

Transportation Asset Management Case Studies

Presented by



U.S. Department
of Transportation
**Federal Highway
Administration**

PAVEMENT MANAGEMENT SYSTEMS The Washington State Experience





A comprehensive, fully integrated Transportation Asset Management System weaves together information on all asset inventories, condition and performance databases, and alternative investment options.

Asset Management Primer, p. 22.
Federal Highway Administration,
December 1999

Note From the Director

With such factors as an aging national infrastructure, increasing congestion, expanding traffic, and limited funds weighing heavily on transportation agencies, State departments of transportation are looking for innovative ways to manage and maintain their transportation assets.

One tool that continues to provide great benefits is Transportation Asset Management (TAM), a strategic approach that strives to provide the best return for each dollar invested by maximizing system performance, improving customer satisfaction, and minimizing life-cycle costs. TAM practices influence transportation decisionmaking by providing decisionmakers with powerful tools to help identify priorities.

TAM endeavors vary from State to State and include efforts in the areas of pavement and bridge management, network preservation, economics in asset management, life-cycle cost analysis, highway safety and operations, and data integration, among others. Because each State's experience is unique—and because FHWA believes that transportation agencies work more efficiently when information on one another's successes is shared—the Office of Asset Management is continuing its series of TAM case study reports begun in 2002.

On behalf of the Office of Asset Management, I am pleased to present this case study on the application of pavement management systems for engineering and economic analysis and decisionmaking. Pavement management systems can be effectively used to perform engineering analysis to improve design, construction, and preservation practices and to support decisionmaking processes by prioritizing pavement preservation and rehabilitation needs. This case study provides good examples of the Washington State Department of Transportation's application of their pavement management system for economic and engineering analysis. I believe that this and other case studies generated by the Office of Asset Management will help transportation agencies meet the increasingly complex challenges facing them today.



Julius (Butch) Wlaschin
Director, Office of Asset Management
April 2008

Note to the Reader

The Transportation Asset Management case study series is the result of partnering between State departments of transportation and the Federal Highway Administration's (FHWA's) Office of Asset Management. FHWA provides the forum, and the States furnish the details of their experiences with asset management.

For each case study, State transportation staff are interviewed, the information is compiled, and the State approves the resulting material. Thus, the case study reports rely on the agencies' own assessment of their experience. Readers should note that the reported results may not be reproducible in other organizations. ■



Executive Summary

The Washington State Department of Transportation (WSDOT) has achieved a dramatic improvement in the condition of its highways since it began its pavement condition survey program in the mid 1960s and pavement management system in the 1970s. The department has conducted a pavement condition survey on the entire State highway system every 2 years since 1969 and every year since 1988. In the late 1970s, WSDOT developed the first version of its Washington State Pavement Management System (WSPMS) and has been refining and using it since to manage the State's pavements. The portion of pavement in good condition increased from 50 percent in 1970 to 93.5 percent in 2005.

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The WSPMS contains annual pavement condition data and detailed construction and traffic history data for the State's 28,800 lane-km (17,900 lane-mi) of highways. WSDOT uses pavement structural condition as a trigger value to identify candidate pavement projects. Analysts use these data together with information from other WSDOT databases to predict the optimal time for pavement rehabilitation activities and to prioritize rehabilitations over a multiyear investment cycle.

In 1993, legislation required that projects be selected on the basis of lowest life-cycle cost. Through life-cycle cost analysis, WSDOT determined that there is a 2- to 3-year optimal window during which a hot-mix asphalt pavement can be rehabilitated at the lowest life-cycle cost. Although initially only agency costs were used in the lowest-life-cycle-cost approach, more recently threshold values for rutting, which affects safety and roughness, have been implemented to address user costs.

WSDOT has also long utilized the WSPMS to conduct engineering and economic analyses for the purposes of improving pavement performance and maximizing the benefits of pavement investments. These analyses include various studies among which pavement smoothness, lowest-life-cycle-cost concept versus the worst-first methodology, impact of increased use of chip seal on highways, performance of dowel bar retrofits, and a few others are briefly mentioned in this case study.

WSDOT has extensively documented the evolution, operation, and results of the WSPMS. Consequently, this case study consists mainly of excerpts from key documents and technical papers. The excerpts offer concepts and practices that could be adapted for use in other States. ■



INTRODUCTION

The Evergreen State, as Washington is called, is the 18th largest State in the Nation and the only State named after a president. It is bordered by Canada to the north, Oregon to the south, Idaho to the east, and the Pacific Ocean to the west. The highest point in the State is Mt. Rainier at 4,392 m (14,410 ft) above sea level; the lowest, the coastline at sea level.

While 580 km (360 mi) long and 386 km (240 mi) wide, Washington State contains six distinct geographic areas: the Olympic Mountains, the Coast Range, the Puget Sound Lowlands, the Cascade Mountains, the Columbia Plateau, and the outlying subrange of the Rocky Mountains. The State's climate ranges from a wet marine environment that receives as much as 4 m (160 in.) of precipitation annually to a rain shadow area east of the Cascades that averages only 0.15 m (6 in.) of precipitation a year. These features—and a rapidly expanding population of more than 6 million—make managing transportation assets in this ruggedly beautiful State a challenge.

In the mid 1960s, to satisfy legislative requirements for a priority programming process, the Washington State Department of Transportation (WSDOT) developed a pavement condition survey program as part of a pavement management system. The department has conducted a pavement condition survey on 100 percent of the State highway system every 2 years since 1969 and every year since 1988. A manual, or windshield, survey was used to collect distress data until 1998. In 1999, WSDOT began using an automated pavement condition survey vehicle.

In 1982, WSDOT fully implemented the Washington State Pavement Management System (WSPMS). The system's development is explained in "An Assessment of the Benefits of the Washington State Pavement Management System:"¹

In an attempt to provide a tool that will not only help in identifying the present needs of the state highway system but also in evaluating the decisions made and forecasting future needs, WSDOT conducted a feasibility study of a pavement management system in the early 1970s. Development of the pavement management system, referred to as the WSPMS, started in the late 1970s and was first implemented during the 1982 programming cycle.

The WSPMS was developed entirely in-house, and it has evolved over the years to be one of the best systems in the Nation. It is used for both

project-level and network-level analyses. At the network level, pavement data are analyzed, and performance curves for more than 9,000 structurally uniform pavement sections are generated and evaluated for programming and engineering purposes. The current WSPMS is a Microsoft Windows–based program that will be replaced by WebWSPMS in the near future. WebWSPMS is a Web-based pavement management application that will provide access to pavement management information and tools custom-tailored to the individual user.

The WSPMS contains the following data: annual pavement condition data, including cracking data since 1969, International Roughness Index (IRI), and rutting data since 1999; and detailed construction and traffic history data for the 28,800 lane-km (17,900 lane-mi) of the Washington State route system.²

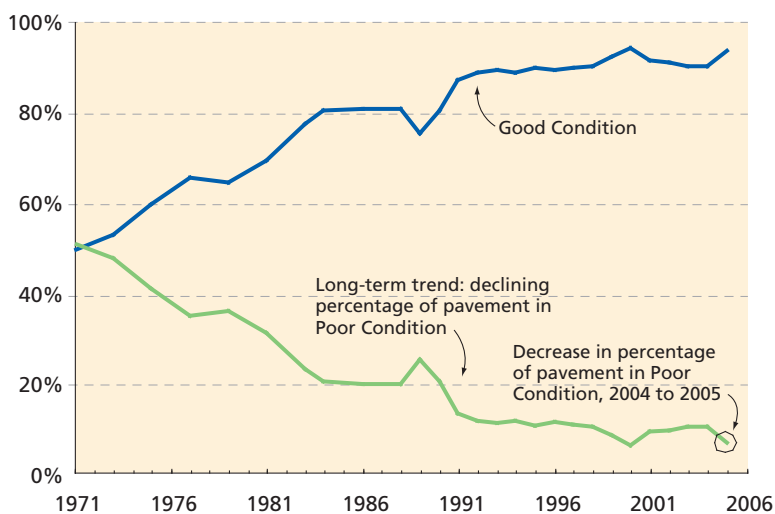
PAVEMENT CONDITION IN WASHINGTON

*Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*³ categorizes the WSDOT route system in three pavement types:

- Hot-mix asphalt pavement: 17,342 lane-km (10,776 lane-mi), 60 percent of network.
- Bituminous surface treatment: 4,843 lane-km (4,843 lane-mi), 27 percent of network.
- Concrete pavement: 3,640 lane-km (2,262 lane-mi), 13 percent of network.

The Gray Notebook for the quarter ending December 31, 2006,⁴ states, “According to the 2005 pavement condition survey, the percentage of all pavements in the ‘good’ category increased from 89.9 percent in 2004 to 93.5 percent in 2005, [which is] an overall increase of 3.6 percent” (p. 53).

The following graph, developed by the WSDOT Materials Lab, illustrates the trend in condition of the State’s highway pavements from 1971 to 2005.



Data source: Washington State Department of Transportation Materials Lab

Figure 1. Trends in poor and good pavement condition of Washington State highways, 1971–2005, following adoption of a pavement condition survey in 1969 and a pavement management system in 1982.

PROJECT PRIORITIZATION AND DECISIONMAKING

One of the most important steps in the implementation of a PMS is monitoring the pavement condition on a regular basis. WSDOT manages the highway system by annually monitoring all pavements to determine where, when, and what maintenance or rehabilitation treatments are warranted in an ongoing process.

This activity is a key element of the Highway System Plan Pavement Preservation Program. The data and analysis required to do this is termed the Washington State Pavement Management System (WSPMS). The WSPMS has evolved over a period of about 30 years. Initially, WSPMS was simply a listing of the condition of pavement segments on the WSDOT route system, but has become a process which uses the pavement condition information along with [construction history,] traffic, and information from other WSDOT data bases to predict the where, when, and what needed for pavement rehabilitation [activities to optimally preserve the pavement network.]⁵

Implementation of the pavement management system by WSDOT has helped the State to improve its pavement condition significantly.

The WSPMS uses pavement structural condition (PSC) as a trigger value to identify candidate pavement projects, as described in the following paragraphs:

Overall pavement distress is termed pavement structural condition (PSC)

and is calculated separately for flexible and rigid pavements. The PSC has an upper limit of 100 (no distress) and a lower limit of zero (extensive distress). WSDOT attempts to program rehabilitation for pavement segments when they are projected to reach a PSC of 50.⁶

WSDOT has given careful consideration to the formulation and interpretation of the PSC itself, and the value of the PSC threshold, in terms of how pavement rehabilitation projects in Washington should be programmed. Cost analyses [lowest life-cycle cost] performed by WSDOT show that unit costs of rehabilitation increase by a factor of three to four for [hot-mix asphalt (HMA)] projects programmed at a PSC of zero compared to projects programmed at a PSC of 40 to 60.⁷

Initial development of threshold values for lowest-life-cycle cost approach was based only on agency costs and did not include user costs.... Threshold values for rutting to address safety and roughness to address user cost were subsequently implemented in identifying [candidate] projects.⁸

WSDOT employs the following process to develop a prioritized list of projects.

Using the pavement condition and performance curves, the WSPMS can forecast the expected [optimum] time to the next rehabilitation for each pavement section. Each candidate project is assigned to a priority group according to its predicted “due date.”⁹

For example, if a pavement section is expected to reach a PSC equal to 50 in 2008, then the pavement section is considered “due” for rehabilitation in 2008.

Priority groups are defined by individual year only for those six years that are encompassed by the investment program. These priority groups, taken collectively, form the priority listing of pavement preservation needs. The priority listing is a useful tool for the central [headquarter] office, program managers and the regions in developing the biennial preservation program. However, the list is supplemented by [review of the digital images collected

as part of annual pavement condition data collection and] additional site visits to verify accuracy, assess causes of defects and determine abilities of the maintenance program to apply preventative or short term remedial treatments before a biennial program is developed.¹⁰

It should be noted that WSDOT takes into consideration the importance of the candidate projects on high-volume routes while preparing the priority list.

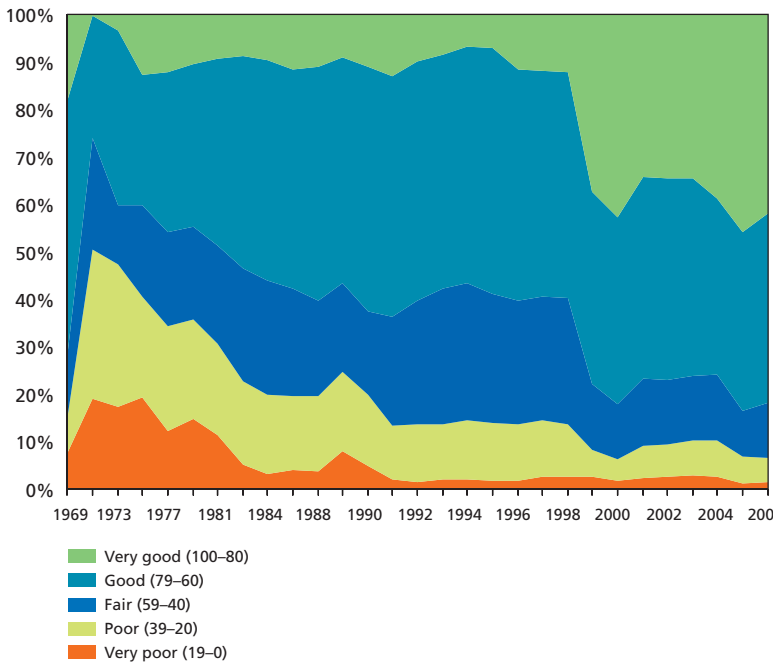
WSDOT attempts to rehabilitate high volume routes (interstate and principal arterial routes) when they are “due” and prevents them from reaching the “past due” category. Also, as part of the biennium rehabilitation projects selection process, “past due” projects may be included if increased user costs on high-volume routes justify their selection.¹¹

Clearly, the focus of the WSDOT pavement management program is on pavement preservation. As mentioned previously, 27 percent of the entire system receives a bituminous surface treatment on a 6- to 8-year cycle. WSDOT applies this type of treatment to low-volume roads with an annual average daily traffic less than 2,000. Typically, 100 percent of chip seal projects that are due are programmed first. The remaining funds address rehabilitation projects (nearly 90 percent of rehabilitation projects are 50-mm [2-in.] overlay projects) with PSC values between 40 and 60, and if any funds are left, remaining past due projects will be programmed.

Implementation of the pavement management system by WSDOT has helped the State to improve its pavement condition significantly. For all route classifications (Interstate, Principal Arterial, Minor Arterial, and Major Collector), the overall PSC scores from 1971 to 2006 are shown in Figure 2. As stated in *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, May 1999¹² “it is notable how this condition measure has improved since 1971—noteworthy is the reduction of those pavements being in the very poor category from about 20 percent of the total lane-miles in the early 1970’s down to about one percent in 1994 and later.”

In 1971, almost 50 percent of the State’s pavements were in poor and very poor condition. Today, a little more than 10 percent of the roads are in poor and very poor condition.

The pavement management system can forecast the optimal time for the next rehabilitation for each pavement section.



Data source: Washington State Department of Transportation Materials Lab

Figure 2. Trends in Washington State pavement structural condition, 1969–2006 (statewide, all pavements).

PMS APPLICATIONS IN ENGINEERING AND ECONOMIC ANALYSIS

Pavement management databases hold substantial amounts of data. This data may be used for programming, economic analysis, and engineering analysis at both network and project levels. WSDOT has been using the PMS data effectively in performing various analyses to provide decision-makers with the information they need. The following examples of engineering and economic analyses performed by WSDOT are taken from State documents.

I-5 Seattle Portland Cement Concrete Pavement Performance Study

WSDOT, the University of Washington, Parametrix, and Nichols Consulting joined together to investigate the performance of concrete pavements on I-5 in the Seattle area, [and the] report was scheduled to be completed by Fall 2007. This study will attempt to determine when [existing] concrete pavements [constructed mostly during the 1960s and far beyond their initial design life of 20 years] on I-5 will fail and how much time WSDOT has to plan and develop reconstruction projects before the pavements deteriorate to an unacceptable level.¹³

Investigation on the Potential Impact of Increased Use of Chip Seal Pavements on Highway System

WSDOT used the WSPMS to correlate traffic thresholds for the effective use of chip seals on roadways with [annual] average daily traffic up to 4,000 instead of the [WSDOT standard of] 2,000 ADT. In 2005, WSDOT initiated a study with the University of Washington to investigate current chip seal application practices, determine whether chip seals can be applied to higher trafficked routes (greater than current practice of routes with less than 2,000 vehicles per day), and determine the statewide economic impacts [that increased] chip seal [use may have.] Since the increased use of chip seals [can] impact the performance of the state owned route system, both a structural and an economic analysis is required.

The expected results of this study are:

- Criteria on the use of chip seals as a lower cost alternative to hot-mix asphalt overlays. Specifically, which WSDOT routes can be converted to a chip seal with assurance that the structural adequacy will not be compromised.
- Criteria that examine whether WSDOT should consider alternating chip seal and hot-mix asphalt paving cycles [to preserve structure while minimizing cost].
- Insight into how to mitigate noise, roughness, performance, and construction issues.
- Improved manual on chip seal design and construction.

The economic analysis portion of this study is currently being finalized. The entire study was to be completed by Fall 2007 and shared in the December 2007 *Gray Notebook*.¹⁴

Worst-First to Lowest Life Cycle Cost

This is an example of utilizing PMS to evaluate programming and funding distribution policies, and to justify the incorporation of the lowest life cycle cost concept into project selection process versus the worst-first methodology. In 1993, the Revised Code of Washington required that project selection be based on the lowest life cycle cost concept. WSDOT determined that there is [an optimal] timing [window] (a range of approximately two to three years) at which a hot-mix asphalt pavement can be rehabilitated at the lowest life cycle cost (see the figure below.) The figure was generated by determining the pavement repair, overlay and overhead costs for the rehabilitation of a hot-mix asphalt pavement at various pavement conditions. These costs were then applied to the entire state network assuming a specific rehabilitation cycle (i.e., every four, eight, ten etc. years). A pavement rehabilitated too soon will have wasted pavement life, while a pavement rehabilitated late will have higher associated repair and rehabilitation costs.¹⁵

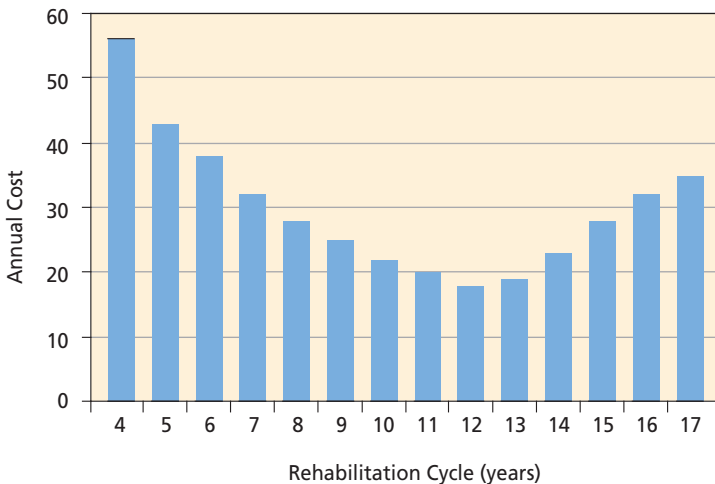


Figure 3. Lowest-life-cycle cost rehabilitation cycle for hot-mix asphalt pavement.

The implementation of this concept has been an easy transition for rehabilitation project selection within the WSPMS; however, for regional officials, the change has been a bit more challenging. One major challenge involves regional officials' hesitancy in selecting a pavement to be rehabilitated that was not in the worst condition. . . . With a bit of perseverance from the Pavement Management Staff, the majority of the Regional offices (five out of the six) bought into the change. The sixth region continued to schedule pavement rehabilitation projects based on the worst first concept. It wasn't until recently (2002) that the sixth Regional office (noted as Region) acknowledged the error in the decision and has now complied with the lowest life cycle cost requirement for rehabilitation project selection.¹⁶

Implementation of Performance Graded (PG) Binders

In 1999 WSDOT implemented PG binders (Asphalt Institute 2003) in all state highway hot-mix asphalt projects. The PG binder establishes specifications for the selection of the asphalt binder to meet the low temperature (for minimizing thermal cracking), the high temperature (for minimizing rutting), and the truck traffic volume and speed (for minimizing rutting) for a specific pavement section. For Washington State, this established two primary asphalt binder types (PG 58-22 and PG 64-28); a third binder grade is selected for mountain passes (PG 58-34). Using WSPMS, an analysis was conducted to characterize the benefits of implementing PG binders [on minimizing] rutting at signalized intersections.

The WSPMS was queried to locate intersections with stopped conditions (i.e., stop sign or signalized intersection). This resulted in eight contracts that utilized PG binders, with one to seven intersections within each project. These eight contracts included three high-temperature binder grades: PG 76, PG 70, and PG 64. With three years of data, the maximum intersection rut depth using a PG [binder] was determined, and a comparison of the average rut depths by binder grade was made.

Though this analysis tended to support the use of PG binders for reducing intersection rutting, this analysis was only based on three years of performance data and the authors acknowledged that the conclusions should not be made until additional performance data was obtained.¹⁷

The international roughness index score was found to be the single best predictor of driver acceptability.

Evaluation of Pavement Smoothness and Resulting Pavement Performance

In June 2002, a research study was completed for the State of Washington to investigate factors associated

with driver-perceived road roughness. This study had four primary objectives. The first objective was to design an experiment that would link roughness data to public perceptions of road roughness. The second objective was to collect data on the public's general perception of pavement roughness in Washington State. The third was to compare the public's perceptions with actual measurements of road roughness and physical roadway attributes. The last objective was to compare these findings with those in other related research.

In this study, drivers were placed in [selected vehicles in] real world driving scenarios and asked to reveal their opinions about pavement roughness. A total of 56 participants each evaluated 40 highway test segments and produced 2,180 separate "observations." Driver evaluations were collected with other data, such as speed and in-vehicle noise, and matched with driver-specific socio-demographic data and pavement-specific data from the Washington State Department of Transportation and its pavement management system.

Results from [the study] indicated that the international roughness index (IRI) is the single best predictor of driver-perceived road roughness and driver acceptability. Pavements with low IRI values generally corresponded with low roughness rankings and high levels of user acceptability. Other factors statistically associated with driver-perceived measures of road roughness included the presence of pavement maintenance, the presence of joints or bridge abutments, the age of the pavement surface, the vehicle type, levels of in-vehicle noise, the speed of vehicle, and the gender and income of the driver.¹⁸

Implementation of Superpave Mix Design

This example demonstrates the data mining capabilities of pavement management systems for conducting engineering analysis at both project and network level to [evaluate and understand positive and negative factors affecting] pavement performance.



WSDOT began placing Superpave designed mixes in 1996 and placed an increasing number each year (two percent in 1997 up to 47 percent in 2002), with full implementation [being] scheduled for 2004. Prior to 1996, WSDOT exclusively used the Hveem mix design procedure and AR4000W asphalt binder (conventional) on all hot-mix asphalt pavements.

A project-by-project comparison of the Superpave and conventional hot-mix asphalt projects was performed using the data contained in the WSPMS. Each Superpave project was compared to the previous overlay or construction (conventional mix) completed at the same location. The PSC, IRI, and rut depths were retrieved from WSPMS for both the Superpave and conventional mix projects at the same age. For all three pavement measures (PSC, IRI, and rutting), the project-by-project comparison was followed by the statewide comparison.¹⁹

Performance of Dowel Bar Retrofits

In 1992, WSDOT constructed a test section to determine the appropriateness of dowel bar retrofit (DBR) and diamond grinding to restore the functionality of the concrete pavement as well as to provide a smooth riding surface. Due to the success of the test section, the first large-scale DBR project was constructed on Interstate 90 (Snoqualmie Pass vicinity) in 1993.

Dowel-bar retrofit is considered cost effective since it is applied only to the faulted lane.

WSDOT continued to monitor this and all other sections of concrete pavement that have been retrofitted with dowel bars. Using data from the WSPMS, performance equations will be developed to relate truck volumes to faulting such that the performance life of dowel bar retrofit could be predicted. Based on the performance of the test section it is anticipated that dowel bar retrofit will extend the life of the concrete pavement by 10 to 15 years. It is estimated that over the next 20 years an additional 300 lane-miles of concrete pavement may require DBR.

Since that time, WSDOT has rehabilitated over 300 miles of existing concrete pavement by dowel bar retrofitting followed by diamond grinding. The average construction costs for DBR is approximately \$450,000 (2006 dollars) per lane-mile (includes all costs: PE, construction, traffic control, etc). The typical cost of a four-inch asphalt overlay, which is the minimum recommended overlay depth for rehabilitating a faulted concrete pavement, is approximately \$525,000 per lane-mile (includes all costs). DBR is considered cost effective since it is only applied to the faulted lane while an asphalt overlay would be required on all lanes, shoulders, ramps, ramp tapers, etc., [significantly increasing the effective lane miles and cost for asphalt overlay.]²⁰

Portland Cement Concrete Pavement Damage Caused by Studded Tires

In the past, it has been difficult to assign a dollar value of the damage to pavement caused by studded tires. [With] improvements in technology, it is now possible to measure the actual amount of damage caused by studded tires on PCC pavements [and hence quantify the dollar value of damage]. [Transverse profile] measurements [conducted as part of the annual pavement condition survey] on PCC pavements indicate that the current damage due to studded tires is approximately \$18.2 million (cost for removing studded tire wear by diamond grinding the concrete surface.)

Over the last five years, WSDOT has constructed a number of PCC pavement test sections to determine what combination of materials could be used to help offset the damage caused by studded tires. Test section approaches have included increasing the concrete strength (making the concrete surface harder would make it more resistant to studded tires), modifying the aggregate gradation (making the aggregate gradation more

uniform to minimize the smaller aggregate which is more susceptible to studded tire wear), adding the Hard-Cem product (this is a product that is typically used to harden industrial floors) and modifying the surface texture (carpet drag versus tining).²¹

SCOPER Design Method

This is an excellent example of engineering uses of pavement management data to improve network level project scoping. The availability of the pavement management database has made it possible to develop SCOPER and to produce practical, more accurate design estimates at an early date, [when project funding needs are determined, but before project specific structural evaluations are made], to result in improved pavement design and performance within the state highway system. The initial scoping design is then available to WSDOT regional engineers as a preliminary estimate for their full design process. SCOPER estimates required overlay thickness approximately 80% of the time to produce designs within 10–15% of the final required design.

The SCOPER process uses the Asphalt Institute's component analysis method with modification to layer coefficient based on Washington characteristics [Asphalt 83; WSDOT 95a²²]. The approach requires that the total pavement structure be developed as a new design for the specified service conditions. The method takes into account pavement condition, type, and thickness of the pavement layers.

SCOPER uses a relationship between pavement structure and traffic to estimate the subgrade's stiffness. The existing structural integrity of the pavement is converted to an equivalent thickness of hot-mix asphalt, which is then subtracted from the required thickness for a new full depth hot-mix asphalt design to determine the required overlay thickness.²³

Performance Grade (PG) Binder Specifications

The WSPMS was used to assist pavement design engineers in selecting the proper asphalt binder grade for each individual project. The PG binder selection module [of WSPMS] accesses the project information concerning state route, milepost limits, roadway speed limit, traffic condition (free, slow, or standing) and the 15-year equivalent single-axle load (ESAL) for



the selected project. The user then enters the expected overlay thickness, design ESALs, and geographical area, and the module provides recommendations for appropriate PG binder designation.²⁴

CONCLUSIONS

Washington State has seen dramatic and sustained improvement in the condition of its highway network over recent decades, concurrent with its use of regular pavement condition surveys and the WSPMS for engineering and economic analysis. The system enables WSDOT to forecast future needs, conduct research that contributes to improved pavement performance, and maximize pavement investments by objectively prioritizing highway preservation and improvement projects. In addition, the WSPMS provides a rational basis for communicating with the State legislature and highway users about stewardship of the State's infrastructure.

Although the WSPMS was developed internally and has been refined over several decades to meet the needs of WSDOT, it can serve as a model

for other States. The WSPMS has features and benefits that other State departments of transportation could adapt to their specific needs at the project and system levels.

The pavement management system enables WSDOT to forecast future needs, conduct pavement performance research, and maximize pavement investments.

Endnotes

1. “An Assessment of the Benefits of the Washington State Pavement Management System.” Linda M. Pierce, Joe P. Mahoney, and Nadarajah Sivaneswaran. Paper presented at the Fifth International Conference on Managing Pavements, Seattle, Washington, August 11–14, 2001.
2. “Mining PMS Data to Evaluate the Performance of New Hot-Mix Asphalt Pavement Design Practices.” L. M. Pierce, N. Sivaneswaran, K. W. Willoughby, and J. P. Mahoney. Paper presented at the 6th International Conference on Managing Pavements, Brisbane, Australia, October 19–24, 2004.
3. *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, May 1999. <http://www.wsdot.wa.gov/biz/mats/pavement/Pavement%20Plan.pdf>. Washington State Department of Transportation, Field Operations Support Service Center, Materials laboratory, Olympia, WA, p. 4.
4. The Gray Notebook. *Measures, Markers and Mileposts: The Gray Notebook for the quarter ending September 30, 2006, WSDOT’s quarterly report to the Governor, the Legislature, and the Washington State Transportation Commission on transportation programs and department management*. p. 53. www.wsdot.wa.gov/Accountability/GrayNotebook/Gnb_archives.htm
5. *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, p. 4.
6. *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, p. 5.
7. *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, p. 14.
8. “An Assessment of the Benefits of the Washington State Pavement Management System.”
9. *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, p.14.
10. “An Assessment of the Benefits of the Washington State Pavement Management System.”
11. “An Assessment of the Benefits of the Washington State Pavement Management System.”
12. *Washington State Highway Pavements: Trends, Conditions, and Strategic Plan*, p. 6.
13. The Gray Notebook, 2006, p. 54.
14. The Gray Notebook, 2006, p. 56.
15. WSDOT PMS reference material included in the FHWA Demonstration Project 108-A, “Pavement Management—Multi-year Prioritization” reference manual, circa 1996. Washington State Department of Transportation, Olympia.

16. "Mining PMS Data to Evaluate the Performance of New Hot-Mix Asphalt Pavement Design Practices."
17. "Mining PMS Data to Evaluate the Performance of New Hot-Mix Asphalt Pavement Design Practices."
18. "A Statistical Analysis of Factors Associated With Driver-Perceived Road Roughness on Urban Highways." Kevan Shafizadeh, Fred Mannering, Linda Pierce; Washington State Transportation Center (TRAC). Research Report, June 2002.
19. "Mining PMS Data to Evaluate the Performance of New Hot-Mix Asphalt Pavement Design Practices."
20. Dowel Bar Retrofit, September 2001 Technical Notes and Materials Laboratory, January 2007, Technical Notes, Washington State Department of Transportation.
21. The Gray Notebook, 2006, p. 55.
22. Asphalt Institute Manual Series 1, 1983, and WSDOT Pavement Guide, Vol. 3, Pavement Analysis Computer Software and Case Studies for Design, Evaluation and Rehabilitation, Section 4.0—Case Study No. 1. Washington State Department of Transportation, 1995. <http://www.wsdot.wa.gov/fasc/EngineeringPublications>
23. *Analysis of PMS Data for Engineering Applications, Reference Manual*, National Highway Institute Course No. 131105. Federal Highway Administration, Washington, DC (<http://www.nhi.fhwa.dot.gov>); <http://.knowledge.fhwa.dot.gov/tam/aashto.nsf/docs> (DNA 5HJJLRFHWA), November 2002.
24. "An Assessment of the Benefits of the Washington State Pavement Management System."



This document was prepared by the U.S. Federal Highway Administration with expert guidance provided by Linda Pierce, Pavement Engineer, Washington State Department of Transportation. The content of this document was gathered from the department's documents and technical notes.

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Additional information on pavement management systems—including National Highway Institute courses, pavement workshops, and publications—is available at the FHWA Web site: <http://www.fhwa.dot.gov/pavement/mana.cfm>

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