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BST Protocol

Bituminous Surface Treatment Protocol

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16. ABSTRACT

This study used the HDM-4 software to test the average annual daily traffic (AADT) and equivalent single axle load (ESAL) levels appropriate as criteria for selecting the application of bituminous surface treatments (BST) to WSDOT pavements. It verified the feasibility of using BSTs to maintain pavements with higher traffic levels than have been applied in the past. It also determined the validity of alternating the application of BST resurfacings and 45-mm hot mix asphalt overlays. In addition, the research estimated the impacts that increased use of BST surfaces would have on the performance of the state-owned route system.

The basic recommendations are as follows:

- ADT of up to 2,000: Apply BSTs unless they are specifically exempted (such as paving through cities, limited BST routes, etc.).
- ADT of 2,000 to 4,000: Apply a combination of BST and HMA overlays used interchangeably, depending upon pavement condition. Exemptions are allowed for paving through cities, limited BST routes, etc.
- ADT of greater than 4,000: Apply HMA overlays.

This report is the first of two planned for the study.

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EXECUTIVE SUMMARY

This study assessed the current bituminous surface treatment (BST) traffic criteria for the Washington State Department of Transportation (WSDOT). This project focused on (1) determining the feasibility of using BST resurfacings to maintain flexible pavements with higher levels of traffic than in the past, and (2) developing a better understanding of the impacts of alternating the application of several BST resurfacings and 45-mm hot mix asphalt (HMA) overlays on a portion of the WSDOT route system. This study was intended to help WSDOT enhance its pavement preservation program through an improved understanding of the use of BST resurfacings. The research also estimated the impacts that an increased use of BST surfaces would have on the performance of the state-owned route system.

This report documents the use of the Highway Development and Management System (HDM-4) software. The University of Washington team had recent experience with HDM-4 version 1.3 (Li et al., 2004). An updated version of the software (version 2.03) was used for the analyses in this report.

The HDM-4 system provides not only pavement performance predictions but estimates of the economic consequences of various resurfacing alternatives. The analyses suggest which pavements that are currently surfaced with HMA could be converted to a BST surface. Importantly, HDM-4 was used to examine user costs associated with differing pavement roughness, which was necessary for comparing HMA overlays to BST resurfacings.

Issues associated with pavement preservation were at the heart of this study. It is widely understood that pavement preservation extends pavement life. In essence, it is the timely application of pavement repair and resurfacing alternatives to maintain or extend a pavement's service life. The major findings of the study are as follows:

- A preservation method of multiple cycles of BSTs followed by a HMA overlay was found to be cost effective for most pavement sections evaluated in this study; although, the economic differences between the preservation options studied were small. The use of BST resurfacings were triggered by 10 percent cracking or less (based on the total pavement area), and HMA overlays were applied when rutting exceeded 10 mm or the International Roughness Index (IRI) was greater than 3.5 m/km.

The basic recommendations are as follows:

- ADT of up to 2,000: Apply BSTs unless they are specifically exempted (such as paving through cities, limited BST routes, etc.).
- ADT of 2,000 to 4,000: Apply a combination of BST and HMA overlays used interchangeably, depending upon pavement condition. Exemptions should be considered for paving through cities, limited BST routes, etc.
- ADT of greater than 4,000 AADT: Apply HMA overlays.

Information on WSDOT's Pavement Preservation funding may assist the reader in understanding why this study was untaken. The following two tables provide a quick view of past and current WSDOT preservation funding. Note that the total available pavement preservation funds are significantly lower for the 2005-2007 biennium; over 30 percent less than average biennium funding over the last 12 years. Furthermore, for 2005-2007, funding for HMA overlays is down 34 percent (in comparison to the biennia average) and up 23 percent for BST resurfacings. Average funding over the 12-year period shows that about $8,000 per lane-mile was spent for HMA overlays (based on 10,776 lane-miles of HMA surfaces) and $2,000 per lane-mile for BST resurfacings (based on 4,823 lane-miles of BST surfaces). Thus, an HMA overlay is about four times more expensive than BSTs. This cost takes into account performance differences (HMA surfaces last longer than BST surfaces) and project costs. That said, one should not lose sight of the fact that much of the WSDOT route system is not suitable for BST surfaces (because of high traffic, noise increases, etc).

WSDOT Preservation Funding—Biennium Basis

Biennium	Total Pavement Preservation Funds (includes overhead, Project Engr, R of W, Safety) *$ millions for biennium*		Preservation Funds by Pavement Type (excludes overhead, Project Engr, R of W, Safety) *$ millions for biennium*			
	Total	% for OH, PE, Safety	HMA	BST	PCCP	Other
1995-1997	258.9	12.5	145.1	14.6	25.5	45.0
1997-1999	305.1	7.8	217.2	16.8	33.4	15.8
1999-2001	259.7	11.2	178.8	21.3	24.5	8.9
2001-2003	248.2	10.2	193.5	16.1	4.8	10.8
2003-2005	221.0	9.7	167.7	19.8	1.5	12.6
2005-2007	162.3	7.4	111.2	22.9	0	17.0
Averages (1995-2007)	242.6	9.8	168.9	18.6	15.0	18.4

Note:

- All biennia fund amounts shown are actual values—the amounts have not been adjusted for inflation. This comment applies for both tables.
- Table 1 based on information from P. Morin (WSDOT), November 2006.

Preservation Funds by Lane-Mile per Year

Biennium	Overall Funding Per Lane Mile Per Year (includes OH, PE, Safety)	Preservation Funds by Pavement Type (excludes overhead, Project Engr, Safety) *$/Lane-Mile/Year*		
		HMA	BST	PCCP
1995-1997	7,248	6,733	1,514	5,637
1997-1999	8,541	10,078	1,742	7,383
1999-2001	7,270	8,296	2,208	5,416
2001-2003	6,948	8,978	1,669	1,061
2003-2005	6,187	7,781	2,053	332
2005-2007	4,543	5,160	2,374	0
Averages (1995-2007)	6,790	7,837	1,928	3,305

Note: Statewide:

- HMA lane-miles: 10,776 (60% of total)
- BST lane-miles: 4,823 (27% of total)
- PCCP lane-miles: 2,262 (13% of total)
- Total lane-miles: 17,861 (100% of total)
- Annual preservation funds assumed to be ½ of biennium total (not strictly correct).
- Source—Washington State Highway Pavements—Trends, Conditions, and Strategic Plan, May 1999.

1: INTRODUCTION

A bituminous surface treatment (BST) is often referred to as a chip seal or seal coat. It is a thin surface treatment of liquid asphalt covered with an aggregate that has an applied thickness of about 0.5-inch or less. BSTs are normally applied to pavements with lower traffic volumes. A study by Uhlmeyer et al. (2000) suggested that HMA pavements thicker than about 6 inches often experience a type of distress that can be mitigated by a BST surface.

It is possible to successfully apply a BST on high speed, high traffic roads when precautions are taken (MnDOT, 1998). The design and construction issues related to using BSTs on high-volume pavements have been addressed in studies by Shuler (1990) and Jackson et al. (1990). This study focused on the levels of annual average daily traffic (AADT) and equivalent single axle loads (ESALs) that appear reasonable for BST resurfacings. The Highway Development and Management System (HDM-4) was used as an economic analysis tool because it integrates material properties, speed limit, climate, vehicle characteristics, pavement structure, and pavement distress models (Kerali et al., 2000). The analyses reported were based on data from the 2003 version of the Washington State Pavement Management System (WSPMS).

1.1: WSDOT BACKGROUND

Over the last 12 years, WSDOT's funding for the pavement preservation program has either suffered from a lack of increases to keep up with needs and inflation or outright cutbacks (as illustrated by the tables contained in the Executive Summary). The prices of pavement materials have dramatically increased within the past two years and have been quite volatile. With constrained budgets, a fundamental issue is how to best allocate the available funding for preservation projects.

WSDOT has about 11,000 lane-miles of HMA surfaced pavement, which accounts for 60 percent of its total lane-miles. It also has almost 5,000 lane-miles of BSTs and 2,000 lane-miles of portland cement concrete pavement (PCCP). The major types of pavement distress for HMA are cracking, rutting, and roughness. A typical preservation method is a 45-mm HMA overlay applied every 10 to 16 years (WSDOT, 2001).

Currently, BST surface applications are used mostly on lower traffic, flexible pavements with AADTs of less than 2,000. Typically, a BST is applied every 5 to 8 years, depending on budget and pavement distress conditions. The current BST program (2005-2007 biennium) accounts for 15 percent of all WSDOT pavement preservation funds; over the last 12 years BSTs accounted for about 8 percent of the program. In light of reduced preservation budgets and the significant annualized cost difference between BST and HMA resurfacings, WSDOT is considering expanding the use of BSTs on selected routes. To aid WSDOT with this decision, this study examined the following:

- What is a reasonable upper level of AADT (both directions) at which BST resurfacings can be used?
- What is a reasonable upper level of annual ESALs at which BST resurfacings can be used?
- What combinations of BST resurfacings and HMA overlays produce a cost effective rehabilitation mix?

1.2: HDM-4

The Highway Development and Management System (HDM-4), originally developed by the World Bank for international use, is a software tool for conducting pavement analyses. It can provide pavement performance predictions, rehabilitation/maintenance programming, funding estimates, budget allocations, policy impact studies, and a wide range of special applications. Its effectiveness is dependent on its ability to accurately model and predict pavement performance, which is affected by the accuracy of the input data and calibration efforts (Kerali et al., 2000). As such, the results should only be used in a broad decision-making context.

In 2004, the HDM-4 (version 1.3) flexible pavement distress models were calibrated for WSDOT, including models for HMA and BST surfaced pavements (Li et al., 2004). The required input data, which are extensive, were converted to the new version 2.03 for this study. Section 2 describes the process and results of the related previous research.

This research used HDM-4 version 2.03 to examine pavement preservation combinations related to BST resurfacings, to estimate the effects of using BSTs with higher levels of AADT, and to estimate the economic impacts.

1.3: RESEARCH OBJECTIVES

The two major goals of this study were as follows:

- Goal 1: Examine and modify, as needed, the criteria for when and where to use BST resurfacings.
- Goal 2: Provide insight or criteria for alternating the application of BST resurfacings and HMA overlays for portions of the WSDOT route system.

1.4: REPORT ORGANIZATION

This document is organized as follows:

Chapter 2 overviews the results from previous work with HDM-4 version 1.3 and related information about the input data, calibration, and results.

Chapter 3 provides a description of the research approach, data preparation, and analysis process used for HDM-4 version 2.03 along with summarizes of the results.

Chapter 4 provides observations about the HDM-4 modeling.

Chapter 5 provides conclusions about the HDM-4 modeling.

Chapter 6 lists recommended changes to the WSDOT BST traffic criteria.

2: REVIEW OF PREVIOUS WORK

In 2004 for a previous WSDOT study, data processing, software testing, model calibration, pavement distress prediction, and an economic analysis was conducted for WSDOT's flexible highway system by using HDM-4 version 1.3.

The work presented in this relatively short chapter describes two separate but related efforts. The first was the data preparation for the software inputs, and the second was the calibration and validation of the pavement distress models. For the reader that wants to skip some, if not most, of the details associated with HDM-4, it is best to move on to either Chapter 3 (analyses) or Chapter 6 (recommendations).

2.1: DATA PREPARATION

HDM-4's required input is organized into data sets that describe road networks, vehicle fleets, pavement preservation standards, traffic and speed flow patterns, and climate conditions. Most of the required pavement performance information was obtained from 2002 data within the Washington State Pavement Management System (WSPMS) (Sivaneswaran et al., 2002). Other data were obtained through available literature and interviews with WSDOT personnel.

The Road Networks data set contains a detailed account of each road section's physical attributes. HDM-4 uses this information to model pavement deterioration and to provide input to other models.

The Vehicle Fleet data set contains vehicle characteristics that are used for calculating speeds, operating costs, and travel times to determine traffic impacts on roads and the resulting costs for the economic analysis. The WSPMS vehicle classification was used for HDM-4 input and included passenger cars, single-unit trucks, double-unit trucks, and truck trains (Sivaneswaran et al., 2003).

Preservation standards define pavement preservation practices, including their costs and effects on pavement conditions when they are applied. Although WSDOT uses a number of different preservation practices, the most common one for flexible pavement is a 45-mm HMA overlay (Kay et al., 1993). The typical target distress for application of a 45-mm HMA overlay is when the total area of pavement cracking is ≥ 10 percent (total roadway area), rut depth is ≥ 10 mm, or the IRI is ≥ 3.5 m/km (although the “trigger” IRI used by WSDOT may be reduced to about 2.8 m/km). Table 1 lists the major inputs. Specific inputs shown in Table 1 are not described in this report.

Table 1: Maintenance standard of 45-mm HMA overlay in HDM-4 version 1.3

General	Name:	45-mm HMA Overlay
	Short Code:	45 OVER
	Intervention Type:	Responsive
Design	Surface Material:	Asphalt Concrete
	Thickness:	45 mm
	Dry Season a:	0.44
	CDS:	1
Intervention	Responsive Criteria:	Total cracked area ≥ 10%
		or Rutting ≥ 10 mm
		or IRI ≥ 3.5 m/km
	Min. Interval:	1
	Max. Interval:	9999
	Last Year:	2099
	Max Roughness:	16 m/km
	Min ADT:	0
	Max ADT:	500,000
Costs	**Overlay**	
	Economic:	19 dollars/m^2 *
	Financial:	19 dollars/m^2 *
	Patching	
	Economic:	47 dollars/m^2 *
	Financial:	47 dollars/m^2 *
	Edge Repair	
	Economic:	47 dollars/m^2
	Financial:	47 dollars/m^2
Effects	Roughness:	Use generalized bilinear model
	a0 =	0.5244
	a1 =	0.5353
	a2 =	0.5244
	a3 =	0.5353
	Rutting:	Use rutting reset coefficient = 0
	Texture Depth:	Use default values (0.7 mm)
	Skid Resistance:	Use default value (0.5 mm)

[*Costs were derived from data provided by WSDOT]

A BST surface application is triggered when the total area of pavement cracking is ≥ 10 percent of the total roadway area. Table 2 lists the major inputs.

Table 2: Maintenance standard of BST resurfacing in HDM-4 version 1.3

General	Name:	BST resurfacing
	Short Code:	BSTCRA
	Intervention Type:	Responsive
Design	Surface Material:	Double Bituminous Surface Treatment
	Thickness:	12.5 mm
	Dry Season a:	0.2
	CDS:	1
Intervention	Responsive Criteria:	total cracked area ≥ 10%
	Min. Interval:	1
	Max. Interval:	100
	Max Roughness:	16 m/km
	Max ADT:	100,000
	BST Economic:	2.04 dollars/m^2 *
	BST Financial:	2.04 dollars/m^2 *
	Patching Economic:	47 dollars/m^2 *
	Patching Financial:	47 dollars/m^2 *
	Edge Repair Economic:	47 dollars/m^2 *
	Edge Repair Financial:	47 dollars/m^2 *
	Crack Seal Economic:	8.5 dollars/m^2 *
	Crack Seal Financial:	8.5 dollars/m^2 *
Effects	Roughness:	Use user defined method
	Roughness:	2 m/km
	Mean rut depth:	0 mm
	Texture Depth:	0.7mm
	Skid Resistance:	0.5mm

*Costs derived from data provided by WSDOT

Traffic flow patterns model temporary variations in traffic (Kerali et al., 2000). HDM-4 uses traffic flow pattern data to model the effects of congestion on vehicle speeds and vehicle operation costs. Two types of traffic flow were modeled: rural and urban.

Speed flow types model the effects of traffic volume on speeds. Four speed flow categories were modeled: one for a four-lane road and three for two-lane roads with different road widths (narrow, standard, and wide). These speed flow characteristics were obtained from local information and the Transportation Research Board's Highway Capacity Manual 2000 (TRB, 2000).

Climate data are used to model climatic effects on road performance and user costs (Kerali et al., 2000). Six different climate regions were modeled: Northwest, Olympic, Southwest, North Central, Eastern, and South Central.

2.2: CALIBRATION

The HDM-4 has three major models: (1) pavement deterioration, (2) vehicle speeds and operating cost, and (3) vehicle emissions (Bennett, 2004). Calibration efforts concentrated on pavement deterioration, while default calibration factors were used for vehicle speed, operating costs, and vehicle emissions.

The vehicle operation costs estimated by HDM-4 with default calibration factors matched the actual reported costs summarized by the Victoria Transport Policy Institute (2003) quite well. WSDOT does not currently consider vehicle emissions in the WSPMS; therefore, the **vehicle emissions models** were not used.

To accurately handle the wide range of variables associated with HDM-4 **pavement distress models**, the WSDOT highways were divided into five distinct categories. These were (1) high traffic HMA, (2) medium traffic HMA, (3) low traffic HMA, (4) BST, and (5) PCCP. The HMA categories were based on the estimated ESALs contained in the WSPMS (see Table 3).

Table 3: HMA calibration categories in HDM-4 version 1.3

Pavement Type	Traffic Level	Annual ESALs on Design Lane	Number of Cases
HMA	High	(500,000+)	374
HMA	Medium	(250,000 to 500,000]	512
HMA	Low	(0 to 250,000]	1595
BST	--	--	412

LIMDEP, an econometric software tool (Econometric Software, 2002), was used to estimate calibration factors on the basis of historical WSPMS data. The calibration factors for cracking, raveling, rutting, potholing, and roughness were developed. The HDM-4 default values were used for skid resistance and surface texture because of limited data and low sensitivity to the prediction models.

Following initial calibration, an extensive validation effort was undertaken whereby incremental changes were made in pavement condition, preservation triggering mechanisms, frequency of triggered preservations, and effects of preservation efforts. The validation effort showed that the HDM-4 models exhibited good predictive abilities. Table 4 lists the validated calibration factors.

Table 4: Calibration results of HDM-4 version 1.3

Calibration Factor	Definition	High Traffic HMA	Medium Traffic HMA	Low Traffic HMA	BST
K_{cia}	Initiation of all structural cracking	1.00	0.84	0.76	0.20
K_{ciw}	Initiation of wide structural cracking	0.40	0.40	0.40	0.30
K_{cpa}	Progression of all structural cracking	0.71	0.78	0.82	0.50
K_{cpw}	Progression of wide structural cracking	0.11	0.30	0.45	0.50
K_{cit}	Initiation of transverse thermal cracking	0.10	0.10	0.10	0.04
K_{cpt}	Progression of transverse thermal cracking	0.20	0.20	0.20	0.62
K_{pi}	Initiation of pothole	*1.00*[a]	*1.10*[a]	*3.00*[a]	*1.00*[a]
K_{pp}	Progression of pothole	*0.10*[a]	*0.08*[a]	*0.40*[a]	*1.00*[a]
K_{rid}	Initial densification of rutting	0.12	0.12	0.12	0.01
K_{rst}	Structural deterioration of rutting	0.15	0.15	0.15	0.22
K_{rpd}	Plastic deformation of rutting	0.01	0.01	0.01	0.02
K_{rsw}	Surface wear of rutting	0.32	0.32	0.32	2.05
K_{gm}	Environmental coefficient of roughness	0.70	0.70	0.70	1.00
K_{gp}	Progression of roughness	1.62	1.62	1.62	0.70
K_{vi}	Initiation of ravelling	*1.00*[a]	*1.00*[a]	*1.00*[a]	*1.00*[a]
K_{vp}	Progression of ravelling	*0.04*[a]	*0.04*[a]	*0.04*[a]	*1.00*[a]
K_{snpk}	Structural number of pavement	*0.00*[a]	*0.00*[a]	*0.00*[a]	*0.00*[2]

Notes:

a. Factor was not calibrated on the basis of WSPMS data. Calibration was done heuristically on the basis of validation results or not at all if insufficient data existed for calibration.

3: RESEARCH APPROACH AND ANALYSES

This research relied on the strategic level analysis in HDM-4 version 2.03 to examine the use of BSTs on roads with higher traffic levels. HDM-4 was used to examine a road network as a whole over a defined time period. This typically involves expenditure estimates for pavement network preservation under various strategies and economic scenarios.

Version 2.03, released in 2006, improved various functions of the software, especially the computational capability of the strategic level analysis. It is able to run up to 700 sections in one strategic analysis with three preservation alternatives over a 50-year analysis period, instead of the maximum 49 sections that version 1.3 could run.

Most of the input data were prepared in version 1.3 and then converted to version 2.03. During this conversion, various data issues occurred, all of which were addressed in this study.

3.1: DATA PREPARATION

The following subsections provide insight into the data issues involved when using the new version of HDM-4.

3.1.1: Version 1.3 Network Data Preparation

To examine AADT limits on the use of BST resurfacings, WSDOT HMA surfaced pavements with AADTs of less than 30,000 and annual design lane ESALs of less than 400,000 were analyzed. Because of missing historical data for some pavement sections (such as surface layer thickness, base layer thickness, construction year, or rehabilitation type), 352 sections (1,320 lane-miles) were excluded, for a final total of 1,626 sections (7,552 lane-miles). The software's strategic analysis could run no more than 700 sections with three preservation methods and a 50-year analysis period. Therefore, the 1,626 sections were divided into three individual analyses (see Table 5). The break points on AADT could have been set differently, but the three shown were selected at the time. The view was that the 8,000 AADT level was likely an upper limit for applying WSDOT BSTs.

Table 5: Road network data categories for HDM-4 version 2.03

AADT	Annual ESALs on Design Lane	Number of Sections	Lane-miles
≤ 8,000	≤ 40,000	623	3,282
≤ 8,000	≥ 40,000 and ≤ 400,000	323	1,797
≥ 8,000 and ≤ 30,000	≤ 400,000	680	2,473

The calibration results from the previous study for version 1.3 were tested and verified as able to generate reasonable results for version 2.03. Therefore, they were used in this research. The three road network input data sets shown in Table 5 are listed in Appendices A1, A2 and A3.

3.1.2: Preservation Standards

Preservation standards data were input directly into version 2.03. Because of price increases in pavement materials, the cost data for 45-mm HMA overlays and BSTs changed following the original 2004 study (Li et al.) and were updated as described below.

The project cost per lane-mile included additional related items such as traffic control, mobilization, crack sealing, pavement repair, tack coat, asphalt materials and placement, road approaches, shoulder dressing, and preliminary and construction engineering.

Estimate of HMA Overlay Preservation Cost

1. WSDOT used an average per lane-mile cost of $90,000 in 2003. At that time the cost of HMA was about $30/ton.

Assumptions:

- A lane-mile is defined as a 12-ft lane and an 8-ft shoulder (Uhlmeyer and Pierce, 2003)
- HMA Overlay thickness is the standard used by WSDOT, 0.15 foot
- HMA density is 150 lb/ft^3, then

$$\text{HMA } \textit{tons/lane-mi} = \frac{(12+8)\,ft * 5280\,ft/mi * 1.8/12\,ft * 150lb/\,ft^3}{2000lb/ton}$$

$$= 1{,}188 \text{ tons/lane-mi}$$

HMA cost (only) at $30/*ton* = 1,188 *tons/lane-mi* * $30/*ton* = $35,640/*lane-mi*

Ratio reflecting all agency project costs $= \frac{\$90000}{\$35640} = 2.5$ (includes traffic control, pavement repairs, safety, drainage, mobilization, sales tax, engineering and contingencies, preliminary engineering)

2. If HMA costs increase to $80/ton, then:

HMA cost (only) at $80/*ton* = 1,188 *tons/lane-mi* * $80/*ton* = $95,040/*lane-mi*

WSDOT total project costs: $95,040*2.5 = $238,000/*lane-mi* = $24.20/$m^2$

Estimate of BST Preservation Cost

The bid price of WSDOT BST preservation treatment, based on the North Central Region 2006 seal contract, was $1.43/$yard^2$ (did not include contingencies, tax, WSDOT project engineering and construction). CRS-2P was $285/ton, and HMA (for pre-level) was $46/ton. A basic assumption is that a 12 ft lane and a 4 ft shoulder are included in a lane-mile.

Other assumptions:

- CRS-2P increases to $400 per ton
- HMA increases to $80 per ton
- Traffic control is included

This would increase the contract price from $13,400*/lane-mi* to $16,800*/lane-mi*. Additional WSDOT project costs include 4 percent contingencies, 8 percent tax, and 12 percent WSDOT project engineering and construction (WSDOT, 2005). The total is about 25 percent added to the bid cost. Therefore, the true agency cost would be $16,800*/lane-mi* * 1.25 = $21,000*/lane-mi* or $2.68/m^2$.

3.1.3: Conversion Errors

After the network data and the strategic level analysis were set up, the whole workspace in version 1.3 was converted to version 2.03 by using the data migration tool available within the new software. Some errors occurred during conversion. The methods used to correct the data are described below.

1: AADT data were lost, and they needed to be input again into version 2.03.

Step 1: Export the related network sheet to an Access file from version 2.03.

Step 2: Export the traffic table in the Access file to Excel.

Step 3: Obtain the traffic data from the WSPMS and input them into the Excel table of Step 2.

Step 4: Copy the AADT column from the Excel table to the traffic table in Access.

Step 5: Import the corrected network data set to HDM-4 version 2.03 and use the same road network set name to overwrite the previous one.

2: Calibration factors were reset to default values. Roughness calibration factors were reset to default values of 1. New analysis sets had to be created because the calibration set name would change after it had been corrected. The analysis sets prepared in version 1.3 and converted to version 2.03 were used to correct traffic growth rate data. To correct the roughness factors, the following steps were taken.

Step 1: Export the calibration factor table to an Access file.

Step 2: Export the CalibItems table from the Access file to an Excel table.

Step 3: Correct the roughness calibration factors.

Step 4: Copy the corrected columns to the CalibItems table and save the change.

Step 5: Import the corrected Access file to HDM-4 version 2.03 under a different calibration set name.

Step 6: Export the related road network table to an Access file.

Step 7: Change the calibration set name to the name of the corrected calibration set in RoadNet table.

Step 8: Import the updated road network table.

Step 9: Check whether the new road network table has changed the calibration set name. If not, repeat steps 6-8.

3: In the project, program, and strategic analysis sets, the currency, analysis period, and discount rate were all reset to default values. These were changed directly in the related analysis set.

4: Traffic growth rate data. After the AADT and calibration sets were corrected, new analysis sets had to be created, but the traffic growth rate data were blank.

Step 1: Export the new strategic level analysis set to an Access file A.

Step 2: Export the strategic analysis set converted from version 1.3 to another Access file B.

Step 3: Copy the StrSecVehGrthSet table from Access file B to Access file A.

Step 4: Save the change and delete the strategic analysis set converted from version 1.3.

3.2: DETERMINATION OF COST EFFECTIVE BST AND HMA OVERLAY COMBINATIONS

Combinations of BST resurfacings and HMA overlays were tested to determine their relative performance.

Three BST and HMA overlay combinations were tested in HDM-4. The first combination involved alternating BST resurfacings and HMA overlays one after another by presetting the BST or HMA overlay construction years. BSTs and overlays were preset to alternate every 8 and 12 years, respectively. Other values could have been chosen, but these fall within typical ranges reported by WSDOT.

Another two combinations involved patterns of multiple BSTs and then an HMA overlay. The WSPMS shows that rutting is infrequently a trigger for WSDOT pavement preservation actions. More often, an HMA overlay is used to restore smoothness and address various types of cracking. A question that was addressed is how rough the pavement could get before an HMA overlay would be necessary. WSDOT has used in the past an upper limit IRI = 3.5 m/km (220 in/mi) to define a “poor” roughness condition (WSDOT, 1999). WSPMS results showed that only 5 percent of HMA surfaced pavements had an IRI of greater than 3.5 m/km in 2002. The FHWA defines an IRI of about 2.8 m/km (170 in/mi) as “poor” for Interstate pavements—which are not the focus of this study. A study conducted for WSDOT in 2002 by Shafizadeh, et al, reported that an IRI of about 3.5 m/km was viewed by a majority of surveyed Seattle area drivers as being unacceptable. This implies that 3.5 m/km may be a bit high as a trigger value. Therefore, an IRI value of 2.8 m/km was also tested, which accounted for about 10 percent of all HMA surfaced pavements in 2002.

The three combinations were as follows:

1) Alternating BST and HMA applications triggered in preset years (abbreviated as “B&O_Year”)

- Assume each BST will last 8 years with applications triggered in years 2006, 2026, 2046.
- Assume each HMA overlay will last 12 years with applications triggered in years 2014, 2034, 2054.

2) BST and HMA applications triggered by distress levels and an IRI of 2.8 m/km (abbreviated as “B&O_D2.8”)

- BST application is triggered at 10 percent cracking.
- HMA overlay application is triggered at 10-mm rutting or an IRI of 2.8 m/km.

3) BST and HMA applications triggered by distress levels and an IRI of 3.5 m/km (abbreviated as “B&O_D3.5”)

- BST application is triggered at 10 percent cracking.
- HMA overlay application is triggered at 10-mm rutting or 3.5 m/km IRI.

The three strategies were applied to each section (AADT of less than 8,000 and ESALs of less than 40,000) to allow HDM-4 to estimate the most cost effective strategy for each section. The HDM-4 results indicated that the B&O_D3.5 strategy was the most cost-effective preservation method for over 70 percent of the sections; however, as will be shown, the differences between these BST/HMA combinations are small. The results are summarized in Table 6.

Table 6: HDM-4 results of the most cost-effective BST and HMA overlay combinations (AADT less than 8,000 and annual design lane ESALs less than 40,000)

Preservation Alternatives	Number of Sections and Percentages		Lane-miles	
B&O_Year	8	1%	15	0.5%
B&O_D2.8	167	27%	840	25.5%
B&O_D3.5	448	72%	2424	74%

As a comparison of the strategies, the results shown in Figure 1 were prepared by applying each of the three strategies to all sections. The plots are the predicted IRI for the entire affected route system over the 50-year analysis period.

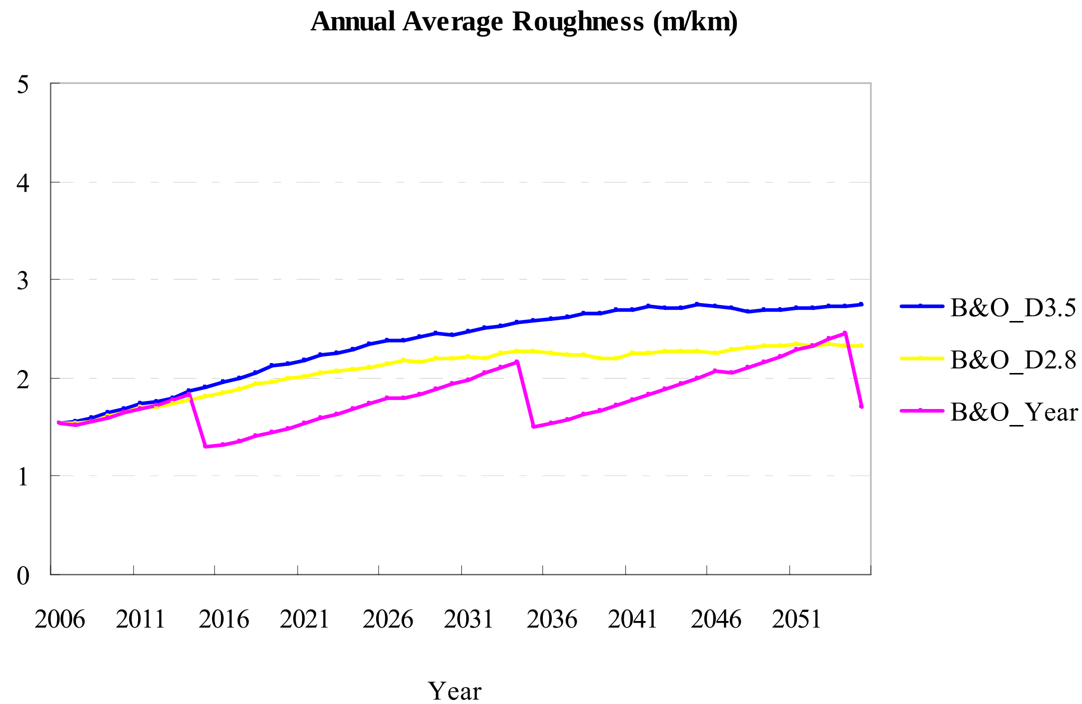

Figure 1: HDM-4 estimated roughness conditions under three BST and HMA overlay combinations (AADT less than 8,000 and annual design lane ESALs less than 40,000)

HDM-4 considers current pavement conditions (IRI, cracking, and rutting), agency costs (WSDOT costs), and road user costs (vehicle operation costs, traffic costs) to define the least expensive preservation alternative for a section. The net present value (NPV) of an alternative is defined as the difference between the decrease in road user costs and the increase in road agency costs in comparison to the base alternative (do nothing was the base alternative for this study). The alternative with the highest NPV is the least expensive. HDM-4 selected B&O_D3.5 as the least expensive preservation method for most of the selected sections, although that strategy does not have the best IRI performance, as shown in Table 7.

Table 7: The HDM-4 estimated economical indicators for BST and HMA overlay combinations

Scenario[c]	Length of Roadway Repaired	Equilibrium IRI[b]	NPV
	(Lane-miles)	*(m/km)*	
B&O_Year	3,111	2.44~1.71	$17,938
B&O_D 2.8	3,168	2.32	$18,146
B&O_D 3.5	3,217	2.72	$18,170

Notes:
a. All costs are in millions of present-day dollars.
b. The IRI that a given funding level can maintain over time.
c. "Unconstrained" implies that budget limitations are not used in triggering a resurfacing.

A section on State Route (SR) 2, milepost 220.88–222.48, was selected to test the performance of the three BST resurfacing and HMA overlay combinations on a specific pavement. The pavement conditions are listed in Table 8.

Table 8: Road condition summary of SR 2 MP 220.88–222.48

Characteristic	Value
Current HMA Surface Thickness	36 mm
Cement Treated Base Thickness	390 mm
IRI	1.4 m/km
Percentage of Pavement Surface Cracked	11.5%
Rut Depth	5 mm
AADT	3,387
Number of Lanes	2
Construction Year	1939
Year of Most Recent HMA Overlay	1995

The three combinations were evaluated for the section. B&O_D3.5 was, as expected, the least expensive preservation standard for this section because it had the highest NPV.

For the 50-year analysis period, HDM-4 was used to estimate the annual average pavement conditions of roughness, cracking, and rutting, with the results shown in figures 2 to 4. As can be seen, there are tradeoffs between these three strategies, with the highest NPV possibly not being the best measure of acceptability.

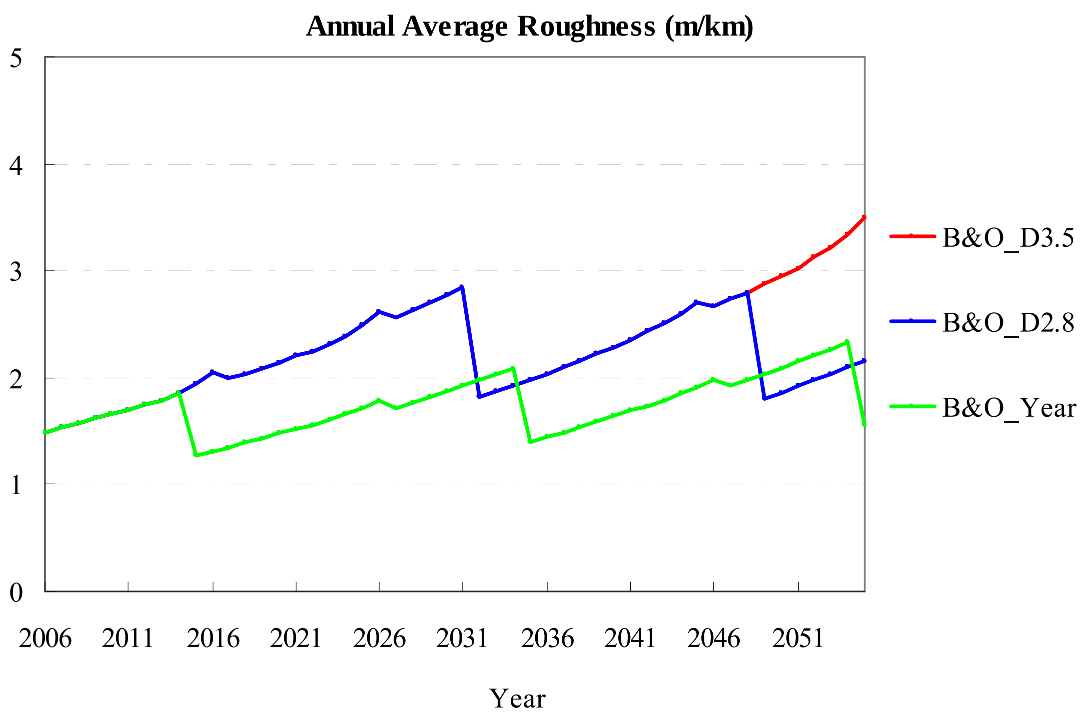

Figure 2: HDM-4 estimated roughness conditions under three BST and HMA overlay combinations for SR 2 MP 220.88–222.48

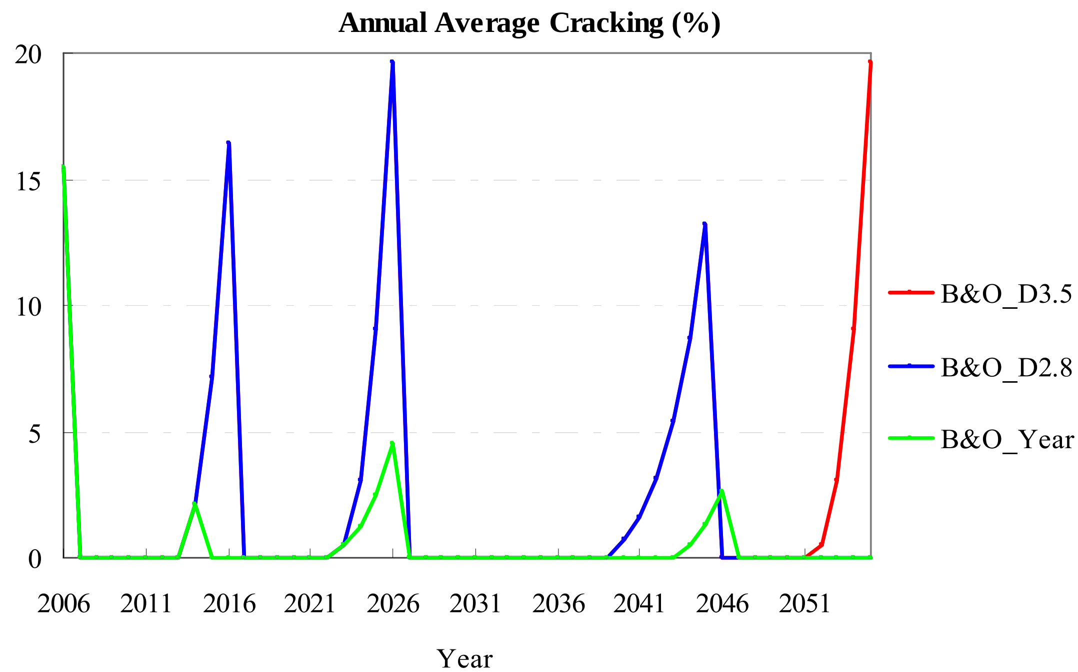

Figure 3: HDM-4 estimated cracking conditions under three BST and HMA overlay combinations for SR 2 MP 220.88–222.48

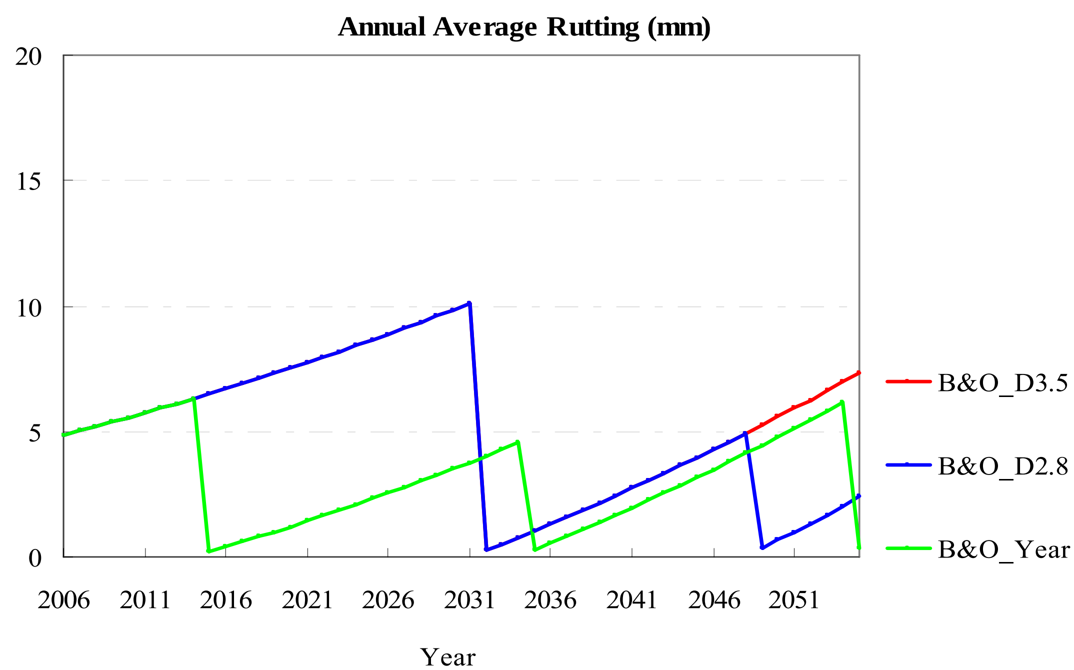

Figure 4: HDM-4 estimated rutting conditions under three BST and HMA overlay combinations for SR 2 MP 220.88–222.48

3.3: EXPANDED PRESERVATION STRATEGY COMPARISONS

The HDM-4 preservation strategy analysis was performed for four preservation strategies for WSDOT pavement sections with AADTs of less than 8,000 and ESALs of less than 40,000 (same AADT and ESALs as before). The data included 623 sections with about 3,280 lane-miles (same sections as shown in Table 6 earlier). The analysis period chosen was 50 years, the longest analysis period that can be used in HDM-4.

The four preservation strategies compared in HDM-4 were as follows:

1. Only HMA overlays (45-mm) were applied to all sections. Application of an overlay was triggered by cracking (10 percent), rutting (10-mm), or IRI (3.5 m/km).
2. Only BSTs were applied to all sections. BST resurfacing was triggered by cracking (10 percent) or IRI (2.8 m/km).
3. The B&O_D3.5 combination was applied to all sections. BST resurfacing was triggered by cracking (10 percent), and HMA overlay was triggered by rutting (10-mm) or IRI (3.5 m/km).
4. Any of the above three strategies could be applied to a section: BST resurfacing only, HMA overlay only, or B&O_D3.5 could be selected.

The four strategies described above were not constrained by budget, meaning that whenever the preservation was triggered, the assumption was that it would be funded and built (which is a very big assumption).

Four strategic-level analyses were assessed with HDM-4 for the 623 sections. Each analysis used only one of the four strategies. Figure 5 shows the estimated annual average roughness conditions over the 50-year analysis period. Use of HMA overlays alone (unconstrained budget scenario), as expected, would produce the lowest IRI. Alternatively, the strategy of choosing among a BST resurfacing, HMA overlay, or B&O_D3.5 would produce the most economical return—but only marginally so, as shown by the NPV (Table 9). This strategy had estimated costs, economic returns, and roughness conditions similar to those of using B&O_D3.5 alone because for more than 70 percent of the sections, HDM-4 chose B&O_3.5 as the preferred rehabilitation option.

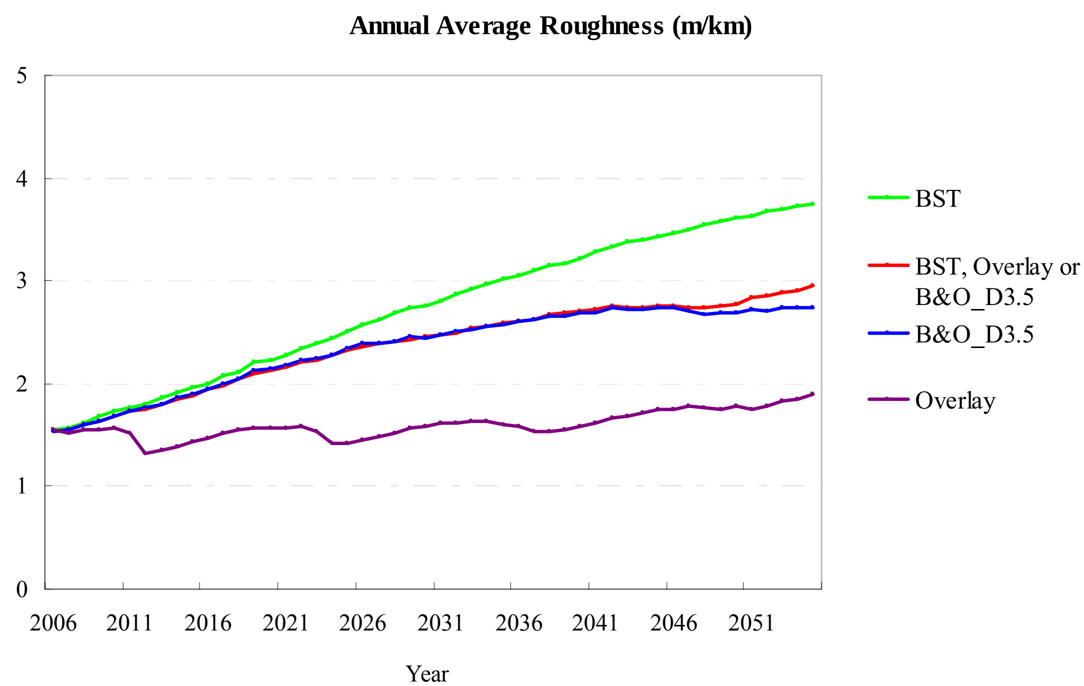

Figure 5: HDM-4 estimated roughness conditions under four budget strategies (AADT less than 8,000 and annual design lane ESALs less than 40,000)

Table 9: HDM-4 estimated economic indicators under four budget scenarios (AADT less than 8,000 and annual design lane ESALs less than 40,000)

Scenario[c]	**Average Annual Budget**[a]	**Length of Roadway Repaired** *(Lane-miles)*	**Equilibrium IRI**[b] *(m/km)*	**NPV**
HMA Overlay	$33	3,017	1.90	$17,758
BST	$18	3,233	3.68	$17,856
B&O_D3.5	$17	3,217	2.72	$18,170
BST, HMA Overlay, or B&O_D3.5	$16	3,234	2.96	$18,187

Notes:
a. All costs are in millions of present-day dollars.
b. The IRI that a given funding level can maintain over time.
c. "Unconstrained" implies that budget limitations are not used in triggering a resurfacing.

Nine sections (47 lane-miles) with missing condition data were excluded from the preservation plan over the 50-year analysis period, resulting in a net of 614 sections. Appendix B lists the 50-year preservation program for the remaining 614 sections. The results are summarized in Table 10.

HMA overlays were selected as the most cost effective for only 3 percent of the sections. Those 3 percent had annual ESALs of more than 20,000 in 2002. Most of them had extensive distress conditions or weak structural support.

BST resurfacings were chosen as the most cost effective for about 19 percent of the sections, and B&O_D3.5 was chosen for about 79 percent. The HDM-4 modeling suggests that combining BSTs with HMA overlays on pavements with higher traffic (up to 8,000 AADT and 40,000 annual design lane ESALs) can be economically justified.

Table 10: HDM-4 output summary (AADT less than 8,000 and annual design lane ESALs less than 40,000)

Preservation Alternatives	Number of Sections		Lane-miles		AADT		Annual ESALs	
					Median	Average	Median	Average
Overlay	16	3%	52	2%	5,791	4,708	26,109	27,014
B&O_D3.5	482	79%	2,291	71%	2,511	3,100	17,511	18,771
BST	116	19%	892	27%	2,220	2,565	19,206	20,020

3.4: SUPPLEMENTAL ANALYSES

It was decided to assess higher AADT levels—of up to 30,000 vehicles per day (vpd). Typically, few state DOTs apply BSTs beyond ADT levels of about 20,000 vpd.

Two groups of sections with higher traffic loads were evaluated: (1) sections with an AADT of less than 8,000 and annual design lane ESALs ranging from 40,000 to 400,000, and (2) sections with an AADT ranging from 8,000 to 30,000 and annual design lane ESALs of less than 400,000. These additional sections totaled 1,626, representing 7,552 lane-miles of pavement.

The HDM-4 was used to generate a 50-year pavement preservation program for the 1,613 sections (7,480 lane-miles). Thirteen sections (72 lane-miles) were excluded from the analyses because of erratic results for the selected preservation methods. The HDM-4 outputs are summarized in Table 11. The results show that HMA overlays were slightly more cost effective for 6 percent of the sections, BSTs for 19 percent, and B&O_D3.5 for 79 percent. The median AADT of sections for the B&O_D3.5 option was 4,700, and the median annual ESAL was about 44,000.

Table 11: HDM-4 output summary (AADT less than 30,000 and annual design lane ESALs less than 400,000)

Preservation Alternatives	Number of Sections		Lane-mile		AADT		Annual ESALs	
					Median	Average	Median	Average
HMA Overlay	103	6%	287	4%	15,647	13,496	78,397	104,039
B&O_D3.5	1,209	75%	5,157	69%	4,697	8,767	43,649	72,999
BST	301	19%	2,036	27%	3,523	6,982	46,414	85,186

4: HDM-4 MODELING OBSERVATIONS

Conclusions based entirely on HDM-4 modeling results should be interpreted with caution because the modeling itself is driven by input data quality and the tendencies of the HDM-4 model. The following are key observations related to HDM-4 output interpretation and model tendencies.

All alternative preservation strategies considered will result in an overall decline in system-wide pavement condition. HDM-4 modeling essentially helps choose the alternative that best balances a minimum reduction in condition with a maximum reduction in cost. This implies that if funding is increased in the future, the overall preservation strategy should be revisited.

While savings can be achieved with some alternative preservation strategies, the savings are generally front-loaded, and many strategies actually cost more toward the end of the 50-year analysis period. This also implies that if funding is increased in the future, the overall preservation strategy should be revisited.

Actual pavement performance may differ from that predicted by HDM-4. While HDM-4 was calibrated to WSPMS data, it is more likely that this will result in a similar performance trend rather than an accurate prediction of performance. This implies that comparing pavement condition in future years with that predicted by HDM-4 is essential in determining the extent to which HDM-4 modeling results are still relevant. The treatment strategy selected by HDM-4 as having the greatest benefit for a particular section of pavement is highly dependent on the initial roughness of that section. BSTs are exclusively assigned to pavements with an initial IRI of 0-2 m/km, while HMA overlays are generally assigned to pavements with an initial IRI of more than 2 m/km. This implies that initial roughness has a large influence over how HDM-4 models pavement deterioration: initially rough pavements tend to get rough more quickly and require HMA overlays, while initially smooth pavements tend to get rough more slowly and require only BSTs. It is important to note that although the treatment strategy is assigned for the entire 50-year analysis period, it is still highly correlated with initial roughness.

B&O_D3.5 is often selected regardless of other factors such as initial roughness, traffic level, or ESAL loading. B&O_D3.5 is the most commonly chosen strategy. It is likely that this is somewhat related to the B&O_D3.5 preservation strategy definition. First, the WSPMS has been set up to make cracking trigger most preservation efforts (Kay et al., 1993). Therefore, cracking is most likely to trigger a treatment. Because the B&O_D3.5 strategy treats cracking with a BST, the majority of treatments are BSTs (over 70 percent). Second, while BSTs may not be able to correct or fully treat cracking deep within the HMA structure, the HDM-4 model essentially assumes this is so. Therefore, as far as a cracking treatment is concerned, HDM-4 treats a BST resurfacing and an HMA overlay equally. Because BSTs cost less, HDM-4 tends to be biased toward BSTs. The HDM-4 typically chooses B&O_D3.5 over BST only because in the HDM-4 model the BST treatment has little effect on rutting or roughness. Therefore, eventually some other type of treatment will be needed to correct rutting and roughness. The B&O_D3.5 strategy offers this in the form of a periodic HMA overlay.

The HDM-4 model schedules a large number of treatments in the first year. This is because the HDM-4 model can draw on the entire 50-year budget at any time. Therefore, in year one the HDM-4 model selects HMA overlays and BSTs for an excessive number of lane miles in order to minimize vehicle operating costs right away.

This strategy generally provides the best cost-benefit ratio over the 50-year analysis period (which is what the HDM-4 model is trying to optimize), but is not realistic within the confines of a typical WSDOT biennial budget. However, if averages are taken from the entire 50-year analysis period, the overall effect of this modeling issue is minimal.

In sum, conclusions from the HDM-4 modeling are general in nature. While it is likely that WSDOT could save money by implementing an alternating BST and overlay preservation strategy for pavements in the 2,000+ AADT range, practical factors should play a significant role in determining the appropriate range, and the resulting preservation strategy should be revisited in the future if the funding scenario changes significantly.

5: HDM-4 MODELING CONCLUSIONS

This study used HDM-4 version 2.03 to test traffic level limitations for BST resurfacings for WSDOT pavement conditions. Traffic levels of up to 30,000 AADT in both directions and 400,000 annual design lane ESALs were assessed. The principal findings were as follows:

1. Results from HDM-4 analyses suggested that applying BST resurfacings on HMA pavements with traffic levels of up to 8,000 AADT and loads of up to 40,000 annual design lane ESALs is economically acceptable. The results indicate a need to revise the current WSDOT BST criteria for traffic levels. This finding, of course, must be tempered with consideration of other factors such as speed limits, location, noise, and the potential for loose aggregate following construction.

2. The final assessment of appropriate ESAL levels for BST routes requires additional structural analysis. The ability to assess ESALs with HDM-4 is too approximate to be definitive.

3. A combination of BST resurfacings and HMA overlays (B&O_D3.5) was found to be the most cost-effective preservation method for most of the sections examined. However, the differences in NPV were generally small between the options studied. In fact, using a fixed application cycle for BSTs and HMA overlays (8 and 12 years, respectively) provided the lowest predicted cracking, rutting, and IRI levels.

4. Pavement sections with a low AADT and high IRI should be first overlaid with an HMA. Following that, a BST is more likely to be a viable, cost-effective preservation alternative.

5. The findings showed that higher AADT routes can be candidates for BST resurfacing. However, the analyses summarized in this report show that the NPVs for the three basic resurfacing strategies (BST, HMA overlay, or a combination of BST and HMA overlays) are not significantly different. Therefore, caution is suggested with respect to changes for WSDOT pavement resurfacing polices.

6: CHANGING THE WSDOT BST CRITERIA

Decisions on changing the WSDOT BST criteria should be based on a rational consideration of the preceding HDM-4 modeling conclusions and the practical implications of such changes.

6.1 CURRENT WSDOT BST CRITERIA

Current WSDOT policy (WSDOT Pavement Guide, Volume 1—Pavement Policy, May 2005) states that BST resurfacings will be used on state highways with an ADT of less than 2,000. Specifically, WSDOT states for new flexible pavement design:

> Those pavements with fewer than 50,000 ESALs/year and ADT less than 2,000 are classified as low volume roadways and shall be considered for a bituminous surface treatment (Class A). The bituminous surface treatment (BST) surface course is considered the most economical choice for low ESAL pavements.
>
> For pavement rehabilitation, WSDOT states:
>
> Pavements with less than 50,000 directional ESALs per year <u>and AADT less than 2,000 are designated as bituminous surface treatments. Exceptions (such as paving through small cities, limited BST use, etc.) to this policy are evaluated on a case-by-case basis</u>.

6.2 POTENTIAL IMPACTS

Table 12 provides an overview of WSDOT lane-miles sorted by pavement type.

Table 12: Lane-miles of each pavement type by AADT

AADT	BST	HMA	Flexible (BST+HMA)	All Pavement Types (BST+HMA+PCC)
0-2000	3,157	1,834	4,991	4,993
2000-4000	819	1,645	2,464	2,486
4000-6000	190	1,423	1,613	1,631
6000-8000	8	840	848	934
8000-10000	1	567	568	660
10000-20000	4	2,094	2,098	2,572
20000-40000	0	1,610	1,610	2,029
40000-80000	0	1,032	1,032	1,360
80000-160000	0	436	436	640
>=160000	0	132	132	360
Total	4,179	11,613	15,792	17,665

Note:
a: Data source WSPMS.
b: The lane-mile totals for BST and HMA differ from those shown earlier in the report. This is due to the use of two different data sources.

Table 13: Percentage of each pavement type by AADT

AADT	BST *(%)*	HMA *(%)*
0-2000	76	16
2000-4000	20	14
4000-6000	4	12
6000-8000	0	7
8000-10000	0	5
10000-20000	0	18
20000-40000	0	14
40000-80000	0	9
80000-160000	0	4
>=160000	0	1
Total	100	100

Data source: WSPMS

Table 13 shows that approximately 49 percent of WSDOT HMA lane-miles are below an AADT of 8,000, an AADT level for which BST resurfacings are economically viable. Currently, 16 percent of WSDOT HMA lane-miles are in the 0 to 2,000 AADT range, where BSTs (at 76 percent) are the standard WSDOT policy. BST resurfacings on pavements with an AADT of up to 8,000 are not recommended because of (1) the large potential economic and business impact of such a drastic change, (2) the imperfect nature of HMD-4 modeling, and (3) the predicted decline in pavement condition (namely IRI levels). Rather, it is prudent for WSDOT to establish an AADT level below which a preservation strategy of alternating BSTs and HMA overlays would be the preferred but not required method. A suggested range for this strategy is 2,000 to 4,000 AADT. If such an AADT range were adopted, the WSDOT preservation policy would become as follows:

- AADT of up to 2,000: BST unless they are specifically exempted (such as paving through cities, limited BST use routes).
- AADT of 2,000 to 4,000: BSTs and HMA overlays used interchangeably, depending upon pavement condition. Exemptions are allowed for paving through cities, limited BST use routes, etc.
- AADT of greater than 4,000 AADT: HMA overlays.

This would result in 14 percent of the current HMA lane-miles (1,645 lane-miles) being eligible for BST resurfacing that previously had not been. An average HMA surface life of 12 years results in about 140 lane-miles paved each year within the traffic range of 2,000 to 4,000 AADT, which assumes an even distribution of due dates. Given the typical performance of BSTs, about 200 lane-miles would be needed for the same 1,645 lane-miles of pavement (which assumes steady state performance conditions).

Given that fully loaded WSDOT costs for HMA overlays and BSTs are about $240,000 and $21,000, respectively (a difference of $219,000, although these numbers change constantly because of changing crude oil prices), a savings of a bit more than $20 million/year could be achieved by initially converting about 100 lane-miles from HMA surfaced pavement to BST surfaced (this assumes that not all 140 lane-miles requiring resurfacing in the 2,000 to 4,000 AADT range in a given year would be resurfaced with a BST). However, over a longer span of time and given the shorter surface life of BSTs (about 1/3 less than HMA along with more pavement repairs), the actual savings would be less. A further reduction in savings would occur because a cost-effective rehabilitation strategy (as shown in the earlier chapters) is generally a series of BST applications followed by an HMA overlay. Realistically, the expected annual savings over a longer span of time would be at least 20 percent less.

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LIST OF APPENDICES

Because many of these appendices would be too large and unwieldy to print, they are available electronically.