,(AC1)^{1.35} \qquad \text{(Eq. 3)}$$

where ACEC = alligator cracking component of equivalent cracking,

AC1 = percent of wheelpath length with <u>hairline</u> alligator cracking,

AC2 = percent of wheelpath length with <u>spalled</u> alligator cracking, and

AC3 = percent of wheelpath length with <u>spalled and pumping</u> alligator cracking.

The percentages of alligator cracking are obtained directly from the WSDOT visual distress survey.

The basis for Equation 3 follows:

	Percent Alligator Cracking		
Deduct Points	Hairline (AC1)	Spalling (AC2)	Spalling + Pumping (AC3)
0	0	0	0
50	25	15	10
100	70	50	40

Essentially, the AC or BST surfacing is assumed to have <u>no</u> structural value (other than a crushed stone base) at alligator cracking levels of 70 percent of the wheel tracks for the <u>hairline</u> level of severity, 50 percent at the <u>spalling</u> level of severity and 40 percent at the <u>spalling and pumping</u> level of severity. Further, about 10 percent of spalling and pumping alligator cracking is a point where a pavement segment should be programmed for some type of rehabilitation treatment. This is approximately equivalent to a PSI of 3.0 (AASHTO definition).

The terms shown in Equation 3 are all based on the spalling and pumping severity level (i.e., AC3). This was achieved by regressing AC1 against AC3 and AC2 against AC3. The regression was performed by trying various exponents ("powers") for AC1 and AC2. The "best" combination of exponent and intercept (b_1) was selected. The following model was used:

$$AC3 = b_0 + b_1\,(AC1 \text{ or } AC2)^{power}$$

(a) $AC3 = f(AC1)$

Using the AC3 severity level as a common basis for alligator cracking, equate AC1 in terms of AC3.

Percent AC1		Percent AC3
0	=	0
25	=	10
70	=	40

The resulting regression equation is:

$$AC3 = 0.017 + 0.129\,(AC1)^{1.35}$$

$$AC3 \equiv 0.13\,(AC1)^{1.35}$$

$R^2 \equiv 100.0\%$
SEE $\equiv$ 0.029
n = 3

(b) $AC3 = f(AC2)$

Again, using the AC3 severity level as the common basis for alligator cracking, equate AC2 in terms of AC3.

Percent AC2		Percent AC3
0	=	0
15	=	10
50	=	40

The resulting regression equation is

$$AC3 = -0.008 + 0.4449\,(AC2)^{1.15}$$

$$AC3 \cong 0.445\,(AC2)^{1.15}$$

$$R^2 \cong 100.0\%$$
$$SEE \cong 0.014$$
$$n = 3$$

3.2.3 Longitudinal and Transverse Cracking Components

3.2.3.1 Introduction

To convert a measure of longitudinal cracking to equivalent alligator cracking, assume that the pavement lane wheel path is divided into 1 ft wide by 1.5 ft long blocks. If each wheel path is 3 ft wide (total of 6 ft) then there are 6 blocks in width and 67 blocks in a 100-ft section length. Refer to Figure E-2 for an illustration of this. The question becomes what amount of longitudinal and transverse cracking is equivalent to alligator cracking? Again, the basis for this estimate will be in terms of AC3.

The basic assumption is that if each 1.5-ft x 1.5-ft block contained a fully developed longitudinal and transverse crack, then this approximates an equivalent amount of alligator cracking of corresponding severity.

3.2.3.2 Alligator Cracking as a Function of Longitudinal Cracking

A fully cracked block (1.5- x 1.5-ft block with a full transverse crack and a full longitudinal crack) is assumed to be equivalent to the same area of alligator cracking; thus,

100 % of wheel track is alligator cracking

= 6 longitudinal cracks + 66.7 transverse cracks

= 6(100) + 66.7(6) ≅ 1,000 ft of cracking

≅ 10 longitudinal cracks (full 100 ft section length)

≅ 1,000 % of longitudinal cracking (refer to rating form shown as Figure E-1)

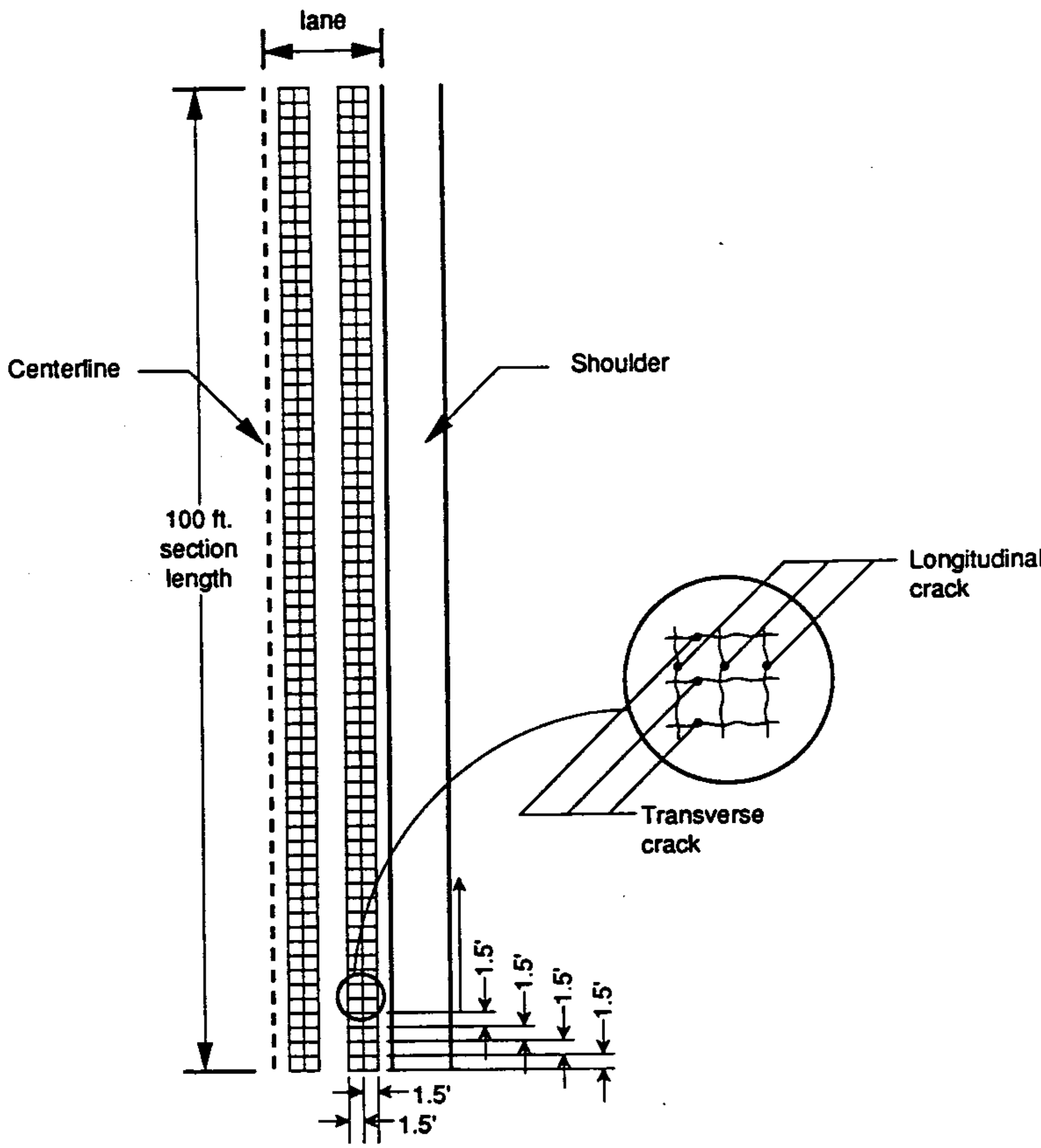


Figure E-2. Illustration of Wheel Path Blocks

1,000 % LC = 100 % AC

or

1 % LC = 0.1 % AC

By substitution into Equation 3:

$$LCEC = (0.1\ LC3) + 0.445\ (0.1LC2)^{1.15} + 0.13\ (0.1LC1)^{1.35} \qquad \text{(Eq. 4)}$$

where LCEC = longitudinal cracking component of equivalent cracking,

LC1 = percent of section length with a less than 1/4 in. width severity level,

LC2 = percent of section length with a greater than 1/4 in. severity level, and

LC3 = percent of section length with a spalling severity level.

3.2.3.3 Alligator Cracking as a Function of Transverse Cracking

Using the same scheme as described in paragraph 3.2.3.2 for longitudinal cracking, the equivalent alligator cracking as a function of transverse cracking is:

100% of wheel track is alligator cracking

= 67 transverse cracks (6 ft)
+ 6 longitudinal cracks) (100 ft)
≃ 1,000 ft

Number of full transverse cracks (as surveyed 8 ft long transverse cracks) ≃ 1,000 ft/8 ft ≃ 125 cracks

Thus, 125 "full" transverse cracks = 100 percent of both wheeltracks with alligator cracking

or each transverse crack per 100 ft = 0.8 % AC

The resulting LCEC equation is by substitution into Equation 3:

$$TCEC = (0.8\ TC3) + 0.445\ (0.8TC2)^{1.15} + 0.13\ (0.8TC1)^{1.35}$$

where TCEC = transverse cracking component of equivalent cracking,

TC1 = number of transverse cracks per 100 ft of section length with a less than 1/4-in. width severity level,

TC2 = number of transverse cracks per 100 ft of section length with a greater than 1/4-in. width severity level, and

TC3 = number of transverse cracks per 100 ft of section length with a spalling severity level.

3.2.4 Patching Component

The following assumptions are used in order to equate patching to alligator cracking:

(a) A full depth AC digout is equivalent to pumping severity level for alligator cracking.

(b) A blade (or cold mix) patch is equivalent to 75 percent spalled alligator cracking.

(c) A BST (or chip seal) patch is equivalent to 75 percent hairline alligator cracking.

Thus the resulting PTEC equation is:

$$PTEC = PT3 + 0.445\ [0.75(PT2)]^{1.15} + 0.13\ [0.75(PT1)]^{1.35}$$

where PTEC = patching component of equivalent cracking,

PT1 = percent of wheel track length with BST patching,

PT2 = percent of wheel track length with blade patching, and

PT3 = percent of wheel track length with full depth patching.

3.3 Illustration of PSC — Flexible Calculations

Now that the basic derivation of the PSC has been covered, a few illustrative calculations follow. These will be based on "typically" observed distress types and quantities.

3.3.1 Low to Moderate Amount of Alligator and Longitudinal Cracking

Calculate PSC for the following conditions:

(a) Alligator cracking: 5 percent of wheel track (hairline severity)

(b) Longitudinal cracking: 150 ft. per station with an average crack width of less than 1/4 in.

(c) PSC = $100 - 15.8 (EC)^{0.5}$, and

$$EC = 0.13 (5)^{1.35} + 0.13 ((0.1)(150))^{1.35}$$

$$= 1.142 + 5.031 = 6.173$$

Thus, PSC = $100 - 15.8 (6.173)^{0.5} \cong 61$. The prior corresponding value for PCR = 100 - (20 + 15) = 65

3.3.2 Low to Moderate Amount of Longitudinal Cracking and Patching

Calculate PSC for the following conditions:

(a) Longitudinal cracking: 50 ft. per station with an average crack width greater than 1/4 in.

(b) Patching: approximately 5 percent of the lane has received a BST patch.

(c) PSC = $100 - 15.8 (EC)^{0.5}$, and

$$EC = 0.445 ((0.1)(50))^{1.15} + 0.13 (0.75 (5))^{1.35}$$

$$= 2.833 + 0.774 = 3.607$$

Thus, PSC = $100 - 15.8 (3.607)^{0.5} \cong 70$. The corresponding value for PCR = 100 - (15 + 20) = 65.

3.3.3 Moderate Amount of Alligator Cracking and Patching

Calculate PSC for the following conditions:

(a) Alligator cracking: 25 percent of wheel track (hairline severity)

(b) Patching: 10 percent of the lane has received an AC patch

(c) $PSC = 100 - 15.8\,(EC)^{0.5}$, and

$$EC = 0.13\,(25)^{1.35} + (10)$$

$$= 10.027 + 10.0 = 20.027$$

Thus, $PSC = 100 - 15.8\,(20.027)^{0.5} \cong 29$. The corresponding value for PCR = 100 - (25 + 35) = 40.

3.3.4 High Amount of Alligator Cracking and Patching

Calculate PSC for the conditions in the previous paragraph, except change the alligator cracking from hairline to spalling severity.

$$PSC = 100 - 15.8\,(EC)^{0.5}$$

$$EC = 0.445\,(25)^{1.15} + (10)$$

$$= 18.030 + 10.0 = 28.030$$

Thus, $PSC = 100 - 15.8\,(28.030)^{0.5} \cong 16$. The corresponding value for PCR = 100 - (40+35) = 25.

4. PAVEMENT STRUCTURAL CONDITION (PSC) — RIGID

4.1 Introduction

To be consistent in rating scheme terminology, the PSC — rigid will be used as the overall measure of rigid pavement condition. As of June 1993, the PSC will be calculated by use of the Washington State Distress Rating Manual [E-1] and distress deducts in terms of equivalent cracking. Four of the six distress types used for WSDOT rigid pavements are, in part, based on the original Pavement Condition Index (PCI) scheme, as will be subsequently described.

4.2 Original PCI Scheme

The rigid pavement PCI as described by Shahin and Kohn [E-2] is calculated from up to 19 different surface distress types as follows:

(a) Blow-up/buckling/shattering
(b) Corner break
(c) Divided slab
(d) Durability ("D") cracking
(e) Faulting
(f) Joint seal damage
(g) Lane/shoulder drop off
(h) Linear cracking

(i) Patching — large and utility cuts
(j) Patching — small
(k) Polished aggregate
(l) Popouts
(m) Pumping
(n) Punchout
(o) Railroad crossing
(p) Scaling/map cracking/crazing
(q) Shrinkage cracks
(r) Spalling — corner
(s) Spalling — joint

The PCI score ranges from 100 (no distress) to 0 (highly distressed). The recommended process for determining the PCI is shown in Figure E-3 as a five step process. These steps are:

(a) Inspect sample units.

This involves selecting representative sample units and inspecting each for the 19 possible distress types and associated severity and density (or extent) levels. The sample is often taken to be about 20 continuous slabs (jointed pavement).

(b) Determine deduct values.

As shown in Figure E-3, the deduct values are continuous as a function of density and severity. Separate equations have been developed for each distress type. These will be presented later in this appendix.

(c) Compute total deduct value.

All deducts for the observed distresses are summed.

(d) Adjust total deduct value.

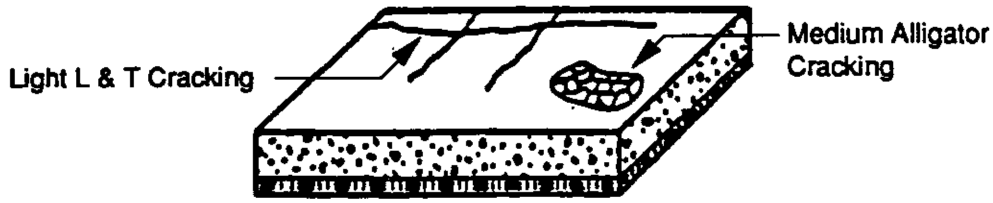
The total deduct value (shown as TDV in Figures E-3 and E-4) is adjusted by the total number of distress types that have deduct values over 5 points. In this way, the PCI cannot be a negative value.

Shahin and Kohn [E-2] suggested the following descriptions for various PCI levels:

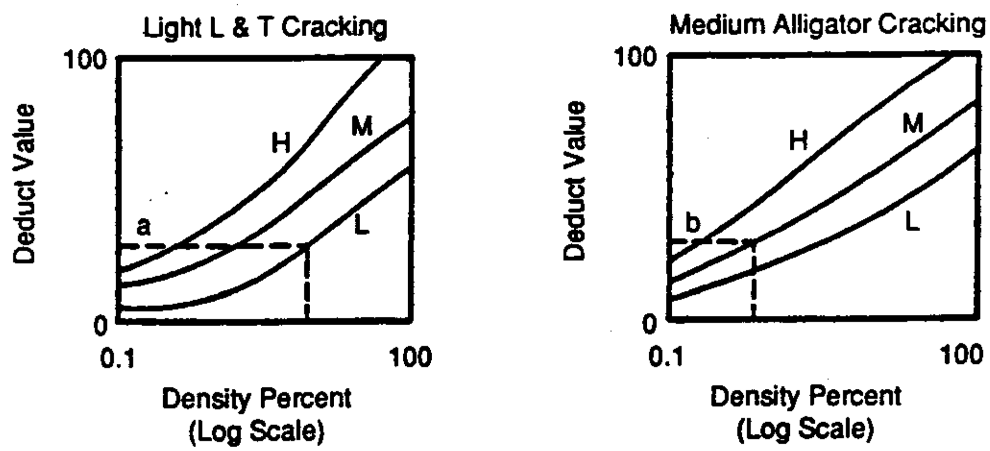
Pavement Condition	PCI Range
Excellent	85-100
Very Good	70-85
Good	55-70
Fair	40-55
Poor	25-40
Very Poor	10-25
Failed	0-10

Further, based on data from the U.S. Army base at Ft. Eustis, Oklahoma, typical performance curves for PCC pavements were presented. This plot is shown as Figure E-5.

Step 1. Inspect sample units: Determine distress types and severity levels and measure density.

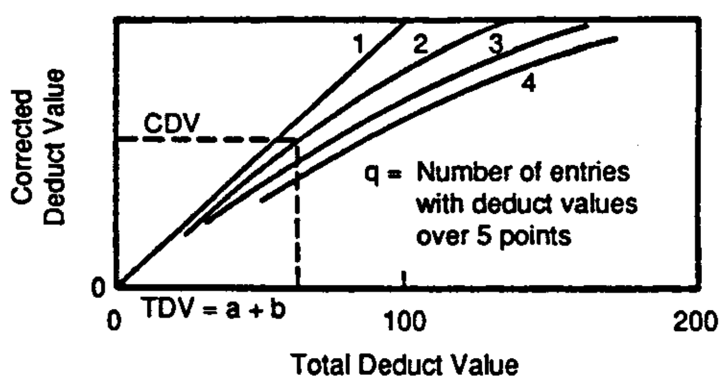


Step 2. Determine deduct values.



Step 3. Compute total deduct value, (TDV) = a + b.

Step 4. Adjust total deduct value.



Step 5. Compute pavement condition index, (PCI) = 100 - CDV for each sample unit inspected.

Figure E-3. PCI Calculation Steps [from Ref. E-2]

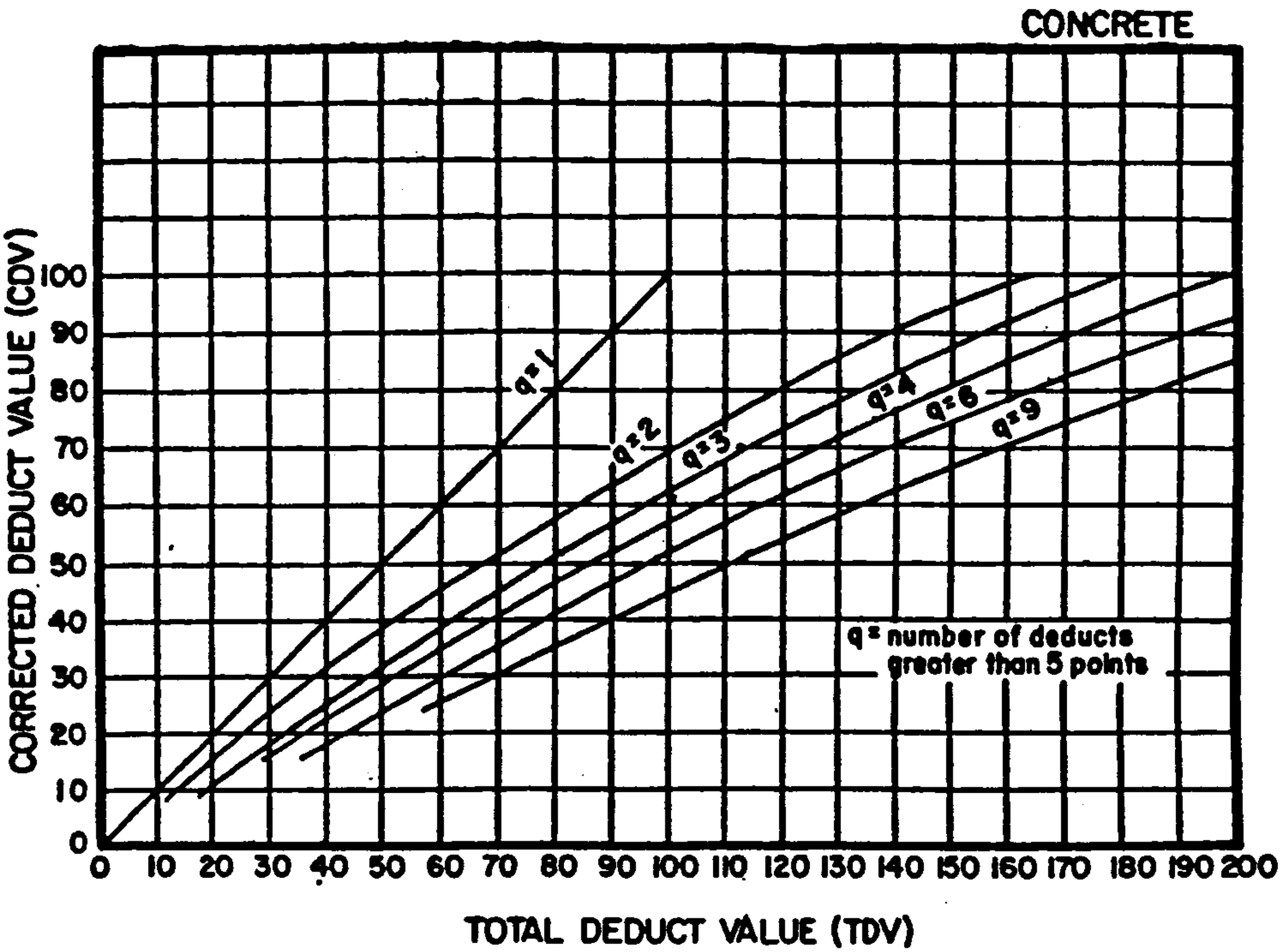


Figure E-4. Corrected Deduct Values for Jointed Concrete (from Reference E-2)

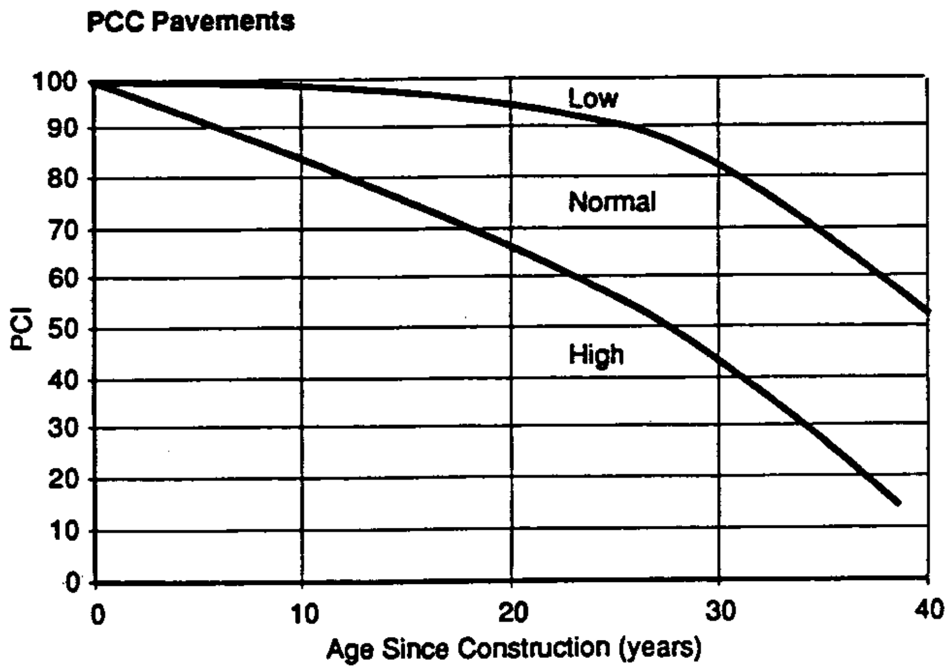


Figure E-5. PCI vs. Age of PCC Performance
[from Ref. E-2]

The region above the upper curve represents a low rate of deterioration and the region below the lower curve a high rate of deterioration.

4.3 Integration of PSC and PCI

4.3.1 Introduction

To accommodate the current distress rating system as used in Washington State [E-1], the existing WSDOT surveyed distress types are used along with the PCI deduct curves to calculate PSC (with the exception of faulting/settlement and slab cracking). The primary distress types of interest for the WSPMS include the following:

(a) Cracking

- Severity (cracks per panel)
- Extent (% of panels cracked)

(b) Joint and crack spalling

- Severity (width of spall)
- Extent (% of joints and cracks spalling)

(c) Pumping and blowing

- Severity (shoulder depression, amount of staining)
- Extent (% of joints and cracks showing evidence of pumping)

(d) Faulting and settlement

- Severity (inches of faulting or settlement at joints or cracks)
- Extent (% of panels faulting or settling)

(e) Patching

- Severity (% of panel area patched)
- Extent (% of all panels in a travel lane that are patched)

(f) Raveling or scaling

- Severity (surface condition of slab)
- Extent (% of pavement surface in the segment)

(g) Wear

- Severity (wear depth in inches)
- Extent (assumed to be full length of segment)

The analogous distress types from the PCI scheme are listed below:

WSDOT	Original PCI
• Cracking	• Linear cracking (includes longitudinal, transverse and diagonal cracks) (Distress No. 28)
• Joint and crack spalling	• Spalling - joint (Distress No. 39)
• Pumping and blowing	• Pumping (Distress No. 33)
• Faulting and settlement	• Faulting (Distress No. 25)
• Patching	• Patching - large (Distress No. 29)
• Raveling and scaling	• Scaling/Map cracking/Crazing (Distress No. 36)
• Wear	• Polished aggregate (Distress No. 31)

The PSC is based on six distress types, four of which are largely based on the PCI deduct equations. These are

- Joint and crack spalling
- Pumping and blowing
- Patching
- Raveling and scaling

The remaining two distress types (slab cracking and faulting and settlement) were developed specifically for WSDOT conditions as will be subsequently detailed.

4.3.2 PSC Equations

4.3.2.1 Introduction

Regression equations were developed for the WSDOT PSC distresses based on the deduct curves for the corresponding PCI based distresses except for slab cracking and faulting/settlement. For those equations based on the PCI deduct curves, 11 data points were used. These points were obtained from the PCI distress plots contained in Reference E-2.

4.3.2.2 Overall PSC Rating

The PSC is calculated as follows:

$$PSC = 100 - \text{deduct points}$$

$$= 100 - 18.6\,(EC)^{0.43} \qquad \text{(Eq. 4)}$$

where PSC = Pavement Structural Condition (Rigid)

EC = equivalent cracking, which is a composite of slab cracking, joint and crack spalling, pumping and blowing, faulting and settlement, patching, and raveling and scaling.

The EC is an additive function as follows:

$$EC = CREC + JSEC + PMEC + FLTEC + PTEC + RSEC \qquad \text{(Eq. 5)}$$

where EC = total equivalent cracking,
CREC = slab cracking component of equivalent cracking,
JSEC = joint and crack spalling component of equivalent cracking,
PMEC = pumping and blowing component of equivalent cracking,
FLTEC = faulting and settlement component of equivalent cracking,
PTEC = patching component of equivalent cracking, and
RSEC = raveling and scaling component of equivalent cracking,

Equation 4 was obtained from the following data:

PSC	Percent Cracked Panels (High Severity, CR3)
100	0
50	10
0	50

The equation was obtained by regression analysis. The actual equation (after rounding) is:

$$PSC = 100.0 - 18.6\,(EC)^{0.43}$$

$R^2 \simeq 100.0\%$
SEE $\simeq 0.04$
$n = 3$

All other forms of distress are in terms of CR3 (high severity slab cracking), thus the term EC is substituted for CR3.

4.3.2.3 Slab Cracking Component

The slab cracking component of equivalent cracking is estimated as follows:

$$CREC = CR3 + 0.24\,(CR2)^{1.16} + 0.0054\,(CR1)^{1.84} \qquad \text{(Eq. 6)}$$

where CREC = slab cracking component of equivalent cracking,
CR1 = percent of slabs with 1 crack per panel,
CR2 = percent of slabs with 2-3 cracks per panel, and
CR3 = percent of slabs with 4 or more cracks per panel.

The percentages of slab cracking are obtained directly from the WSDOT visual distress survey.

The basic data for Equation 6 follows:

	Percent Cracked Panels		
Deduct Points	Low (CR1)	Medium (CR2)	High (CR3)
0	0	0	0
25	25	—	—
50	—	25	10
75	100	—	—
100	—	100	50

The basis for the deduct equations is a PSC of 25 at an extent of 100 percent for low severity cracking (1 crack per panel) and a PSC of 0 at either 100 percent medium severity cracking (2-3 cracks per panel) or 50 percent high severity cracking (4 or more cracks per panel).

The terms in Equation 6 are all based on the high severity level (4 or more cracks per panel) (i.e., CR3). This was achieved by regressing CR1 against CR3 and CR2 against CR3. The following model was used:

$$CR3 = b_0 - b_1 \, (CR1 \text{ or } CR2)^{power}$$

(a) $CR3 = f(CR1)$

Using the CR3 severity level as a common basis for slab cracking, equate CR1 in terms of CR3 for equal deduct points.

Approx. Deduct Points	Percent CR1		Percent CR3
0	0.00	=	0.00
25	25.00	=	2.00
75	100.00	=	25.65

The resulting regression equation is:

$$CR3 = 0.00053 + 0.00536 \, (CR1)^{1.84}$$
$$CR3 \simeq 0.0054 \, (CR1)^{1.84}$$

$R^2 \simeq 100.0\%$
SEE $\simeq 0.00046$
$n = 3$

(b) CR3 = f(CR2)

Again, using the CR3 severity level as the common basis for slab cracking, equate CR2 in terms of CR3 for equal deduct points.

Approx. Deduct Points	Percent CR2		Percent CR3
0	0.00	=	0.00
50	25.00	=	10.00
100	100.00	=	50.00

The resulting regression equation is:

$$CR3 = -0.00637 + 0.23934\ (CR2)^{1.16}$$
$$CR3 \simeq 0.24\ (CR2)^{1.16}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.00596
n = 3

4.3.2.4 Joint and Crack Spalling Component

$$JSEC = 0.075\ (JS3)^{1.14} + 0.0061\ (JS2)^{1.27} + 0.0034\ (JS1)^{1.03} \qquad \text{(Eq. 7)}$$

where JSEC = joint and crack spalling component of equivalent cracking,
JS1 = percent of joints and cracks with spalls 1/8" - 1" in width,
JS2 = percent of joints and cracks with spalls 1" - 3" in width,
JS3 = percent of joints and cracks with spalls greater than 3" wide.

To convert joint and crack spalling to equivalent slab cracking, Equation 7 was based on the following:

	Percent of Spalled Joints and Cracks		
Deduct Points	Low (JS1)	Medium (JS2)	High (JS3)
0	0	0	0
6	25	—	—
10	50	—	—
11	—	25	—
12	100	—	—
19	—	50	—
25	—	100	—
29	—	—	25
42	—	—	50
58	—	—	100

The association between deduct points and the various percentages of spalled joints and cracks was based on the original PCI curves (Spalling - Joint (PCI)) via the following polynomial regression equations:

- Low severity

  Deduct = $-0.5175 + 0.27904(x) - 0.0015268(x^2)$

  R^2 = 99.4%
  SEE = 0.3973
  n = 11

- Medium severity

  Deduct = $-0.4825 + 0.51717(x) - 0.0026399(x^2)$

  R^2 = 99.8%
  SEE = 0.4529
  n = 11

- High severity

  Deduct = $0.6993 + 1.52514(x) - 0.018164(x^2) + 0.0000865(x^3)$

  R^2 = 99.9%
  SEE = 0.7870
  n = 11

The terms in Equation 7 are all based on regressing the "JS" components against Equivalent Cracking (actually CR3) for equal deduct points.

(a) CR3 = f(JS1)

Approx. Deduct Points	Percent JS1		Percent CR3
0	0.00	=	0.00
6	19.00	=	0.07
12	93.00	=	0.36

The resulting regression equation is:

$$CR3 = -0.00006 + 0.00338\,(JS1)^{1.03}$$
$$CR3 \simeq 0.0034\,(JS1)^{1.03}$$

R^2 ≃ 100.0%
SEE ≃ 0.00006
n = 3

(b) CR3 = f(JS2)

Approx. Deduct Points	Percent JS2		Percent CR3
0	0.00	=	0.00
11	25.00	=	0.36
25	96.00	=	2.00

The resulting regression equation is:

$$CR3 = -0.00105 + 0.006077\ (JS2)^{1.27}$$
$$CR3 \simeq 0.0061\ (JS2)^{1.27}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.00097
n = 3

(c) CR3 = f(JS3)

Approx. Deduct Points	Percent JS3		Percent CR3
0	0.00	=	0.00
30	26.00	=	3.06
58	99.00	=	14.12

The resulting regression equation is:

$$CR3 = -0.0072 + 0.07498\ (JS3)^{1.14}$$
$$CR3 \simeq 0.075\ (JS3)^{1.14}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.0068
n = 3

4.3.2.5 Pumping and Blowing Component

$$PMEC = 0.0069\ (PM1 + PM2 + PM3)^{1.45} \qquad \text{(Eq. 8)}$$

where PMEC = pumping and blowing component of equivalent cracking,

PM1 = percent of joints or cracks which show pumping (slight shoulder depression, little or no staining),

PM2 = percent of joints or cracks which show pumping (moderate shoulder depression with obvious staining),

PM3 = percent of joints or cracks which show pumping (severe shoulder depression and/or significant staining).

To convert pumping to equivalent slab cracking, Equation 8 was based on the following:

Deduct Points	Percent of Slabs Pumping
0	0
15	25
26	50
38	100

Pumping and Blowing (WSDOT) is analogous to Pumping (PCI). Further, all severities are treated the same (i.e., low = medium = high). The original PCI deduct curve was used to generate the percentages of slabs pumping and associated deduct points via the following polynomial equation:

$$\text{Deduct} = 0.2483 + 0.663601(x) - 0.00284965(x^2)$$

R^2 = 100%
SEE = 0.2581
n = 11

The terms in Equation 8 are all based on regressing the "PM" components against Equivalent Cracking (CR3) for equal deduct points.

(a) CR3 = f(PM1, PM2, PM3)

Approx. Deduct Points	Percent PM1		Percent CR3
0	0.00	=	0.00
25	50.00	=	2.00
38	98.00	=	5.30

The resulting regression equation is:

$$CR3 = 0.00098 + 0.00687\ (PM1 + PM2 + PM3)^{1.45}$$
$$CR3 \simeq 0.0069\ (PM1 + PM2 + PM3)^{1.45}$$

R^2 = 100.0%
SEE = 0.00113
n = 3

4.3.2.6 Faulting and Settlement Component

$$FLTEC = FLT3 + 0.0915\,(FLT2)^{1.46} + 0.00115\,(FLT1)^{2.32} \qquad \text{(Eq. 9)}$$

where FLTEC = faulting and settlement component of equivalent cracking,

FLT1 = percent of panels with 1/8" - 1/4" faulting or settlement at joints or cracks,

FLT2 = percent of panels with 1/4" - 1/2" faulting or settlement at joints or cracks,

FLT3 = percent of panels with greater than 1/2" faulting or settlement at joints or cracks.

To convert faulting and settlement to equivalent slab cracking, Equation 9 was based on the following:

	Percent of Slabs Faulting or Settling		
Deduct Points	Low (FLT1)	Medium (FLT2)	High (FLT3)
0	0	0	0
50	50	25	10
100	100	75	50

The terms in Equation 9 are all based on regressing the "FLT" components against Equivalent Cracking (CR3) for equal deduct points.

(a) CR3 = f(FLT1)

Approx. Deduct Points	Percent FLT1		Percent CR3
0	0.00	=	0.00
50	50.00	=	10.00
100	100.00	=	50.00

The resulting regression equation is:

$$CR3 = -0.00637 + 0.001146\,(FLT1)^{2.32}$$
$$CR3 \simeq 0.00115\,(FLT1)^{2.32}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.0060
n = 3

(b) CR3 = f(FLT2)

Approx. Deduct Points	Percent FLT2		Percent CR3
0	0.00	=	0.00
50	25.00	=	10.00
100	75.00	=	50.00

The resulting regression equation is:

$$CR3 = -0.02607 + 0.09153\ (FLT2)^{1.46}$$
$$CR3 \simeq 0.0915\ (FLT2)^{1.46}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.0244
n = 3

(c) CR3 = f(FLT3)

Approx. Deduct Points	Percent FLT3		Percent CR3
0	0.00	=	0.00
50	10.00	=	10.00
100	50.00	=	50.00

The resulting regression equation is:

$$CR3 = 0.0 + 1.0\ (FLT3)^{1.0}$$
$$CR3 = FLT3$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0
n = 3

4.3.2.7 Patching Component

$$PTEC = 0.103\ (PT3)^{1.19} + 0.0079\ (PT2)^{1.55} + 0.00194\ (PT1)^{1.57} \quad \text{(Eq. 10)}$$

where PTEC = patching component of equivalent cracking,

PT1 = percent of panels patched (1 to 9 percent of panel surfaces covered),

PT2 = percent of panels patched (10 to 24 percent of panel surfaces covered),

PT3 = percent of panels patched (25 percent or more of panel surfaces covered).

To convert patching to equivalent slab cracking, Equation 10 was based on the following:

	Percent of Slabs Patched		
Deduct Points	Low (PT1)	Medium (PT2)	High (PT3)
0	0	0	0
10	25	—	—
18	—	25	—
19	50	—	—
28	100	—	—
33	—	50	—
35	—	—	25
49	—	100	—
53	—	—	50
73	—	—	100

Patching (WSDOT) is analogous to Patching—Large (PCI). The original PCI curves were used to generate (approximately) the percentages of slabs patched and associated deduct points via the following polynomial regression equations:

- Low severity

  $$\text{Deduct} = -1.6810 + 0.51379(x) - 0.0021970(x^2)$$

  R^2 = 99.2%
  SEE = 1.021
  N = 11

- Medium severity

  $$\text{Deduct} = -1.9965 + 0.88386(x) - 0.0037704(x^2)$$

  R^2 = 99.5%
  SEE = 1.300
  n = 11

- High severity

  $$\text{Deduct} = 1.301 + 1.78225(x) - 0.019024(x^2) + 0.00008343(x^3)$$

  R^2 = 99.8%
  SEE = 1.131
  n = 11

The terms in Equation 10 are all based on regressing the "PT" components against Equivalent Cracking (CR3) for equal deduct points.

(a) $CR3 = f(PT1)$

Approx. Deduct Points	Percent PT1		Percent CR3
0	0.00	=	0.00
18	51.00	=	0.93
28	98.00	=	2.60

The resulting regression equation is:

$$CR3 = -0.001028 + 0.00194\,(PT1)^{1.57}$$
$$CR3 \simeq 0.00194\,(PT1)^{1.57}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.00115
$n = 3$

(b) $CR3 = f(PT2)$

Approx. Deduct Points	Percent PT2		Percent CR3
0	0.00	=	0.00
31	49.00	=	3.30
50	100.00	=	10.00

The resulting regression equation is:

$$CR3 = -0.0042 + 0.00794\,(PT2)^{1.55}$$
$$CR3 \simeq 0.0079\,(PT2)^{1.55}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.00454
$n = 3$

(c) $CR3 = f(PT3)$

Approx. Deduct Points	Percent PT3		Percent CR3
0	0.00	=	0.00
37	26.00	=	4.97
71	93.00	=	22.58

The resulting regression equation is:

$$CR3 = 0.00704 + 0.1026\ (PT3)^{1.19}$$
$$CR3 \simeq 0.103\ (PT3)^{1.19}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.0067
n = 3

4.3.2.8 Raveling or Scaling Component

$$RSEC = 0.052\ (RS3)^{1.29} + 0.0159\ (RS2)^{1.18} + 0.0014\ (RS1)^{1.18} \quad \text{(Eq. 11)}$$

where RSEC = raveling and scaling component of equivalent cracking,
RS1 = percent of pavement surface with <u>slight</u> raveling or scaling,
RS2 = percent of pavement surface with <u>moderate</u> raveling or scaling,
RS3 = percent of pavement surface with <u>severe</u> raveling or scaling.

To convert raveling and/or scaling to equivalent slab cracking, Equation 11 was based on the following:

	Percent of Pavement Surface		
Deduct Points	Low (RS1)	Medium (RS2)	High (RS3)
0	0	0	0
5	25	—	—
8	—	10	—
9	50	—	—
11	100	—	—
16	—	25	10
24	—	50	—
31	—	100	—
32	—	—	25
46	—	—	50
66	—	—	100

Raveling and Scaling (WSDOT) is analogous to Scaling/Map Cracking/Crazing (PCI). The association between deduct points and the various percentages of pavement surface was based on the original PCI curves via the following polynomial regression equations:

- Low severity

$$\text{Deduct} = 0.1556 + 0.234779(x) - 0.00122960(x^2)$$

R^2 = 99.8%
SEE = 0.1855
n = 11

- Medium severity

$$\text{Deduct} = 0.9056 + 0.83304(x) - 0.009642(x^2) + 0.00004283(x^3)$$

R^2 = 99.5%
SEE = 0.8321
n = 11

- High severity

$$\text{Deduct} = 1.776 + 1.6530(x) - 0.020452(x^2) + 0.00010305(x^3)$$

R^2 = 99.6%
SEE = 1.528
n = 11

The terms in Equation 11 are all based on regressing the "RS" components against Equivalent Cracking (CR3) for equal deduct points.

(a) CR3 = f(RS1)

Approx. Deduct Points	Percent RS1		Percent CR3
0	0.00	=	0.00
6	28.00	=	0.07
11	93.00	=	0.29

The resulting regression equation is:

$$CR3 = -0.00016 + 0.00138\,(RS1)^{1.18}$$
$$CR3 \simeq 0.0014\,(RS1)^{1.18}$$

R^2 ≃ 100.0%
SEE ≃ 0.00016
n = 3

(b) CR3 = f(RS2)

Approx. Deduct Points	Percent RS2		Percent CR3
0	0.00	=	0.00
16	25.00	=	0.71
32	98.00	=	3.55

The resulting regression equation is:

$$CR3 = 0.00086 + 0.01587\ (RS2)^{1.18}$$
$$CR3 \simeq 0.0159\ (RS2)^{1.18}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.0008
n = 3

(c) CR3 = f(RS3)

Approx. Deduct Points	Percent RS3		Percent CR3
0	0.00	=	0.00
42	43.00	=	6.68
66	97.00	=	19.06

The resulting regression equation is:

$$CR3 = 0.00268 + 0.05214\ (RS3)^{1.29}$$
$$CR3 \simeq 0.052\ (RS3)^{1.29}$$

$R^2 \simeq 100.0\%$
SEE $\simeq$ 0.0030
n = 3

5. COMPARISON OF FLEXIBLE PAVEMENT CONDITION RATINGS

5.1 Introduction

This section will be used to present a comparison of the PCR, PSC, and original PCI score and their associated deduct values. This should assist in understanding the relative basis of each.

This information is presented in Tables E-3 through E-8. Each table is used to address only one distress type as follows:

- Table E-3: Alligator cracking — hairline
- Table E-4: Alligator cracking — spalling
- Table E-5: Alligator cracking — spalling and pumping
- Table E-6: Longitudinal cracking
- Table E-7: Transverse cracking
- Table E-8: Patching

The deduct values for each rating scheme (PCR, PSC, and PCI) will be described below.

5.2 Alligator Cracking — Hairline, Spalling, Spalling and Pumping

The deduct points were calculated as follows:

(a) PCR

The deduct points were obtained from Table E-1.

(b) PSC

Hairline deducts = $(15.8)\,[0.13\,(\%\text{ of AC hairline})^{1.35}]^{0.5}$
Spalling deducts = $(15.8)\,[0.445\,(\%\text{ of AC spalled})^{1.15}]^{0.5}$
Spalling and pumping deducts = $(15.8)\,(\%\text{ of AC spalled and pumping})^{0.5}$

(c) PCI

The PCI severities of low (L), medium (M), and high (H) for alligator cracking are essentially the same as WSDOT. The percent of wheeltrack length per segment (WSDOT) assumed a 3 ft wide wheelpath and two wheelpaths. Thus,

1% (WSDOT) = 0.5% (PCI).

5.3 Longitudinal Cracking

The deduct points were calculated as follows:

(a) PCR

The deduct points were obtained from Table E-1.

(b) PSC

Low severity (1/8"-1/4") = $(15.8)\,[(0.13)\,((0.1)\,(\text{LC of low severity}))^{1.35}]^{0.5}$
Medium severity (1/4"+) = $(15.8)\,[(0.445)\,((0.1)\,(\text{LC of medium severity}))^{1.15}]^{0.5}$
High severity (spalled) = $(15.8)\,((0.1)\,(\text{LC of high severity}))^{0.5}$

(c) PCI

The PCI severities of low (L), medium (M), and high (H) correspond to those used by WSDOT. Extent (or density) for PCI longitudinal cracking is measured in linear feet (converted to an area by assuming a 1 foot width) and for WSDOT as a percentage of section length. Thus,

Table E-3. Comparison of Rating Scores for Alligator Cracking (Hairline)

Distress Extent (% of Wheel Track/Station)	PCR Deduct Points	PSC Deduct Points	PCI Deduct Points[2]	Condition Score[1]		
				PCR	PSC	PCI
1	20	5.7	6	80	94	94
5	20	16.9	18	80	83	82
12.5	20	31.3	27	80	69	73
24	20	48.7	35	80	51	65
25	25	50.0	36	75	50	64
37	25	65.2	40	75	35	60
49	25	78.8	42	75	21	58
50	30	80.0	44	70	20	56
62	30	92.4	46	70	8	54
74	30	100.0	48	70	0	52
75	35	100.0	49	65	0	51

[1] Calculations include no other distress types or other severities of alligator cracking, rounded to the nearest whole number.

[2] PCI deducts based on low severity level.

Table E-4. Comparison of Rating Scores for Alligator Cracking (Spalling)

Distress Extent (% of Wheel Track/Station)	PCR Deduct Points	PSC Deduct Points	PCI Deduct Points[2]	Condition Score[1]		
				PCR	PSC	PCI
1	35	10.0	15	65	90	85
12.5	35	45.0	41	65	55	70
24	35	65.5	49	65	34	51
25	40	67.1	50	60	33	50
37	40	84.1	54	60	16	46
49	40	98.8	58	60	1	42
50	45	99.9	58	55	0	42
62	45	100.0	62	55	0	38
74	45	100.0	64	55	0	36
75	50	100.0	64	50	0	36

1 Calculations include no other distress types or other severities of alligator cracking, rounded to the nearest whole number.

2 PCI deducts based on medium severity level.

Table E-5. Comparison of Rating Scores for Alligator Cracking (Spalling and Pumping)

Distress Extent (% of Wheel Track/Station)	PCR Deduct Points	PSC Deduct Points	PCI Deduct Points[2]	Condition Score[1]		
				PCR	PSC	PCI
1	50	15.8	22	50	84	78
12.5	50	55.9	56	50	44	44
24	50	77.4	65	50	23	35
25	55	79.0	65	45	21	35
37	55	96.1	70	45	4	30
49	55	100.0	74	45	0	26
50	60	100.0	74	40	0	26
62	60	100.0	76	40	0	24
74	60	100.0	79	40	0	21
75	65	100.0	79	35	0	21

[1] Calculations include no other distress types or other severities of alligator cracking, rounded to the nearest whole number.

[2] PCI deducts based on high severity level.

Table E-6. Comparison of Rating Scores for Longitudinal Cracking

Distress		PCR Deduct Points	PSC Deduct Points	PCI Deduct Points	Condition Rating[1]		
Extent	Severity				PCR	PSC	PCI
1	1/8"-1/4"	5	1.2	0	95	99	100
1	1/4"+	15	2.8	0	85	97	100
1	spalled	30	5.0	4	70	95	96
99	1/8"-1/4"	5	26.8	15	95	73	85
99	1/4"+	15	39.4	28	85	61	72
99	spalled	30	49.7	56	70	50	44
100	1/8"-1/4"	15	27.0	15	85	73	85
100	1/4"+	30	39.6	28	70	60	72
100	spalled	45	50.0	56	55	50	44
199	1/8"-1/4"	15	42.9	22	85	57	78
199	1/4"+	30	58.8	38	70	41	62
199	spalled	45	70.5	76	55	30	24
200	1/8"-1/4"	30	43.0	22	70	57	78
200	1/4"+	45	59.0	38	55	41	62
200	spalled	60	70.7	76	40	29	24

[1] Calculations include no other distress types or other severities of longitudinal cracking, rounded to the nearest whole number.

Table E-7. Comparison of Rating Scores for Transverse Cracking

Distress		PCR Deduct Points	PSC Deduct Points	PCI Deduct Points	Condition Rating[1]		
Extent	Severity				PCR	PSC	PCI
1	1/8"-1/4"	5	5	2	95	95	98
1	1/4"+	10	9	9	90	91	91
1	spalled	15	14	18	85	86	82
4	1/8"-1/4"	5	12	9	95	88	91
4	1/4"+	10	21	20	90	79	80
4	spalled	15	28	42	85	72	58
5	1/8"-1/4"	10	15	11	90	85	89
5	1/4"+	15	23	22	85	77	78
5	spalled	20	32	44	80	68	56
9	1/8"-1/4"	10	22	16	90	78	84
9	1/4"+	15	33	30	85	67	70
9	spalled	20	42	59	80	58	41
10	1/8"-1/4"	15	23	17	85	77	83
10	1/4"+	20	35	31	80	65	69
10	spalled	25	45	62	75	55	38

[1] Calculations include no other distress types or other severities of transverse cracking, rounded to the nearest whole number.

Table E-8. Comparison of Rating Scores for Patching

Distress		PCR Deduct Points	PSC Deduct Points	PCI Deduct Points	Condition Rating[1]		
Extent	Severity				PCR	PSC	PCI
1	BST	20	4.7	2	80	95	98
1	Blade	25	8.9	10	75	91	90
1	AC	30	13.7	19	70	84	81
5	BST	20	13.9	10	80	86	90
5	Blade	25	22.5	22	75	77	78
5	AC	30	30.6	37	70	65	63
6	BST	25	15.7	12	75	84	88
6	Blade	30	25.0	24	70	75	76
6	AC	35	33.5	40	65	61	60
25	BST	25	41.2	25	75	59	75
25	Blade	30	56.9	45	70	43	55
25	AC	35	68.4	72	65	21	28
26	BST	30	42.3	26	70	58	74
26	Blade	40	58.2	46	60	42	54
26	AC	50	69.8	73	50	19	27

[1] Calculations include no other distress types or other severities of patching, rounded to the nearest whole number.

1% section length (WSDOT) = 0.083 % density (PCI) (based on an area 12 ft by 100 ft) or

WSDOT		PCI
1%	=	0.083%
99%	=	8.2%
100%	=	8.3%
199%	=	16.5%
200%	=	16.6%

5.4 Transverse Cracking

The deduct points were calculated as follows:

(a) PCR

The deduct points were obtained from Table E-1.

(b) PSC

Low severity = (15.8) [(0.13) ((0.8) (TC of low severity))$^{1.35}$]$^{0.5}$
Medium severity = (15.8) [(0.445) ((0.8) (TC of medium severity))$^{1.15}$]$^{0.5}$
High severity = (15.8) ((0.8) (TC of high severity))$^{0.5}$

(c) PCI

The PCI severities of low (L), medium (M), and high (H) correspond to those used by WSDOT. Extent (or density) for PCI transverse cracking is measured in lineal feet (converted to area by assuming a 1-foot width) and for WSDOT as cracks per 100 ft. If we assume one lane 12-ft wide and 100-ft long, one transverse crack = 1% density, or

WSDOT (cracks/100 ft)	PCI (% density)
1 crack	1%
4 cracks	4%
5 cracks	5%
9 cracks	9%
10 cracks	10%

5.5 Patching

The deduct points were calculated as follows:

(a) PCR

The deduct points were obtained from Table E-1.

(b) PSC

BST patch (low severity) = $(15.8)\,[(0.13)\,((0.75)\,(\%\text{ BST patching}))^{1.35}]^{0.5}$
Blade patch (medium severity) = $(15.8)\,[(0.445)((0.75)(\%\text{ blade patching}))^{1.15}]^{0.5}$
AC patch (high severity) = $(15.8)\,((\%\text{ of AC patching}))^{0.5}$

(c) PCI

The WSDOT and PCI severities do not match; however, the PCI severities of low (L), medium (M), and high (H) were taken as indicative of the WSDOT BST, blade, and AC patch severity levels, respectively. The extent of percent of both wheel paths (WSDOT) was assumed equal to PCI density.

5.6 Comparisons

In general, the PSC values are slightly higher than the PCR and PCI values for very low levels of distress and substantially lower for high levels of distress. An exception to this is transverse cracking when comparing PSC and PCI.

6. COMPARISON OF RIGID PAVEMENT CONDITION RATINGS

6.1 Introduction

This section will be used to present a comparison of the PCR and PSC and their associated deduct values.

This information is contained in Tables E-9 through E-11. Each table is used to address only one distress type as follows:

- Table E-9: Cracking
- Table E-10: Joint and cracking spalling
- Table E-11: Faulting and settlement

A review of the three tables shows some agreement between the PCR and PCI scores. The PSC scores are, in general, substantially lower than the PCR scores. Table E-12 is used to illustrate typical PSC scores for pumping and blowing, patching, and raveling and scaling.

6.2 Illustration of PSC Calculations

A few illustrative calculations follow. These will be based on "typically" observed distress types and quantities.

Table E-9. Comparison of Rating Scores for Cracking

Distress		PCR Deduct Points	PSC Deduct Points		Condition Rating[1]		
						PSC	
Extent	Severity		Original Curve (Ref. E-2)	Deduct Equation	PCR	Original Curve (Ref. E-2)	Deduct Equation
1	1	5	1.0	2.0	95	99	98
1	2-3	10	1.2	10.1	90	99	90
1	4+	15	4.0	18.6	85	96	81
9	1	5	5.5	11.2	95	94	89
9	2-3	10	8.0	30.1	90	92	70
9	4+	15	20.0	47.8	85	80	52
10	1	5	6.0	12.2	95	94	88
10	2-3	10	9.0	31.8	90	91	68
10	4+	15	20.5	50.1	85	80	50
24	1	5	12.5	24.3	95	88	76
24	2-3	10	17.0	49.1	90	83	51
24	4+	15	32.8	72.9	85	67	27
25	1	5	12.8	25.1	95	87	75
25	2-3	10	17.5	50.1	90	82	50
25	4+	15	33.0	74.2	85	67	26
26	1	10	13.0	25.9	90	87	74
26	2-3	20	18.0	51.1	80	82	49
26	4+	30	33.5	75.5	70	66	24
50	1	10	19.5	43.5	90	80	56
50	2-3	20	27.5	70.9	80	72	29
50	4+	30	45.8	100.0	70	54	0
51	1	20	19.8	44.2	80	80	56
51	2-3	35	27.8	71.6	65	72	28
51	4+	50	46.0	100.9	50	54	0
100	1	20	23.0	75.3	80	77	25
100	2-3	35	38.0	100.1	65	62	0
100	4+	50	64.5	134.7	50	36	0

[1] Calculations include no other distress types. Ratings rounded to the nearest whole number. PSC = 0 if deduct points exceed 100.0.

Table E-10. Comparison of Rating Scores for Joint and Crack Spalling

Distress		PCR Deduct Points	PSC Deduct Points		Condition Rating[1]		
			Original Curve (Ref. E-2)	Deduct Equation	PCR	PSC	
Extent	Severity					Original Curve (Ref. E-2)	Deduct Equation
1	1/8"-1"	5	1.0	1.6	95	99	98
1	1"-3"	10	1.0	2.1	90	99	98
1	3+"	15	2.8	6.1	85	97	94
9	1/8"-1"	5	2.0	4.3	95	98	96
9	1"-3"	10	3.8	6.9	90	96	93
9	3+"	15	14.0	17.9	85	86	82
10	1/8"-1"	5	2.0	4.5	95	98	96
10	1"-3"	10	4.0	7.3	90	96	93
10	3+"	15	15.0	18.9	85	85	81
15	1/8"-1"	5	3.0	5.4	95	97	95
15	1"-3"	10	6.0	9.1	90	94	91
15	3+"	15	21.0	23.0	85	79	77
24	1/8"-1"	10	4.8	6.6	90	95	93
24	1"-3"	20	10.0	11.8	80	90	88
24	3+"	30	28.8	29.0	70	71	71
25	1/8"-1"	10	5.0	6.7	90	95	93
25	1"-3"	20	10.8	12.0	80	89	88
25	3+"	30	29.0	29.6	70	71	70
50	1/8"-1"	10	10.0	9.1	90	90	91
50	1"-3"	20	19.0	17.6	80	81	82
50	3+"	30	41.5	41.6	70	58	58
51	1/8"-1"	15	10.2	9.2	85	90	91
51	1"-3"	30	19.5	17.7	70	80	82
51	3+"	50	42.0	42.0	50	58	58

[1] Calculations include no other distress types. Ratings rounded to the nearest whole number.

Table E-11. Comparison of Rating Scores for Faulting and Settlement

Distress		PCR	PSC Deduct Points		PCR	PSC Condition Rating[1]	
Extent	Severity	Deduct Points	Original Curve (Ref. E-2)	Deduct Equation	Condition Rating[1]	Original Curve (Ref. E-2)	Deduct Equation
1	1/8"-1/4"	5	0.5	1.0	95	100	99
1	1/4"-1/2"	10	1.0	6.7	90	99	93
1	1/2"+	15	2.0	18.6	85	98	81
9	1/8"-1/4"	5	2.2	9.1	95	98	91
9	1/4"-1/2"	10	7.0	26.4	90	93	74
9	1/2"+	15	16.0	47.8	85	84	52
10	1/8"-1/4"	5	2.5	10.1	95	98	90
10	1/4"-1/2"	10	7.5	28.2	90	92	72
10	1/2"+	15	17.0	50.1	85	83	50
15	1/8"-1/4"	5	4.0	15.1	95	96	85
15	1/4"-1/2"	10	11.5	36.4	90	88	64
15	1/2"+	15	23.5	59.6	85	76	40
16	1/8"-1/4"	10	4.5	16.1	90	96	84
16	1/4"-1/2"	20	12.0	37.9	80	88	62
16	1/2"+	30	24.5	61.3	70	76	39
24	1/8"-1/4"	10	9.0	24.1	90	91	76
24	1/4"-1/2"	20	19.0	48.9	80	81	51
24	1/2"+	30	34.0	72.9	70	66	27
25	1/8"-1/4"	10	9.8	25.1	90	90	75
25	1/4"-1/2"	20	19.8	50.2	80	80	50
25	1/2"+	30	35.5	74.2	70	64	26
36	1/8"-1/4"	20	17.5	36.2	80	82	64
36	1/4"-1/2"	30	29.0	63.1	70	71	37
36	1/2"+	40	47.0	86.8	60	53	13
100	1/8"-1/4"	20	30.0	100.2	80	70	0
100	1/4"-1/2"	30	54.0	119.8	70	46	0
100	1/2"+	40	83.5	134.7	60	16	0

[1] Calculations include no other distress types. Ratings rounded to the nearest whole number. PSC = 0 if deduct points exceed 100.0.

Table E-12. Typical PSC Scores for Pumping/Blowing, Patching, and Raveling/Scaling

Distress				PSC Deduct Points			PSC Condition Rating		
	Severity								
Extent	Pumping	Patching	Raveling	Pumping	Patching	Raveling	Pumping	Patching	Raveling
1	Low	1-9%	Slight	2.2	1.3	1.1	98	99	99
1	Medium	10-24%	Moderate	2.2	2.3	3.1	98	98	97
1	High	>25%	Severe	2.2	7.0	5.2	98	93	95
9	Low	1-9%	Slight	8.6	5.6	3.4	91	94	97
9	Medium	10-24%	Moderate	8.6	10.0	9.6	91	90	90
9	High	>25%	Severe	8.6	21.5	17.6	91	78	82
10	Low	1-9%	Slight	9.2	6.0	3.5	91	94	96
10	Medium	10-24%	Moderate	9.2	10.8	10.1	91	89	90
10	High	>25%	Severe	9.2	22.7	18.7	91	77	81
24	Low	1-9%	Slight	15.9	10.8	5.5	84	89	94
24	Medium	10-24%	Moderate	15.9	19.3	15.7	84	81	84
24	High	>25%	Severe	15.9	35.6	30.4	84	64	70
25	Low	1-9%	Slight	16.3	11.1	5.5	84	89	94
25	Medium	10-24%	Moderate	16.3	19.8	16.0	84	80	84
25	High	>25%	Severe	16.3	36.3	31.1	84	64	69
100	Low	1-9%	Slight	38.7	28.4	11.4	61	72	89
100	Medium	10-24%	Moderate	38.7	49.9	32.4	61	50	68
100	High	>25%	Severe	38.7	73.9	67.1	61	26	33

[1] Calculations include no other distress types. Ratings rounded to the nearest whole number.

6.2.1 Low to Moderate Amount of Cracking and Joint and Crack Spalling

Calculate PSC for the following conditions:

(a) Cracking: 5 percent of panels cracked (low severity)

(b) Joint and crack spalling: 10 percent of joints and cracks are spalling (low severity)

(c) PSC = 100 - Deducts

- Cracking — low severity
  $CREC = 0.0054\ (5)^{1.84} = 0.1044$

- Joint and cracking spalling — low severity
  $JSEC = 0.0034\ (10)^{1.03} = 0.0364$

- $EC = 0.1044 + 0.0364 = 0.1408$

- $PSC = 100 - 18.6\ (0.1408)^{0.43} = 100 - 8.0 = 92$

(d) The prior, corresponding PCR = 100 - (5 + 5) = 90.

6.2.2 High Amount of Faulting and Settlement — One Level of Severity

Calculate the PSC for the following conditions:

(a) Faulting and settlement: 100 percent of panels with low severity faulting (1/8 - 1/4 in.)

(b) PSC = 100 - Deducts

- Faulting and settlement — low severity
  $FLTEC = 0.00115\ (100)^{2.32} = 50.1993$

- $EC = 50.1993$

- $PSC = 100 - 18.6\ (50.1993)^{0.43} = 100 - 100.2 \simeq 0$

(c) The prior, corresponding PCR = 100 - 20 = 80.

6.2.3 High Amount of Faulting and Settlement — Two Levels of Severity

Calculate the PSC for the following conditions:

(a) Faulting and settlement: 75 percent of panels with low severity faulting (1/8-1/4 in.) and 25 percent of the panels with moderate severity (1/4-1/2 in.) (Note: Condition survey not currently conducted so as to identify two levels of severity for one distress type.)

(b) PSC = 100 - Deducts

- Faulting and settlement — low severity (75%) and medium severity (25%)

  $FLTEC = 0.0915\ (25)^{1.46} + 0.00115\ (75)^{2.32} = 35.8094$

- EC = 35.8094

- $PSC = 100 - 18.6\ (35.8094)^{0.43} = 100 - 86.6 \simeq 13$

(c) The prior, corresponding PCR = 100 - (20) = 80 (assumes that only the dominant distress extent and severity was recorded by the raters for faulting).

7. COMPARISON OF FLEXIBLE AND RIGID PAVEMENTS (PSC)

Table E-13 provides a quick overview of how three of the more critical pavement distresses impact PSC scores. For flexible pavements, the distress selected was alligator cracking. For rigid pavements, slab cracking and faulting were used. At both very low and high extents, the PSCs are similar.

Table E-13. Comparison of PSC Scores for Selected Distress Types — Flexible and Rigid Pavements

Distress				PSC		
Extent	Severity			Flexible— Alligator Cracking Only	Rigid — Slab Cracking Only	Rigid — Faulting Only
	Flexible	Rigid				
	Alligator Cracking	Slab Cracking	Faulting and Settlement			
1	Hairline	1	1/8" - 1/4"	94	98	99
1	Spalling	2-3	1/4" - 1/2"	90	90	93
1	Spalling and Pumping	4+	1/2"+	84	81	81
24	Hairline	1	1/8" - 1/4"	51	76	76
24	Spalling	2-3	1/4" - 1/2"	34	51	51
24	Spalling and Pumping	4+	1/2"+	23	27	27
50	Hairline	1	1/8" - 1/4"	20	56	50
50	Spalling	2-3	1/4" - 1/2"	0	29	22
50	Spalling and Pumping	4+	1/2"+	0	0	0
100	Hairline	1	1/8" - 1/4"	0	25	0
100	Spalling	2-3	1/4" - 1/2"	0	0	0
100	Spalling and Pumping	4+	1/2"+	0	0	0

8. PSC RANGES AND VALUES

Tables E-14 and E-15 are used to illustrate the range of PSC deduct values based on the extent limits used in the WSDOT pavement condition rating form (refer to Figure E-1). Tables E-16 and E-17 are the extent levels (which set the deduct values) which are actually used in WSPMS as of 1993. In other words, if a rater notes for a specific flexible pavement section which has alligator cracking with a 1-9 percent extent, then a value of 5 percent is used in WSPMS to calculate the deduct value (which is 17 for hairline, 27 for spalling, and 35 for spalling and pumping — refer to Table E-16). If 10-24 percent alligator cracking is noted, then a 15 percent extent is actually used in the PSC calculations.

9. REFERENCES

E-1. Northwest Pavement Management Systems Users Group and R.K. Kay, *Pavement Surface Condition Rating Manual*, Washington State Department of Transportation, Olympia, Washington, March 1992.

E-2. Shahin, M.Y., and S.D. Kohn, *Pavement Maintenance Management for Roads and Parking Lots*, Report no. CERL-TR-M-294, U.S. Army Construction Engineering Research Laboratory, Champaign, Illinois, October 1981.

Table E-14. Range of Flexible Pavement Deducts[1] for Calculating PSC Based on Rating Form

Extent[2]

Distress	Severity: Type of Cracking	Percent of Wheel Track Length per Section: 1	9	10	24	25	49	50	100
Alligator Cracking	(1) Hairline	6	25	27	49	50	79	80	100
	(2) Spalling	10	37	40	66	67	99	100	100
	(3) Spalling and Pumping	16	47	50	77	79	100	100	100

Distress	Severity: Crack Width or Condition	Percent of Section Length: 1	99	100	199	200
Longitudinal Cracking	(1) ≤ 1/4"	1	27	27	43	43
	(2) > 1/4"	3	39	40	59	59
	(3) Spalled	5	50	50	70	71

Distress	Severity: Crack Width or Condition	Number of Cracks per 100 ft: 1	4	5	9	10
Transverse Cracking	(1) ≤ 1/4"	5	12	15	22	23
	(2) > 1/4"	9	21	23	33	35
	(3) Spalled	14	28	32	42	45

Distress	Severity: Type of Patch	Percent of Wheel Track Length per Section: 1	9	10	24	25
Patching	(1) BST	5	21	22	40	41
	(2) Blade	9	32	34	56	57
	(3) AC	16	47	50	77	79

Notes: [1] Deducts rounded to nearest whole number

[2] Rating Form — refer to Figure E-1 (Appendix E)

Table E-15. Range of Portland Cement Concrete Deducts[1] for Calculating PSC Based on Rating Form Extent Measures[2]

Distress	Severity	Extent				
Cracking (1/8"+)	Cracks per Panel	Percent of Panels				
		1	9	10	24	25
	(1) 1	2	11	12	24	25
	(2) 2-3	10	30	32	49	50
	(3) 4+	19	48	50	73	74
Spalling at Joints and Cracks	Average Width (in.)	Percent of Joints				
		1	9	10	24	25
	(1) 1/8 - 1	2	4	4	7	7
	(2) 1 - 3	2	7	7	12	12
	(3) 3+	6	18	19	29	30
Faulting, Settlement	Average Displacement (in.)	Percent of Panels				
		1	9	10	24	25
	(1) 1/8 - 1/4	1	9	10	24	25
	(2) 1/4 - 1/2	7	26	28	49	50
	(3) 1/2+	19	48	50	73	74
Pumping/ Blowing	Type of Pumping	Percent of Joints or Cracks				
		1	9	10	24	25
	(1) Low	2	9	9	16	16
	(2) Medium	2	9	9	16	16
	(3) High	2	9	9	16	16
Patching	Percent of Slab Patched	Percent of Panels				
		1	9	10	24	25
	(1) 1 - 9%	1	6	6	11	11
	(2) 10 - 24%	2	10	11	19	20
	(3) 25% +	7	22	23	36	36
Raveling/ Scaling	Type of Raveling	Percent of Surface Area				
		1	9	10	24	25
	(1) Low	1	3	4	6	6
	(2) Medium	3	10	10	16	16
	(3) High	5	18	19	30	31

Notes: [1] Deducts rounded to nearest whole number
[2] Rating form — refer to Figure E-1 (Appendix E)

Table E-16. Flexible Pavement Deducts[1] for Calculating PSC[2] in WSPMS

Distress	Severity	Extent[2]			
Alligator Cracking	Type of Cracking	Percent of Wheel Track per Length per Section			
		5	15	30	60
	(1) Hairine	17	35	57	90
	(2) Spalling	27	50	75	100
	(3) Spalling and Pumping	35	61	87	100
Longitudinal Cracking	Crack Width or Condition	Percent of Section Length			
		30	130	230	
	(1) ≤ 1/4"	12	32	47	
	(2) > 1/4"	20	46	64	
	(3) Spalled	27	57	76	
Transverse Cracking	Crack Width or Condition	Number of Cracks per 100 ft			
		2	7	12	
	(1) ≤ 1/4"	8	18	26	
	(2) > 1/4"	14	28	39	
	(3) Spalled	20	37	49	
Patching	Type of Patch	Percent of Wheel Track per Length per Section			
		5	15	30	
	(1) BST	14	29	47	
	(2) Blade	23	42	63	
	(3) AC	35	61	87	
Raveling	Type of Raveling	Percent of Lane			
		25	50	100	
	(1) Low (2) Medium (3) High	No Deducts	No Deducts	No Deducts	
Flushing	Type of Flushing	Percent of Lane			
		25	50	100	
	(1) Low (2) Medium (3) High	No Deducts	No Deducts	No Deducts	

Notes: [1] Deducts rounded to nearest whole number
[2] Nomial extent based on performance curve simulations performed at the WSDOT Materials Laboratory

Table E-17. Portland Cement Concrete Deducts[1] for Calculating PSC in WSPMS

Distress	Severity	Extent[3]		
	Cracks per Panel	Percent of Panels		
		5	15	30
Cracking (1/8"+)	(1) 1	7	17	29
	(2) 2 - 3	22	39	55
	(3) 4+	37	60	80
	Average Width (in.)	Percent of Joints		
		5	15	30
Spalling at Joints and Cracks	(1) 1/8 - 1	3	5	7
	(2) 1 - 3	5	9	13
	(3) 3+	13	23	32
	Average Displacement (in.)	Percent of Panels		
		5	15	30
Faulting, Settlement	(1) 1/8 - 1/4	5	15	30
	(2) 1/4 - 1/2	18	36	56
	(3) 1/2+	37	60	80
	Type of Pumping	Percent of Joints or Cracks		
		5	15	30
Pumping/ Blowing	(1) Low	6	12	18
	(2) Medium	6	12	18
	(3) High	6	12	18
	Percent of Slab Patched	Percent of Panels		
		5	15	30
Patching	(1) 1 - 9%	4	8	13
	(2) 10 - 24%	7	14	22
	(3) 25%+	16	28	40
	Type of Raveling	Percent of Surface Area		
		5	15	30
Raveling/ Scaling	(1) Low	2	4	6
	(2) Medium	7	12	18
	(3) High	13	23	34

Notes: [1] Deducts rounded to nearest whole number

APPENDIX F

DISTRICT INTERVIEWS

APPENDIX F

DISTRICT INTERVIEWS

1. INTRODUCTION

All six WSDOT Districts were interviewed relative to the WSPMS (the same questions were used in each District). A summary for each district will be presented followed by the summary.

2. DISTRICT SUMMARIES

WSPMS Discussions
District 1 — Bellevue
March 20, 1991

Attendees

- Tim M. Smith, District Materials Engineer
- Chris Johnson, Assistant District Materials Engineer
- Dennis M. Sipila, Assistant Program Management Engineer
- Roy E. Grinnell, Assistant Program Manager
- R. Keith Key, PMS Engineer
- Joe P. Mahoney, University of Washington

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

   (a) When is this done and how often?

   D. Sipila stated that the District will start the process in late summer. The project definition/scoping process takes about one year to complete.

   (b) How is the process accomplished within the District? (Who is involved in the process within the District?)

   D. Sipila stated that the process begins by examining the pavement distress survey data and driving selected routes. The District does a van tour of the potential projects. Again, the list of projects is produced in D. Sipila's shop. This list is given to T. Smith who also goes on the van tour. D. Sipila stated that he goes with T. Smith recommendations 90 percent of the time. The scoping process is done once during the biennium. The primary person doing the scoping is R. Grinnell.

(c) How effective is the current scoping process based on :

(i) Information from WSPMS?

See (ii) below.

(ii) District process?

Overall, D. Sipila and T. Smith feel fairly good about their current scoping approach. They expressed concern about the consistency, accuracy, and categories currently obtained in the annual condition surveys (more on this later). There was no specific discussion about how the "scoped" projects compared to "final designs."

2. What items are best "liked" by the District with regard to the current WSPMS?

Responses included

- Historical record of pavement distress and contract data. The District is pleased with the annual distress survey.
- Project specific performance curve projection.

3. What items are most "disliked" by the District with regard to the current WSPMS?

A primary concern stated by D. Sipila related to the distress surveys. He felt that there exists a lack of consistency in obtaining the pavement condition data. He would like to see a quality check of this data (for example, taking a "check" sample (statistically based) to verify accuracy). R. Grinnell agreed that this is a problem — further he had noticed a lack of consistency among rating teams.

D. Sipila also expressed some concern about the curve building process.

Concerns about distress surveys also included:

- R. Grinnell feels that longitudinal cracking should be further subdivided.
- D. Sipila concerned about reflection cracking. For example, Headquarters might evaluate a pavement with reflection cracking as a P1; the District, on the other hand, is not likely to address this type of distress (presumably not a high priority item). T. Smith is more concerned about reflective cracking since Maintenance does not address this problem. D. Sipila added that he does not want to see crack sealing let as a contract.
- ACP Interstate: D. Sipila wants the PCR to show wear of ACP. He feels WSDOT is shortchanged in this regard because a P4 can go to a P1 in one year (or survey). Further, rutting, in general, is a problem.

4. What items should be incorporated into (or developed for) WSPMS?

(a) T. Smith feels that the new scoping tool under development for WSPMS will help the District do a better job during the initial scoping phase. This should result in Sipila's and Smith's views of appropriate project scope being "closer together." They both felt this development is a very good idea.

(b) D. Sipila wants the distress rating system to be improved. Specifics were stated earlier.

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

   An improved understanding of WSPMS is important. More documentation is needed but not too much detail (both D. Sipila and R. Grinnell agreed on this point). R. Grinnell wants to know more about the performance curve development process. T. Smith also agreed that more documentation is desirable. C. Johnson agrees that an overview is needed. None of the District 1 personnel at the meeting want large amounts of detail about WSPMS. R. Grinnell wants to see additional information on the visual rating system (deduct points, etc.) and how CPMS is integrated into WSPMS.

6. How "correct" are data within WSPMS for:

   (a) Structural sections (layers, thicknesses, date of construction, etc.)?

   Apparently, the information within WSPMS is fairly accurate.

   (b) Pavement condition data?

   Needs improvement as stated earlier in this report.

   (c) Other categories of information?

   None mentioned.

7. Does the current version of the WSPMS identify projects for programming

   (a) early enough?

   Apparently, the answer is generally yes. However, improvements in the pavement condition survey will help. The annual surveys were a major improvement.

   (b) correct (best) locations?

   Mixed results here in that a fair amount of "on site" examination needed to assure best projects are selected.

   (c) Other?

   None mentioned.

8. General comments

   - T. Smith stated that the District is currently doing more thin ACP overlays. Chip seals are essentially out due to compliants. He added that chip seals are currently about $30,000 lane-mile due to traffic control costs (24 hour control).

- D. Sipila is concerned about ACP/PCC widening. These type of projects fail much too early (and often).

- It was agreed that having an overview of statewide pavement conditions would be helpful. Further, they would welcome a "state-of-the-state" type of report. R. Grinnell felt that some of this kind of information (summary statistics for example) should be listed right on the priority array.

- There did not seem to be any interest in some type of statewide optimizing scheme for WSPMS.

WSPMS Discussions
District 2 — Wenatchee
April 17, 1991

Attendees

- Ed Stuart, Program Manager
- Jerry Roseburg, District Materials Engineer
- Dave House, Construction Engineer
- Stan Delzer, Design/Plans Engineer
- Keith Kay, PMS Manager
- Joe P. Mahoney, University of Washington

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

(a) When is this done and how often?

Currently do this once a biennium but may go to once/year (actually making it a "continuing" process). The scoping process begins with the availability of the newest pavement condition survey.

(b) How is the process accomplished within the District? (Who is involved in the process within the District?)

E. Stuart develops a list of potential projects and then passes this on to J. Roseburg for thickness/type recommendations. Policy "helps" in BST selection (recall ADT of 2000 or less). Following this, E. Stuart and others individually drive the potential projects. They may start using a van tour, according to S. Delzer, which would include the local maintenance supervisor, lead tech, District Maintenance Engineer, and District Administrator (however, this is not done at this time). E. Stuart noted that he plans to hire a scoper/estimator person in his shop soon.

(c) How effective is the current scoping process based on :

(i) Information from WSPMS?

See (ii) below.

(ii) District process?

E. Stuart feels that the overall process works well. He estimated that the scoped projects agree with the final project designs more than 75 percent of the time. Differences can be attributed to a number of reasons including project scope change due to severe weather, WSDOT maintenance activities, etc. S. Delzer noted that it is not a good idea to program projects too far into the future. Why? Changed conditions such as the pavement condition decreasing below that initially anticipated.

2. What items are best "liked" by the District with regard to the current WSPMS?

According to E. Stuart:

- 30 mile screen
- contract history

3. What items are most "disliked" by the District with regard to the current WSPMS?

S. Delzer noted that District contract level BSTs are not noted in the WSPMS historical contract file. Further, these types of District level contracts have been increasing over the last 3 to 4 years since the Districts have been given the freedom to do this. S. Delzer will send this information to K. Kay. (Note: these projects are on the Priority Array.)

4. What items should be incorporated into (or developed for) WSPMS?

(a) E. Stuart: stated the "scoper" should be fully developed and implemeneted. Specifically, he wants the required thicknesses needed (presumably both AC and cushion course).

(b) S. Delzer: agreed with E. Stuart on (a) above.

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

E. Stuart and S. Delzer both feel that a general understanding of the WSPMS is needed down to the E1 level. E. Stuart, S. Delzer, and J. Roseburg felt on-site training was the best way to achieve this. Training should range from the basis of the pavement condition survey through the priority array. Overall, more documentation of WSPMS is needed!

S. Delzer mentioned that there will be major new WSDOT training requirements and it will be somewhat technical. Therefore, a new training activity, such as WSPMS, should be short in duration.

6. How "correct" are data within WSPMS for:

(a) Structural sections (layers, thicknesses, date of construction, etc.)?

"Pretty good."

(b) Pavement condition data?

E. Stuart: The survey agrees with what he sees about 98 percent of the time (i.e., he estimates that about 2 percent of the segments have been improperly surveyd).

(c) Other categories of information?

None mentioned.

7. Does the current version of the WSPMS identify projects for programming

(a) early enough?

E. Stuart: yes, but the project limits are a problem. Little (short) segments are a problem. The 30-mile screen does help E. Stuart in this regard. K. Kay urged E. Stuart to put his limits (Ed's) into CPMS. E. Stuart stated that his preference is to program "long" jobs (10 to 20 miles, if possible). E. Stuart wants to know more about "analysis units" (K. Kay stated that these are based on trips).

(b) correct (best) locations?

See (a) above.

(c) Other?

None mentioned.

8. General comments

- S. Delzer questions how important is it to program jobs with largely transverse cracks.
- S. Delzer looks forward to the rutting estimates from the new profilometer in order to improve the District's estimate of prelevel.
- K. Kay discussed how the profilometer rut data will be presented.
- S. Delzer would like to have cross slope information due to WSDOT policy requirements.

WSPMS Discussions
District 3 — Tumwater
March 21, 1991

Attendees

- Tom Sandwick, Assistant Program Manager
- Darrell Perry, Scoping Engineer
- Dave Morrow, Materials Engineer
- Roger Santo, Soils Engineer
- David Dye, Program Manager
- Jim Brascher, Assistant Project Development Engineer
- Newton Jackson, Materials Laboratory
- Keith Kay, Materials Laboratory
- Linda Pierce, Materials Laboratory
- Joe Mahoney, University of Washington

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

   (a) When is this done and how often?

   District does this biennially, thus far, but may go to an annual basis since an annual condition survey is available. Currently, T. Sandwick and J. Brascher start examining pavement condition survey data in late June or early July. The "scoping tour" occurs during the following March-April time period.

   (b) How is the process accomplished within the District? (Who is involved in the process within the District?)

   T. Sandwick stated that the most recent pavement condition survey is used by D. Perry to develop the initial scope. D. Perry first looks at the potential projects and consults with the Maintenance Superintendent for the area. D. Morrow does an estimate from D. Perry's list — D. Perry then completes the initial scope. Overall, there is quite a bit of "give and take" during this process. Further, J. Brascher must decide whether the project is 2R or 3R.

   (c) How effective is the current scoping process based on :

   (i) Information from WSPMS?

   T. Sandwick's assessment is that the process is working well — most of the time. He stated that about 90 percent of the system is performing adequately. Further, he felt that going to an annual condition survey will improve the process.

   (ii) District process?

   See above. It was stated that the initial scoped funds are about twice that available after completion of the initial scope.

2. What items are best "liked" by the District with regard to the current WSPMS?

- No. 1: Pavement condition survey data
- No. 2: Pavement inventory data (very helpful)

3. What items are most "disliked" by the District with regard to the current WSPMS?

- Segments (analysis sections) — too many along most routes (D. Perry). Would like to see an option to "speed" up process.

4. What items should be incorporated into (or developed for) WSPMS?

- Would like a printout of data based on selected MP limits — not those which are automatically defined by WSPMS (R. Santo).
- Wants information sooner (D. Dye).
- Wetland inventory (T. Sandwick).
- Improved training relative to WSPMS (D. Perry).
- For P1 projects, District would like to have a recommendation as to surfacing (presumably type and depth) — better initial scope would reduce $ changes in budgeting process (T. Sandwick).
- Rutting measurement in condition survey — very important (J. Braschler, T. Sandwick, D. Morrow).

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

Definitely more <u>training</u> and <u>documentation</u> on WSPMS is needed. The number of individuals that need this information is limited. T. Sandwick would like to have a "state-of-the-state" report based on WSPMS data. Further, would like to have specific statistics — such as performance lives. Feels both "reports" are needed.

6. How "correct" are data within WSPMS for:

(a) Structural sections (layers, thicknesses, date of construction, etc.)?

Fairly accurate.

(b) Pavement condition data?

Overall, the data are quite accurate. The condition data are wrong about 10 percent of the time (T. Sandwick).

(c) Other categories of information?

None stated.

7. Does the current version of the WSPMS identify projects for programming

(a) early enough?

yes and no (T. Sandwick)

(b) correct (best) locations?

There exists a major need to define project limits (T. Sandwick).

(c) Other?

WSPMS helps to minimize the impact of project work on the public.

8. General comments

- D. Dye feels that the WSPMS must be made available to maintenance personnel. Further, the District Programming Office only sees the pavements once a year.

- N. Jackson would like for the Districts to check the condition rating teams.

- Previously, District BST work was not reflected within the WSPMS. Concern is that pavements are still in poor condition after such in-house work (T. Sandwick).

- T. Sandwick feels that the condition data is the most important information from WSPMS (they use the "paper" report). D. Perry uses MIDAL to match (or consolidate) P1 and P2 projects in order to obtain reasonable project lengths.

- D. Perry spends much of his time on "global" decisions such as assessing whether a project should be P1, P2, or P3, safety issues, etc. Federal funds often require safety improvements which usually doubles the cost of the project.

- N. Jackson mentioned that a new approach to network optimization may be added to WSPMS. J. Brascher asked "what will it buy us?" He added that District 3 now does "worst first." Further, priority programming is based on lane-miles (District 3 will do about 500 (+) lane-miles for the biennium).

WSPMS Discussions
District 4 — Vancouver
July 23, 1991

Attendees

- Allan McDonald, District Program Manager
- Art Schoonover, Program Control
- Ed Blodgett, Project Development Engineer
- Glenn Schneider, Materials Engineer
- Rich Laing, Assistant Materials Engineer
- Larry Gifford, Scoping Engineer
- John Deputy, Scoping Engineer
- Keith Kay, PMS Manager
- Joe Mahoney, University of Washington

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

(a) When is this done and how often?

L. Gifford noted that this has become a continuous process. Further, projects are scoped about 1-1/2 bienniums ahead. When new condition surveys are received they are used to "check" the scoped projects to see if changes are needed.

(b) How is the process accomplished within the District? (Who is involved in the process within the District?)

A. Schoonover noted that the initial effort starts with the Priority Array from which the initial project list is developed. The scope is added to each project and is based on a number of factors including pavement condition, district level development, economic development in the vicinity of the project, etc. A. McDonald noted that input from maintenance is sought. Overall, Program Management does the scoping. Currently, the district does not do a "scoping tour" but will likely do so in the future on 3R work. The Scoped projects are sent to the District Materials Lab for review.

The FWD data is used in resurfacing reports but not in scoping projects (according to G. Schneider).

According to A. Schoonover, about 10 percent of the projects are "hard to call" with regard to setting scope.

(c) How effective is the current scoping process based on :

(i) Information from WSPMS?

G. Schneider noted that he is generally pleased with the WSPMS input into the scoping process (from his Materials Engineer viewpoint). From a Program Management view (A. Schoonover), the process has improved due to annual condition surveys. A major problem with the previous two year condition survey cycle was that the project priorities (P1, P2, etc.) changed too much between scoping and final design.

(ii) District process?

Program Management does the initial scoping process. A. Schoonover feels that the process can work well and generally does. He does use the project specific performance curves, but on a selective basis (helps with timing decisions). The District Materials Lab would prefer to spread out the review period of the scoped projects (they can receive about 12 or so scopes to review in one batch).

2. What items are best "liked" by the District with regard to the current WSPMS?

(a) G. Schneider

- Easy to use.
- Mile by mile condition rating.
- Pavement construction history.

(b) A. Schoonover

- PMS (overall) is a good "starting point."

3. What items are most "disliked" by the District with regard to the current WSPMS?

(a) G. Schneider

- Would like to have the contract numbers for all contracts in the construction history file.

- Improved traffic (ESAL) estimates.

(b) L. Gifford

- Need to add ramps to WSPMS.

(c) A. Schoonover

- Needs to better estimate prelevel quantities to reestablish cross slope.

- Wants condition survey to include improved rutting and ride measures.

(d) J. Deputy

- Improved rutting measure is needed to improve estimates of prelevel quantities.

(e) A. McDonald

- An improved PCC condition rating scheme.

4. What items should be incorporated into (or developed for) WSPMS?

(a) A. Schoonover

- Crown slope
- Ramp pavement ratings (not necessarily every year).

(b) G. Schneider

- Contract numbers for <u>all</u> projects in the historical job file.

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

(a) A. McDonald

Yes, more understanding is needed.

(b) L. Gifford

Agrees with A. McDonald.

(c) Who?

Include District Materials Lab, design project engineers and maintenance (both engineers and superintendents).

6. How "correct" are data within WSPMS for:

(a) Structural sections (layers, thicknesses, date of construction, etc.)?

According to G. Schneider, the structural section data is "correct" about 75 percent of the time.

(b) Pavement condition data?

- G. Schneider: condition surveys good.
- J. Deputy: correct about 90 percent of the time.
- A. Schoonover: correct about 80 percent of the time and may be getting worse.

(c) Other categories of information?

None mentioned.

7. Does the current version of the WSPMS identify projects for programming

(a) early enough?

- G. Schneider: "pretty good" — projects being paved at about the right time.
- E. Blodgett: is concerned about suggested WSPMS timing.
- R. Laing: sees a need for better, earlier timing.

(b) correct (best) locations?

- A. Schoonover: WSPMS definitely helps.
- J. Deputy: helps in combining P1 and P2 projects.

(c) Other?

None mentioned.

8. General comments

- None — time for lunch.

WSPMS Discussions
District 5 — Yakima
June 10, 1991

Attendees

- Rod Johnson, Project Development Engineer
- Leonard Pittman, Assistant Project Development Engineer
- Tom Lyon, Operations Engineer
- Ken Flett, Scoping Engineer
- Bob MacNeil, Program Management Manager
- Dwain Dunn, Project Control
- Arnie Korynta, District Materials Engineer

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

   (a) When is this done and how often?

   B. MacNeil: Ongoing process (K. Flett's full-time job). Every two years the District has a "meeting of the minds." A. Korynta provides recommendations on the scoped jobs.

   (b) How is the process accomplished within the District? (Who is involved in the process within the District?)

   See (a) above.

   (c) How effective is the current scoping process based on :

   (i) Information from WSPMS?

   - T. Lyon: The effectiveness is good in that 98-99 percent of project scopes not changed.
   - R. Johnson: Some projects are a problem in that pavement distresses such as rutting or flushing are not treated properly.

   (ii) District process?

   See (i) above.

2. What items are best "liked" by the District with regard to the current WSPMS?

   - T. Lyon: The WSPMS attempts to place all potential projects on a "level playing field" which results in an objective process. He also feels the WSPMS has helped the District from making poor project related decisions.

- B. MacNeil: Takes the "politics" out of the process.

- D. Dunn: Likes the historical contract data contained within the WSPMS.

3. What items are most "disliked" by the District with regard to the current WSPMS?

   - A. Korynta: Ignores limits of jobs (does not like small jobs).

   - T. Lyon: Maintenance personnel cannot use WSPMS due to incompatibility of computer hardware. He, in the past, has printed specific WSPMS Maintenance Area results and provided same to maintenance personnel.

   - D. Dunn: Would like the annual condition surveys to be done earlier; hence, earlier delivery of the revised WSPMS.

4. What items should be incorporated into (or developed for) WSPMS?

   - A. Korynta: Add improved rutting measurements (lots of interest expressed in rutting measurements by several individuals).

   - B. MacNeil: Very concerned about faulting joints in PCC pavements.

   - R. Johnson: Add a measure of flushing and also Friction Numbers. (Note: K. Kay noted that a measure of FN has been added to WSPMS.)

   - T. Lyon: Need more insight into actual pavement distress, not just condition rating. Also wants pavement design/rehabilitation shortcourse training for the Districts.

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

   - T. Lyon: Wants WSPMS documentation! Further, information should be "packaged" so that is is suitable for individuals rotating through various jobs within WSDOT. The knowledge and use of WSPMS is <u>not</u> widespread throughout WSDOT.

   - R. Johnson: A WSPMS manual should be prepared so that it can be easily updated.

6. How "correct" are data within WSPMS for:

   (a) Structural sections (layers, thicknesses, date of construction, etc.)?

      - T. Lyon: 80 to 90 percent accurate.

      - A. Korynta: Currently, does not let K. Kay know when he finds incorrect information. Structural section information is improving each year.

(b) Pavement condition data?

- T. Lyon: Correct about 90 percent of the time.

(c) Other categories of information?

None mentioned.

7. Does the current version of the WSPMS identify projects for programming

(a) early enough?

- B. MacNeil: Adequate
- T. Lyon: Probably OK (not certain).
- D. Dunn: Would like to fix some P2's with BST's.

(b) correct (best) locations?

- A. Korynta: Adequate; however, an improved rutting measure will help.

- D. Dunn: Good on non-Interstate, but not for Interstate.

(c) Other?

None mentioned.

8. General comments

None mentioned.

WSPMS Discussions
District 6 — Spokane
June 11, 1991

Attendees

- Don Walther, Program Manager
- Elmer Swanson, District Materials Engineer
- Red Riebe, Program Development Engineer
- Gordon Olson, Design/Plans Engineer

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

   (a) When is this done and how often?

   D. Walther stated that the scoping process begins anew when the priority array is made available. Current mode is to identify P1 projects. Most intense activity is "at budget time."

   (b) How is the process accomplished within the District? (Who is involved in the process within the District?)

   A Project Engineer is assigned to scope each project. In some situations they have scoped projects as a team. The district does not currently have a Scoping Engineer nor are there immediate plans to create a position for one. (D. Walther)

   (c) How effective is the current scoping process based on :

   (i) Information from WSPMS?

   D. Walther mostly agrees with the results from WSPMS. He generally will disagree with 4 to 5 project selections each programming cycle (out of about 400). Both D. Walther and R. Riebe stated that Program Managers should be given the pavement condition rating course taught by K. Kay. (Note: An overview of PMS/WSPMS should be given at the same time.)

   (ii) District process?

   D. Walther feels the District scoping process is adequate. G. Olson stated that the process has improved since the individuals involved spend more time in the field reviewing potential projects. There is always the problem of balancing monies from federal and state sources.

   The issue of "scoped" versus "final design" differences was discussed. D. Walther noted that when scoping an AC overlay a standard thickness of 0.15 ft was used. The District Materials Engineer often recommends a thicker overlay when the resurfacing report is complete. This "disagreement" occurs too often in District 6.

(It was noted that District 6 has $30,000,000 available for the biennium — 50/50 split between federal and state funds.)

2. What items are best "liked" by the District with regard to the current WSPMS?

- D. Walther: Overview of important information.
- R. Riebe: User friendly.

3. What items are most "disliked" by the District with regard to the current WSPMS?

- In general, it is felt that there should be more interaction between WSPMS and maintenance.
- E. Swanson: Noted that chip seal thickness overstated in contract file.
- R. Riebe: Contract data — difficult to identify which projects have occurred.

4. What items should be incorporated into (or developed for) WSPMS?

- E. Swanson: Improve estimates of traffic growth rate.

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

- G. Olson: More WSDOT personnel need to know about WSPMS.
- D. Walther: Would like to see a WSPMS shortcourse for District personnel. Noted that K. Kay's excellent efforts have reduced the need for WSPMS documentation, but should do so anyway.
- E. Swanson: Agrees with comment made by G. Olson and wants a straightforward users guide.

6. How "correct" are data within WSPMS for:

(a) Structural sections (layers, thicknesses, date of construction, etc.)?

- E. Swanson/D. Walther: Good information, generally very accurate.

(b) Pavement condition data?

- D. Walther: Difficult to evaluate PCR numbers.
- E. Swanson: He is interested in specific distress types.
- D. Walther/E. Swanson: Do no fully understand condition survey collection process. More information on this would be desirable.

(c) Other categories of information?

None mentioned.

7. Does the current version of the WSPMS identify projects for programming

(a) early enough?

- D. Walther: Probably so; however, have not used this feature fully due to the District's P1 backlog of projects.
- R. Riebe: Likes the curve projections.

(b) correct (best) locations?

- D. Walther: Wants names added to project limits.

(c) Other?

None mentioned.

8. General comments

None mentioned.

3. OVERALL SUMMARY

The overall summary of the responses to the WSPMS/District checklist is in accordance with the original checklist questions.

Responses to WSPMS/District Checklist

1. Rehabilitation scoping

(a) When is this done and how often?

The responses ranged from "a continuous process" to "once a biennium" to "annually."

(b) How is the process accomplished within the District? (Who is involved in the process within the District?)

In all Districts, the process starts in Program Management. Specifics of how the process is done vary from District to District.

(c) How effective is the current scoping process based on :

(i) Information from WSPMS?

Overall, the Districts feel that the effectiveness of information from the WSPMS is good. The annual condition surveys have been a significant help. However, pavement distress such as rutting needs to be better measured and incorporated into the decision-making process.

(ii) District process?

Overall each District feels that their own unique process works well; however, they noted a number of areas which could be improved.

2. What items are best "liked" by the District with regard to the current WSPMS?

Commonly noted items:
- Historical record of project specific contract information.
- Project specific performance curves.
- Ease of use
- Objective process

3. What items are most "disliked" by the District with regard to the current WSPMS?

Commonly noted items:
- Need more interaction between WSPMS and maintenance.
- Improve process for identifying project limits.
- Add ramps to WSPMS.
- Improve traffic estimates.
- Improve condition survey.
  - Rutting
  - Estimation of prelevel quantities
- District level BST's not automatically added to WSPMS.
- Consistency of condition surveys.
- Too many analysis sections.

4. What items should be incorporated into (or developed for) WSPMS?

Commonly noted items:
- Information available sooner.
- Improved WSPMS training.
- Rutting measure better incorporated into WSPMS.
- Improved rehabilitation scoping process for P1's.
- Condition surveys for ramps and treatment in WSPMS.
- Improved PCC condition survey/rating.

5. How important is it within the District to achieve an improved understanding of how the WSPMS works? If this is important, which individuals need such information? Is additional WSPMS documentation needed?

Comments include:

- Very important — need WSPMS documentation.
- Need to explain WSPMS to a "large" audience. Will enhance use of WSPMS.

6. How "correct" are data within WSPMS for:

(a) Structural sections (layers, thicknesses, date of construction, etc.)?

- Overall, good. Accuracies that were stated ranged from 75 to 90 percent.

(b) Pavement condition data?

- Responses ranged from "needs improvement" to 98 percent accurate.

(c) Other categories of information?

- None mentioned.

7. Does the current version of the WSPMS identify projects for programming

(a) early enough?

- Generally, the answer was "yes." However, a number of suggestions were made.

(b) correct (best) locations?

- Generally, the answer was "yes." However, a number of qualifications to this question were made. Such responses included:
  - Too much "on-site" examination required.
  - Major need to define project limits.
  - Need improved measures and use of rutting data.
  - WSPMS works best for non-interstate pavements.

(c) Other?

- Little response to this question.

8. General comments

- Miscellaneous comments mostly covered by prior questions.