Chip Seal Performance Measures— Best Practices

WA-RD 841.1

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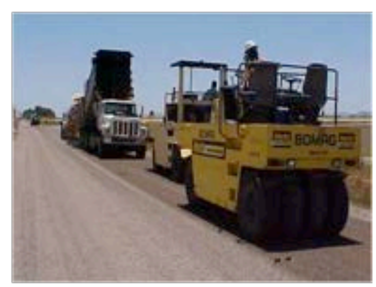
Nathan Kebede

March 2015



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WSDOT Research Report

Chip Seal Performance Measures—Best Practices

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16. Abstract

The Washington State Department of Transportation (WSDOT) has a long history of designing, constructing, and maintaining chip seal or bituminous surface treatment pavements. However, to date WSDOT has not developed pavement performance indicators or models to predict chip seal service life, but rather assumes an average life of 6 to 8 years. Due to funding constraints and good pavement management practices, WSDOT has increased the number of pavement segments that are candidates for receiving chip seal applications. In order to improve predictions of chip seal performance and improve their demonstrated cost effectiveness, chip seal performance indicators are needed.

The objectives of this research project are to evaluate different performance indicators for chip seal treatments and to develop trigger values for these indicators that will indicate the end of service life and the appropriate index values for resurfacing. Under Phase I of this study, a formal literature review and detailed survey of transportation agency practices were conducted to identify which pavement distress or combination of distresses best characterize the optimal timing for chip seal application. This report summarizes the findings of the literature review, agency survey, WSDOT pavement management and performance modeling practices, and a recommendation of potential performance models for further evaluation as additional data become available.

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CHAPTER 1. INTRODUCTION

The Washington State Department of Transportation (WSDOT) has a long history of designing, constructing, and maintaining chip seal or bituminous surface treatment pavements. However, to date WSDOT has not developed pavement performance indicators or models to predict chip seal service life, but rather assumes an average life of 6 to 8 years. Currently, WSDOT uses the same performance indicators for chip seal pavements that are used for asphalt pavements. These distress indicators include rutting, roughness (based on the International Roughness Index [IRI]), and cracking (as defined by the pavement structural condition [PSC] indicator). However, chip seal pavements do not necessarily behave in the same manner as asphalt pavements. The more common asphalt pavement distress types may include rutting, transverse cracking, and longitudinal cracking, while the primary distress types for chip seal pavements are raveling and bleeding (see figure 1).

a. Raveling. b. Bleeding (photo courtesy of WSDOT).

Figure 1. Examples of raveling and bleeding.

Due to funding constraints and good pavement management practices, WSDOT has increased the number of pavement segments that are candidates for chip seal applications. Therefore, the ability to more accurately predict the most appropriate timing for chip seal pavements will not only improve WSDOT's management of the chip seal pavements, but will also result in substantial cost savings. Those cost savings would be realized by extending service life and applying the chip seal treatment to the right pavement at the right time (i.e., applying too early wastes pavement life, while applying too late results in higher costs due to more extensive pavement repair). For example, extending a chip seal's pavement life by 1 year results in approximately a 15 percent (or $1.6 million per year) reduction in annual chip seal costs (WSDOT 2014). However, to improve the prediction of chip seal performance and therefore better quantify cost effectiveness, performance prediction measures specific to chip seal pavements are needed.

Study Objectives

The primary objectives of this research are to evaluate performance indicators for chip seal pavements and to develop trigger values for these performance indicators that will indicate the end of service life and the appropriate pavement condition indices values for resurfacing.

Study Approach

The scope of work for this project includes the following tasks:

- Task 1–Kick-off Meeting.
- Task 2–Conduct Literature Search.
- Task 3–Conduct Detailed Agency Interviews.
- Task 4–Evaluate Chip Seal Procedures.
- Task 5–Prepare Report Summarizing Best Practices.
- Task 6–Develop Phase II Plan.
- Task 7–Present Findings.

Report Organization

This report consists of five chapters (including this one) and two appendices, as summarized below:

- Chapter 1. Introduction.
- Chapter 2. Literature Search.
- Chapter 3. Survey of Agency Chip Seal Practices.
- Chapter 4. WSDOT Pavement Condition and Performance Modeling Techniques.
- Chapter 5. WSDOT Chip Seal Design, Construction, and Project Selection Practices.
- Chapter 6. Proposed Performance Measures.
- Appendix A. Agency Survey Questions.
- Appendix B. Summary of Agency Survey Responses.

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CHAPTER 2. LITERATURE SEARCH

Introduction

A formal literature search was conducted for this project by querying the Transportation Research International Documentation (TRID) database managed by the Transportation Research Board (TRB), the National Transportation Information Service (NTIS) and the Engineering Index (EI Compendex) databases, and conference websites and/or CD-ROMs where significant attention was focused on performance prediction measures/models within pavement management activities. The research team also reviewed papers and presentations provided at the TRB's Annual Meetings and at the International Conferences on Managing Pavement Assets.

Chip seals are one of many pavement preservation treatments used in the U.S. and worldwide. Chip seals are generally considered effective for preserving existing asphalt- and chip seal-surfaced pavements that are distressed with longitudinal, transverse, and block cracking; raveling; friction loss; low-severity bleeding; and moisture infiltration. However, chip seals are not recommended on pavements with unsealed cracks greater than 0.25 in wide, medium- to high- severity alligator cracking, rutting greater than 1 in deep, very rough surfaces, or those which are structurally deficient (NHI 2013). In addition, chip seals may accelerate stripping in susceptible asphalt pavements (Morian, Gibson, and Epps 1998; Huang and Dong 2009; NHI 2013). The expected performance life of chip seals have been reported to range from 1 to 12 years depending on site-specific circumstances; however, 4 to 6 years is common for single chip seals (one application of binder followed by one application of aggregate) and 5 to 7 years for double chip seals (one application of binder and aggregate followed by a second application of binder and aggregate) (NHI 2013).

There are a number of factors that can influence chip seal performance. These factors include (Shuler et al. 2011; Testa and Hossain 2014):

- Construction technique.
- Condition of contractor's equipment.
- Skill and knowledge of contractor's employees.
- Knowledge and training of inspection personnel.
- Condition of existing pavement.
- Asphalt binder and aggregate properties.

- Asphalt binder and aggregate application rates.
- Uniformity of application.
- Adhesion between the chip seal and the existing pavement.
- Aggregate interlock.
- Strength of the underlying base or condition of underlying pavement.
- Amount and type of traffic.
- Environmental and drainage conditions.

In general, there are two commonly used methods for measuring chip seal performance: engineering-based and qualitative. Each method is further described in the following sections.

Engineering-Based Performance Indicators

Friction Number

Pavement surface friction characteristics are a function of both macrotexture and microtexture. Friction testing is commonly measured in accordance with ASTM E274, *Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire.* Microtexture is a function of the frictional properties of the individual aggregate, while macrotexture is a function of the aggregate size, shape, and gradation. Figure 2 depicts the difference between microtexture and macrotexture.

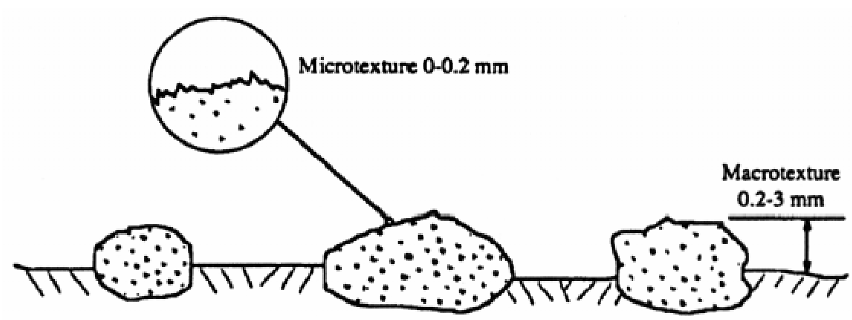


Figure 2. Example of microtexture and macrotexture (Tighe et al. 2000).

Friction testing is conducted using a trailer containing the test equipment (test tire, water dispenser, braking system, and drag-force measurement system) towed behind a vehicle traveling at a constant speed, typically 40 mph (see figure 3). Water is discharged in front of the test tire, the trailer brakes are applied to fully lock the test tire, and the resistive drag force is measured. The friction number is defined as (Hall et al. 2009):

$$FN(V) = 100\mu = 100\,F/W \qquad \text{(Eq. 1)}$$

where:

FN = friction number.
V = velocity of the test tire (mph).
μ = coefficient of friction.
F = tractive horizontal force applied to the tire (lb).
W = vertical load applied to the tire (lb).

Figure 3. Locked-wheel friction trailer (photo courtesy of WSDOT).

Friction testing can be performed using either a ribbed test tire (AASHTO M 261 or ASTM E501) or a smooth test tire (AASHTO M 286 or ASTM E524). The ribbed tire is more sensitive to changes in microtexture, and the smooth tire is more sensitive to macrotexture. In general, friction numbers using the ribbed tire are higher than the values using the smooth tires.

A study conducted on low-volume roads in south-central Utah evaluated friction number data (collected in accordance with ASTM E274 using a ribbed tire) and accident data to determine the safety benefits over the life of chip seal pavements (Seneviratne and Bergener 1994). The evaluation of friction numbers before and after chip seal application indicated an average of a 24 point increase in friction number. However, there was no correlation between the before and after friction number (i.e., the before friction number did not impact the friction number measured after chip seal application). Seneviratne and Bergener (1994) determined that there was no definite relationship between accident rate and friction number on chip sealed pavements, but, in general, the study indicated that chip sealed pavements tend to result in lower crash rates for both wet and dry weather conditions. The study also concluded that the reduction in crashes cannot be solely attributed to chip seal treatments.

Romero and Anderson (2005) evaluated the performance life of chip seal treatments based on a number of features including traffic volume, aggregate source, asphalt supplier, roughness, and friction number. Due to the lack of sufficient data, Romero and Anderson (2005) focused the evaluation of chip seal performance life on skid number and roughness. For skid number, the developed performance equation (equation 2) resulted in a very low correlation (primarily due to the large number of variables influencing surface friction).

$$SN = -0.3815\,(Age) + 59.4487 \quad R^2 = 0.0069 \qquad \text{(Eq. 2)}$$

where:

SN = skid number.

Age = years since construction.

Due to the poor correlation, Romero and Anderson (2005) proposed a different approach that evaluated chip seal skid number based on the percent of total miles with a skid number less than 40. A skid number less than 40 was selected because this value would typically trigger other corrective action requirements (Romero and Anderson 2005). The resulting performance equation using this approach is shown in Equation 3.

$$SN(\%) = 1.9176\,(Age) - 1.2403 \quad R^2 = 0.825 \qquad \text{(Eq. 3)}$$

where:

$SN(\%)$ = Percent of miles with skid number < 40.

Age = Years since construction (based on 6 years of data).

Romero and Anderson (2005) determined the corresponding treatment life based on the percent of miles needing corrective action (see table 1). For example, if it assumed that 50 percent of the chip seal miles will need corrective action in a given year, then the corresponding treatment life would be 27 years (depending on traffic level). It should be noted that Table 1 represents corresponding pavement life based only on skid number; treatment life may be less due to other modes of failure.

Table 1. Chip seal performance (Romero and Anderson 2005).

Percent of Miles Needing Corrective Action	Corresponding Life
10	6 years
25	14 years
50	27 years
75	40 years

Texture Depth

Although there are a number of different methods for measuring texture depth, the most commonly used and accepted procedure is ASTM E965, *Standard Test Method for Measuring Pavement Macrotexture Depth Using a Volumetric Technique* (ASTM 1996). In this test method, the mean texture depth is determined using the sand patch method which has shown to provide a good indication of chip seal performance (Roque, Anderson, and Thompson 1991). Mean texture depth is determined by:

$$MTD = \frac{4V}{\pi D^2} \qquad \text{(Eq. 4)}$$

where:

MTD = mean texture depth (in).
V = test material volume (in^3).
D = average diameter of area covered by test material (in).

Roque, Anderson, and Thompson (1991) conducted a study for the Pennsylvania DOT to evaluate the effects of materials (e.g., polymer modification, aggregate gradation), design features (e.g., existing condition, traffic volume), and construction practices (e.g., emulsion type and rate, rolling pattern) on the performance of chip seal treatments. Pavement sections were evaluated based on visual evaluations, skid resistance, and mean texture depth. The sand patch method was used to measure the mean texture depth of the pavement surface. The study found that the mean texture depth decreased over time due to aggregate wear and embedment (Roque, Anderson, and Thompson 1991). A forward stepwise multi-linear regression model was developed to associate mean texture depth with emulsion application rate:

$$MTD = 0.096 - 0.125 \times EAR \qquad R^2 = 0.71 \tag{Eq. 5}$$

where:

MTD = mean texture depth (in).
EAR = emulsion application rate (gal/yd^2).

Transport New Zealand (TNZ) utilizes a similar test to the sand patch test in the evaluation of chip sealed pavements. The TNZ test involves spreading 2.75 in^3 of sand (between the No. 30 and No. 50 sieve sizes) using a straightedge until the sand is level with the top of the aggregate (TNZ 1981). Figure 4 demonstrates the concept of TNZ sand circle test.

The results of the sand circle test are used in the development of a performance model to calculate the texture depth 12 months after construction. The 12-month texture depth is used as an indicator of how well the chip seal will perform for the remainder of its life (based on the assumption that chip seal failure is due to flushing). Final acceptance of the chip seal treatment is based on achieving the required texture depth, without any significant chip loss. The New Zealand texture depth deterioration model is shown in equation 6.

$$Td_1 = 0.07 \times ALD \times logY_d + 0.9 \tag{Eq. 6}$$

where:

Td_1 = texture depth in 1 year (mm).
Y_d = design life (years).
ALD = average least dimension of the aggregate (mm).

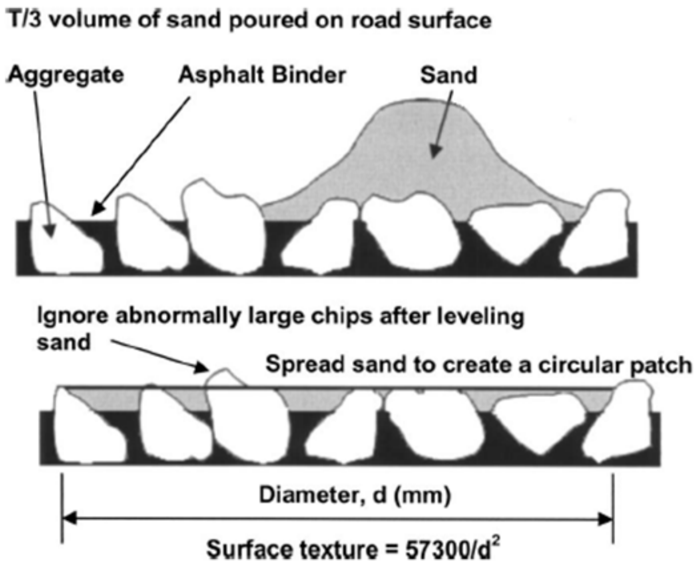


Figure 4. Sand circle test (TNZ 1981).

New Zealand chip seal failure is determined when the chip seal's texture depth is less than 0.7 mm (0.028 in) for posted speeds less than 70 km/hr (44 mph); or less than 0.9 mm (0.035 in) for posted speeds greater than 70 km/hr (44 mph).

The TNZ method was evaluated by the Texas DOT to compare the service life of emulsified and hot-applied asphalt chip seal treatments in the San Antonio District (Gransberg 2008). The mean texture depth was determined using the TNZ circle sand test and measured over a 2.5-year period on roadway sections constructed with either an emulsion or hot-applied asphalt chip seal; the results are shown in figure 5.

In relation to texture depth, Gransberg (2008) concluded:

- Roads with emulsified chip seals lose their texture depth at a slower rate than roads with hot-applied asphalt. However, this was probably due to the higher amount of flushing on the asphalt roadways prior to sealing.
- When compared to the 1-year texture depth calculated using Equation 6, two of the five hot-applied asphalt chip seals would have failed the test. All emulsion roads passed the TNZ criteria.

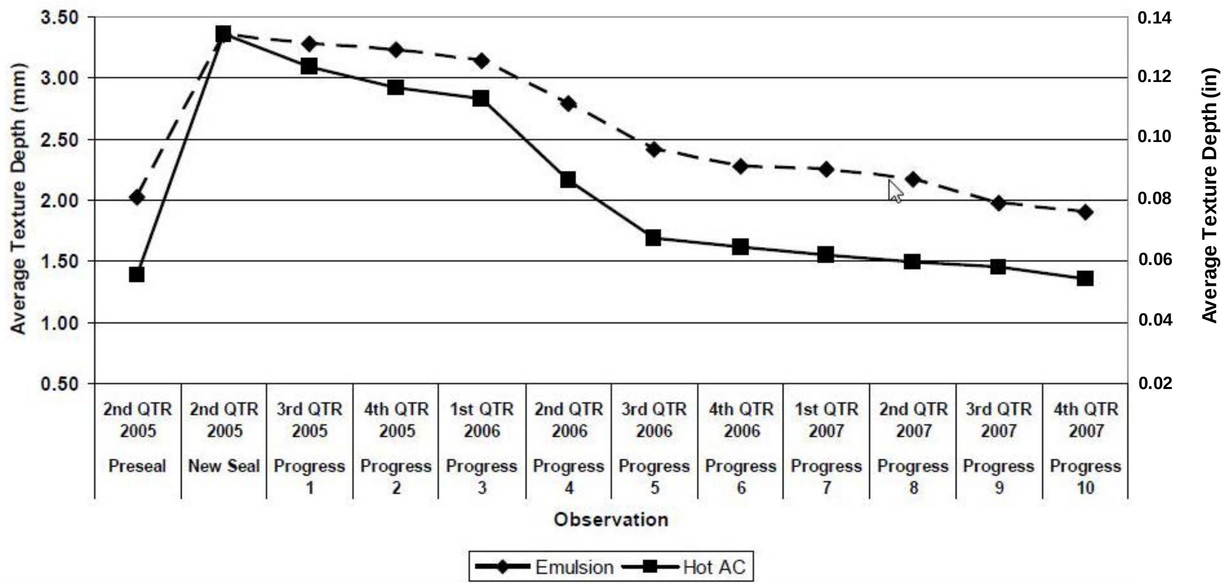


Figure 5. Comparison of mean texture depth for emulsion and hot-applied asphalt chip seals (Gransberg 2008).

Mean Profile Depth

The mean profile depth (MPD) is a measure of macrotexture that can be calculated from a pavement profile according to ASTM E1845 (Flintsch et al. 2003). The MPD is defined as the difference in height between the profile and a horizontal line through the top of the highest peak (see figure 6). The MPD is a two-dimensional estimate of the sand patch test or MTD and is calculated as:

$$MPD = \frac{Peak\ Level\ (1st) + Peak\ Level\ (2nd)}{2} \times Average\ Level \quad \text{(Eq. 7)}$$

where:

MPD = Mean profile depth.
Peak Level (1st) = Highest peak level.
Peak Level (2nd) = Second highest peak level.
Average Level = Average of all peak levels.

MPD typically ranges from 400 to 2,500 microns for asphalt pavement surfaces. High values of MPD generally indicate greater levels of raveling or a higher percentage of aggregate with positive texture (Rada et al. 2013).

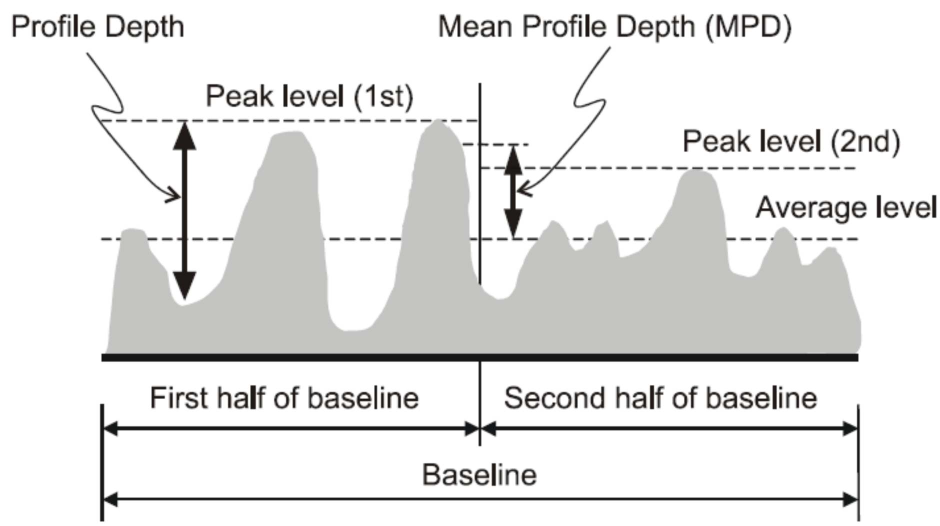


Figure 6. Example of mean profile depth (Vilaca et al. 2010).

Huang (2012) evaluated a number of pavement evaluation technologies, one of them being the Texas DOT 3D texture system. Figure 7 illustrates the accuracy, repeatability, and speed independency of the TxDOT transverse scanning equipment on test targets with known depth and at variable speeds.

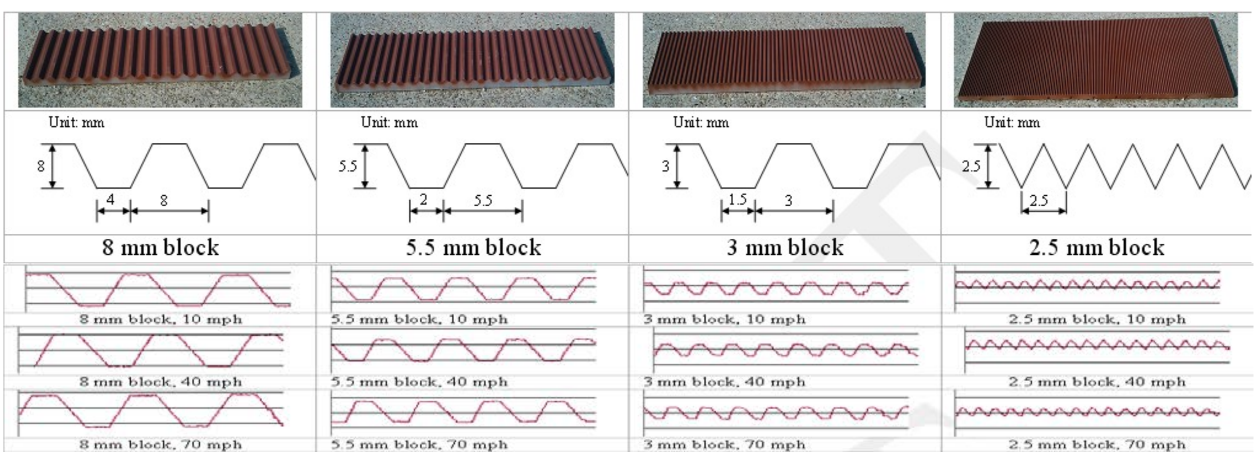


Figure 7. Example of results using the Texas DOT 3D texture system (Huang 2012).

Huang (2012) compared the MPD results determined using the 3D scan and the sand patch test (figure 8) and found that there was a strong correlation between the two test methods. Sengoz, Topal, and Tanyel (2012) also found a strong correlation between the MTD as determined from the sand patch test and the MPD determined using a 3D laser scanning device (figure 9).

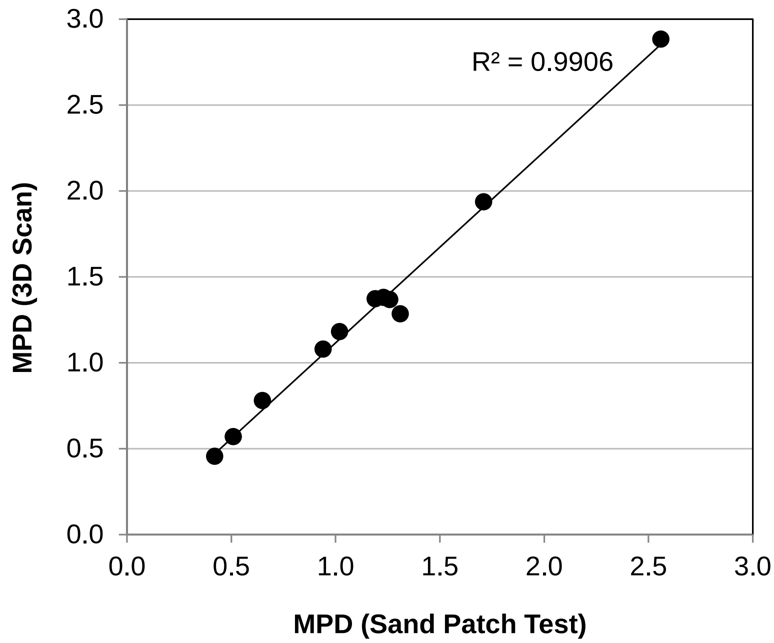


Figure 8. Comparison of MPD from 3D scan and sand patch test (redrawn from Huang 2012).

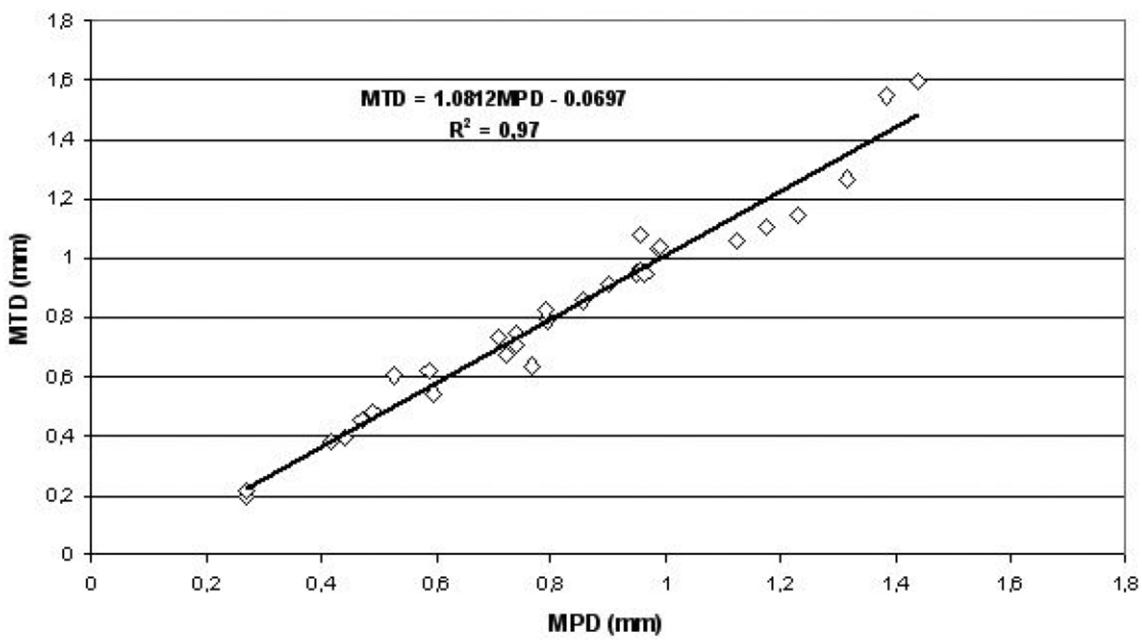


Figure 9. Comparison of MTD and MPD (Sengoz et al. 2012).

The laser crack measurement system (LCMS) used by Pavemetrics, Inc. can be used to analyze macrotexture over the entire road surface. The LCMS can be used to measure MPD, but also to evaluate MTD using a digital model to replicate the sand patch test over the full lane width (Laurent et al. nd). The index calculated using the digital sand patch model, referred to as the road porosity index (RPI), is defined as the volume of voids at the surface that would be occupied by the sand divide by a user defined surface area (see figure 10) and is calculated as:

$$RPI = \frac{Volume_{air\,void} - Volume_{raveling} - Volume_{cracks}}{Surface\ Area} \quad \text{(Eq. 8)}$$

where:

RPI = Road porosity index.
$Volume_{air\,void}$ = Volume of voids at the road surface.
$Volume_{raveling}$ = Volume of voids due to raveling.
$Volume_{cracks}$ = Volume of voids due to cracking.

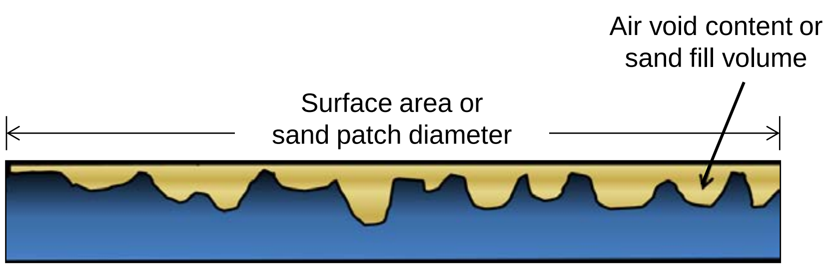


Figure 10. Schematic of digital sand patch model
(redrawn from Laurent et al. nd).

RPI measurements have been shown to be highly repeatable and closely match the MPD measurements collected using standard texture lasers (Laurent et al. nd).

Qualitative Performance Indicators

Visual Surface Ratings

The Utah DOT pavement performance models consider current traffic volumes, pavement condition, construction history, current costs, treatment strategy, and funding scenarios for identifying pavement preservation and rehabilitation projects (Utah 2009). Within the Utah DOT pavement management system, pavement condition indices are developed for both asphalt-and concrete-surfaced pavements. Asphalt pavement indices include roughness (based on IRI), rutting, environmental cracking, and wheelpath cracking. The asphalt pavement indices use the following equations (R^2 values were not provided):

$$Ride\ Index = 118 - 0.4 \times IRI \tag{Eq. 9}$$

$$Rut\ Index = 100 - 25 \times Rut \tag{Eq. 10}$$

$$\begin{aligned} ENV = 100 - [&0.947 \times (low\ tran + 0.1 \times low\ long + 0.1 \times low\ block) + \\ &1.263 \times (med\ tran + 0.1 \times med\ long + 0.1 \times med\ block) + \\ &1.894 \times (high\ tran + 0.1 \times high\ long + 0.1 \times high\ block)] \end{aligned} \tag{Eq. 11}$$

$$WPCK = 100 - (0.079 \times low\ WP + 0.158 \times med\ WP + 0.316 \times high\ WP) \tag{Eq. 12}$$

where:

- IRI = International Roughness Index (in/mi).
- Rut = rut depth (in).
- ENV = environmental cracking index.
- low = low severity.
- med = medium severity.
- $high$ = high severity.
- $tran$ = transverse cracking (percent, where 100 percent > 53 cracks per 0.1 mile).
- $long$ = longitudinal cracking (percent, where 100 percent > 528 ft per 0.1 mile).
- $block$ = block cracking (percent, where 100 percent > 528 ft per 0.1 mile).
- $WPCK$ = wheelpath cracking index.
- WP = wheelpath cracking (percent, where 100 percent = 1,584 ft^2 per 0.1 mile).

Morian, Gibson, and Epps (1998) conducted an evaluation of the Long-Term Pavement Performance (LTPP) Experiment SPS-3 sites in an attempt to develop performance prediction models for maintenance treatments based on 5-years of performance data. A multiple regression analysis was conducted using pavement age, original pavement condition (good, fair, and poor) based on the Pavement Rating Score (PRS), traffic level (high, medium, and low), pavement structural adequacy (structural number ratio), climate zone, and subgrade type as the independent variables. PRS is an analysis approach specifically developed by the researchers for the LTPP SPS-3 sections. It is a single distress index that includes other individual distress parameters (fatigue cracking, longitudinal cracking, transverse cracking, patching, bleeding, and rutting). PRS is based on a scale of 0 (failed) to 100 (perfect condition). Deduct values are assigned to individual distress and severity levels. The PRS model for chip seal pavements is shown in Equation 11.

$$PRS = 45.26 + 4.37\,Age + 9.79\,IC - 9.21\,SA + 10.43\,SG \quad \text{(Eq. 13)}$$
$$R^2 = 0.306;\ \text{standard error of estimate} = 18.08$$

where:

PRS = Pavement Rating Score (0 to 100 scale).
Age = chip seal age (years).
IC = initial or pretreatment condition.
SA = structural adequacy (SN ≤ 1 or SN > 1).
SG = subgrade type (fine or coarse).

The Ministry of Transportation of Ontario (MTO) developed pavement performance prediction models based on pavement type, traffic volume, climate zone, subgrade type, and total pavement thickness (Li and Kazmierowski 2004). Performance prediction is based on a Pavement Condition Index (PCI) that considers both a Distress Manifestation Index (DMI) and IRI. The resulting MTO PCI equation for surface treatment pavements is:

$$PCI = 10 \times (0.1 \times RCI)^{0.5} \times DMI \times 0.962 \quad \text{(Eq. 14)}$$
$$R^2 = 0.962$$

where:

PCI = Pavement Condition Index.
RCI = Ride Comfort Index or IRI. RCI ranges from 10 (perfect condition) to 0 (very poor).
DMI = Distress Manifestation Index. Reflects the overall pavement surface condition and ranges from 1 (very poor) to 10 (excellent).
$= 10 \times \frac{DMI_{Max} - \sum_{i=1}^{n} W_i(s_i + d_i)}{DMI_{Max}}$
DMI_{Max} = the maximum value theoretically assigned to an individual pavement distress. For surface treated pavements = 180.

W_i = weighting factor, ranging from 0.5 to 3.0, representing the relative weight or attribute to overall pavement surface condition of each evaluated pavement section.

Distress Type	W_i
Raveling	3.0
Streaking	1.0
Shoving	2.0
Distortion	3.0
Pavement-Edge Breaking	2.0

Distress Type	W_i
Flushing	2.0
Potholing	1.0
Rutting	3.0
Longitudinal Crack	1.0
Alligator Crack	3.0

s_i = severity of distress expressed on a 5-point scale, ranging from 0.5 to 4.0.

d_i = density of distress occurrence expressed on a 5-point scale, ranging from 0.5 to 4.0.

The MTO trigger values for RCI, DMI, PCI, and IRI for surface treatment pavements are shown in table 2.

Table 2. Performance indices and trigger values for surface treatment (Li and Kazmierowski 2004).

Road Class	RCI[1]	DMI	PCI	IRI
Freeway	6.0	7.3	65.0	N/A
Arterial	5.8	7.0	55.0	3.2
Collector	5.1	6.8	50.0	3.7
Local	5.1	6.8	45.0	3.7

[1] $RCI = 15.7 / e^{(0.307\ IRI)}$

As part of NCHRP Project 14-14, *Optimal Timing of Pavement Preventive Maintenance Treatment Applications*, a framework was developed for determining the optimal timing of preventive maintenance treatments for both asphalt and concrete pavements (Peshkin, Hoerner, and Zimmerman 2004). The developed methodology considered a variety of agency treatments (e.g., crack sealing, fog seals, chip seals, thin asphalt overlays) and different ways of monitoring performance (e.g., friction, roughness, overall pavement condition). The research focused on developing a methodology that would assist agencies in placing the right treatment on the right pavement at the right time. A systematic procedure for identifying optimal timing of preventive maintenance treatments was developed and includes (Peshkin, Hoerner, and Zimmerman 2004):

- Identification of specific objectives of the preventive maintenance program: Overall agency expectations need to be clearly defined.
- Selection of treatments and definition of guidelines on their appropriate use: Since each treatment provides unique benefits, or can be subjected to different constraints, guidelines should be developed on the selection, use, and performance of treatments specific to local/regional conditions (such as traffic and climatic conditions).
- Definition of typical performance of pavements when no treatment is applied, as well as the expected performance for different treatments: Analysis of historical data available should be conducted to develop pavement performance models with and without treatment application.
- Identification and tracking of appropriate performance measures for different treatments and analysis of data and calculation of optimal timing of treatments: Treated sections should be monitored periodically to keep track of performance over time.

Treatment benefit is defined as the difference in condition over time between the treated pavement and the performance of the same pavement if no treatment had been applied. An illustration of the benefit associated with the application of a preventive maintenance treatment is shown in figure 6.

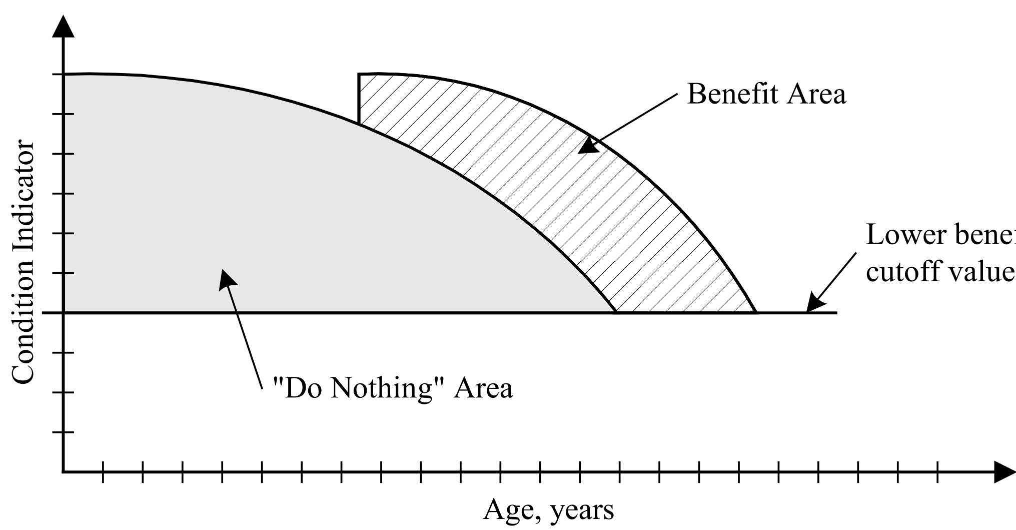


Figure 11. Illustration of treatment benefit (Peshkin, Hoerner, and Zimmerman 2004).

Data extracted from the Kansas DOT pavement management system was used to develop chip seal performance prediction models using linear regression (Liu, Hossain, and Miller 2009). Performance prediction models were developed for IRI and a variety of surface distress as a function of condition after 1 year, traffic level, equivalent single axle load (ESAL) applications, and highway class (interstate, U.S. highways, and state highways). The Kansas DOT chip seal performance prediction models for IRI, rut depth, transverse cracking, and fatigue cracking include:

$$IRI = 3.97091 + 0.8932\ Initial\ IRI + 2.87797 Age + 1.29244\ Class \quad \text{(Eq. 15)}$$

$$\mathrm{RD} = 0.03621 + 0.76501\ \mathrm{Initial\ RD} - 0.00404\ \mathrm{Class} \quad \text{(Eq. 16)}$$

$$\mathrm{TCR} = -0.0765 + 0.7833\ \mathrm{Initial\ TCR} + 0.0175\ \mathrm{Age} + 0.0561\ \mathrm{Class} \quad \text{(Eq. 17)}$$

$$\mathrm{FCR} = -0.24839 + 0.49664\ \mathrm{Initial\ FCR} + 0.00008\ \mathrm{ESAL} + 0.15381\ \mathrm{Class} \quad \text{(Eq. 18)}$$

where:

IRI = International Roughness Index (in/mile).
RD = rut depth (in).
TCR = equivalent number of full-width transverse cracks per 100-ft segment.
FCR = equivalent fatigue cracks per 100 ft segment (ft/100 ft).
Initial IRI = first year IRI value after chip seal application (in/mile).
Initial RD = first year RD value after chip seal application (in).
Initial TCR = first year TCR value after chip seal application.
Initial FCR = first year FCR value after chip seal application.
Age = chip seal service year.
ESAL = cumulative equivalent 18 kip single axle loads.
Class = highway class (Interstate = 1; U.S. highways = 2; and state highways = 3).

The IRI equation was based on 844 observations with an R^2 value of 0.867. In addition, while the IRI performance prediction equation is appropriate for predicting the progression of IRI increase, the equation should be used with caution on roadways with severe roughness (as roughness increases beyond 100 to 125 in/mile, there is larger disagreement between the observed value and the predicted value) (Liu, Hossain, and Miller 2009).

The RD equation was based on 848 observations with an R^2 value of 0.735. Liu, Hossain, and Miller (2009) also noted that additional factors may be required to predict rut depth performance on chip seal pavements, such as material type and pavement thickness. Liu, Hossain, and Miller determined that for approximately 58 percent of the validation sites the predicted rut depth matched the measured rut depth.

The TCR equation was based on 722 observations with an R^2 value of 0.632. Liu, Hossain, and Miller (2009) noted that additional factors may be required to predict transverse crack performance on chip seal pavements, such as material type, pavement thickness, and characteristics prior to chip seal application. They also indicated that this equation should be used with caution for predicting transverse cracking on pavement segments with a high transverse cracking at year 1.

The FCR equation was based on 804 observations with an R^2 value of 0.527. Liu, Hossain, and Miller (2009) noted that validation of the model resulted in a very low correlation between observed and predicted fatigue cracking. Therefore, they indicate that chip seal application may not be an appropriate application for addressing fatigue-cracked asphalt-surfaced pavements.

In a study conducted by Hein and Rao (2010), regression models were developed for various preventive maintenance treatments using the Pavement Condition Rating (PCR), which is based on a score of 0 (poor) to 100 (excellent). Performance models were developed based on condition prior to preventive maintenance application, pavement type, and traffic level (when sufficient data was available). The resulting regression equations for chip seal pavements are shown in table 3. Regression models shown in table 3 reflect all pavement types and all traffic levels evaluation (e.g., insufficient data was available to develop pavement type- and traffic level-specific models). However, the corresponding R^2 values are relatively low.

Table 3. PCR regression models for chip seal pavements (Hein and Rao 2010).

Condition Prior to Treatment[1]	Regression Model	No. of Segments	R^2	Treatment age by PCR (years)		
				80	75	65[2]
Fair	$PCR = 88.058 - 1.3704 \times Age$	33	0.22	6.0	9.0	12.0
Good	$PCR = 93.381 - 2.0178 \times Age$	20	0.38	6.5	9.5	12.0
All	$PCR = 90.082 - 1.6146 \times Age$	53	0.25	6.3	9.0	12.0

[1] Fair condition = PCR 70 – 80; good condition 80 – 90.
[2] Estimated.

Rajagopal (2010) extracted data from the Ohio DOTs Pavement Management Information System to evaluate performance and cost effectiveness of chip seal treatments. Performance models were based on pavement condition only and did not include material type, traffic volume, or climate conditions. Pavement condition is expressed in terms of the PCR. The PCR calculation is based on deduct and weighting values depending on distress type, severity, and extent (ODOT 2004). Asphalt pavement distress types include raveling, bleeding, patching, debonding, crack sealing deficiency, rutting, settlement, potholes, wheel track cracking, block/transverse cracking, longitudinal cracking, edge cracking, and thermal cracking. Generated chip seal performance models based on the pavement condition prior to chip seal application include (Rajagopal 2010):

$$PCR_{61\ to\ 65} = -7.2265\ Age + 92.666\ (R^2 = 0.75; n = 37) \quad \text{(Eq. 19)}$$

$$PCR_{66\ to\ 70} = -4.7031\ Age + 93.059\ (R^2 = 0.60;\ n = 132) \quad \text{(Eq. 20)}$$

$$PCR_{71\ to\ 75} = -4.6069\ Age + 94.745\ (R^2 = 0.74;\ n = 147) \quad \text{(Eq. 21)}$$

$$PCR_{76\ to\ 80} = -4.0023\ Age + 94.229\ (R^2 = 0.53;\ n = 203) \quad \text{(Eq. 22)}$$

$$PCR_{81\ to\ 85} = -4.9661\ Age + 95.511\ (R^2 = 0.60;\ n = 140) \quad \text{(Eq. 23)}$$

$$PCR_{86\ to\ 90} = -3.9791\ Age + 95.873\ (R^2 = 0.71; n = 107) \quad \text{(Eq. 24)}$$

where:

$PCR_{xx\ to\ yy}$ = PCR range prior to chip seal application.
Age = chip seal age (years).

Morian et al. (2011) evaluated all years of performance monitoring data for selected maintenance treatments (thin HMA overlays, slurry seals, crack sealing, and chip seals) of the LTPP SPS-3 experiment. Survival curves, using the Kaplan-Meier Survival Analysis method, were developed according to the original pavement condition (good, fair, and poor) and the survival probability of reaching a treatment age based on a PRS value of 50. Figure 7 shows the survival curves for chip seal treatments, and indicates that pavement segments in good condition prior to chip seal application survived longer than pavement segments whose prior condition was in fair or poor condition.

A polynomial model was fit through the average survival curve to determine a performance equation. The resulting performance equation for chip seal pavements includes:

$$S = -0.027 \times Life^2 - 0.0179 \times Life + 1 \quad \text{(Eq. 25)}$$
$$R^2 = 0.98$$

where:

S = survival probability.

$Life$ = life expectancy (years).

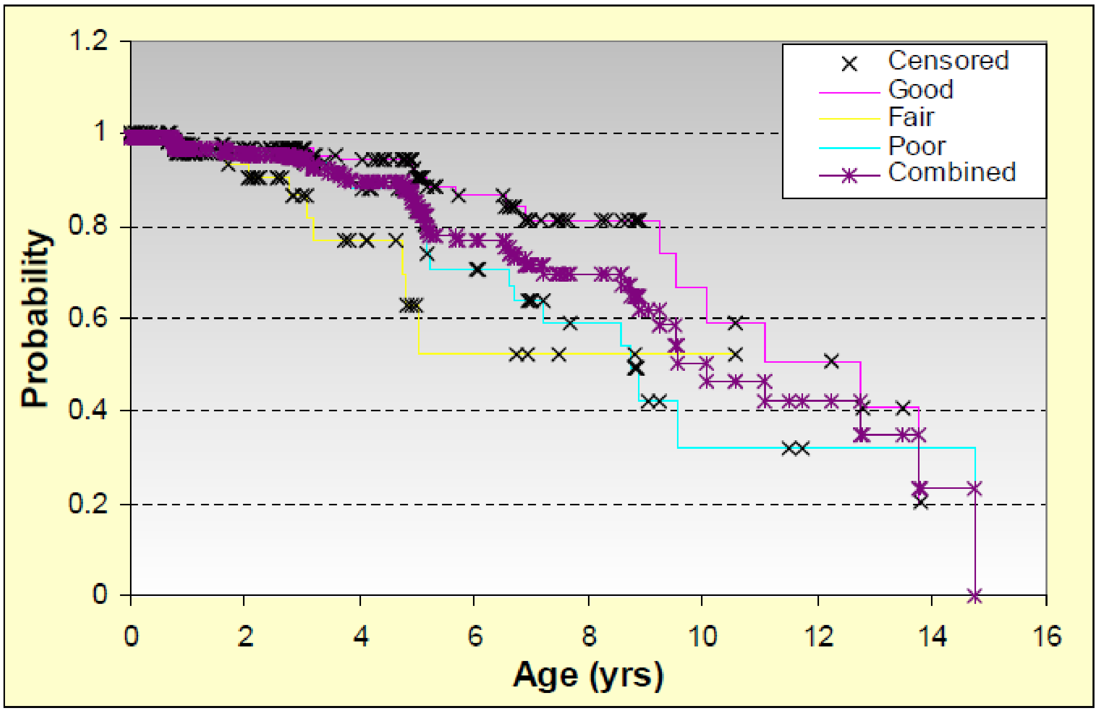


Figure 12. Survival curves for chip seal treatments (Morian et al. 2011).

The life expectancy at three levels of survival probability (0.5, 0.6, and 0.8) was calculated for each treatment type and is shown in table 4. The performance of treatments can then be associated with the owner's level of risk for each roadway classification. For example, for high profile roadways the owner may want to minimize the risk of lower-than-expected performance by selecting a higher survival probability. For lower road classifications, where the risk of not achieving expected performance is less critical, a lower survival probability would be appropriate.

Table 4. Survival probability results (Morian et al. 2011).

Treatment Type	Estimated Life (years) at Given Survival Probability		
	0.50	0.60	0.80
Control Section	7.5	6.1	3.2
Crack Sealing	7.4	6.3	3.6
Slurry Seal	8.6	7.4	4.7
Chip Seal	10.7	9.3	5.9
Thin Overlay	10.0	9.1	7.0

As part of a larger study, Liu and Gharaibeh (2013) extracted data from the LTPP database on 184 pavement sections that received a chip seal treatment (sites located in the U.S. and Canada). In this study, all pavement segments consisted of an asphalt pavement layer over granular base and/or directly over the subgrade. Pavement segments were grouped according to climatic zones (i.e., dry, dry-freeze, wet non-freeze, and wet freeze). Liu and Gharaibeh (2013) defined end of service life as the "application of a subsequent preservation or rehabilitation treatment" or as "reaching pre-defined threshold values of key distress types or roughness." The pre-defined threshold values used for defining end of service are provided in table 5.

Table 5. Distress and IRI threshold values for end of service (Liu and Gharaibeh 2013).

Distress	Threshold Value
Fatigue cracking	484 square feet (or 8 percent of section area)
Longitudinal cracking	1,181 feet
Transverse cracking	230 feet
Patching	484 square feet (or 8 percent of section area)
IRI	172 in/mile
Rutting	0.75 in

Liu and Gharaibeh (2013) conducted a survival analysis to determine the probability distribution of chip seal survival time. The survival time was defined as the duration (in years) between treatment application and failure (application of a treatment or distress threshold). Models were developed based on chip seal age and cumulative ESAL applications, and are presented in table 6. Due to insufficient data, models were not developed for the dry non-freeze climate zone. Figures 8 and 9 illustrate the developed models for chip seal pavements based on age and ESALs, respectively.

Table 6. Probability of failure models (Liu and Gharaibeh 2013).

Climatic Zone	Age		ESAL	
	Model[1]	R^2	Model[1]	R^2
Dry Freeze[2,3]	$POF = 1 - e^{-(Age/10.92)^{0.60}}$	0.98	$POF = 1 - e^{-(ESAL/3.73)^{2.57}}$	0.97
Wet Freeze[2,4]	$POF = 1 - e^{-(Age/5.25)^{0.89}}$	0.96	$POF = 1 - e^{-(ESAL/2.93)^{3.99}}$	0.94
Wet Non-Freeze[2,5]	$POF = 1 - e^{-(Age/15.69)^{0.84}}$	0.92	$POF = 1 - e^{-(ESAL/3.43)^{4.79}}$	0.95

1 *POF* = probability of failure.
2 Upper age boundary of 16 years.
3 Upper ESAL boundary of 6,000,000.
4 Upper ESAL boundary of 3,000,000.
5 Upper ESAL boundary of 15,000,000.

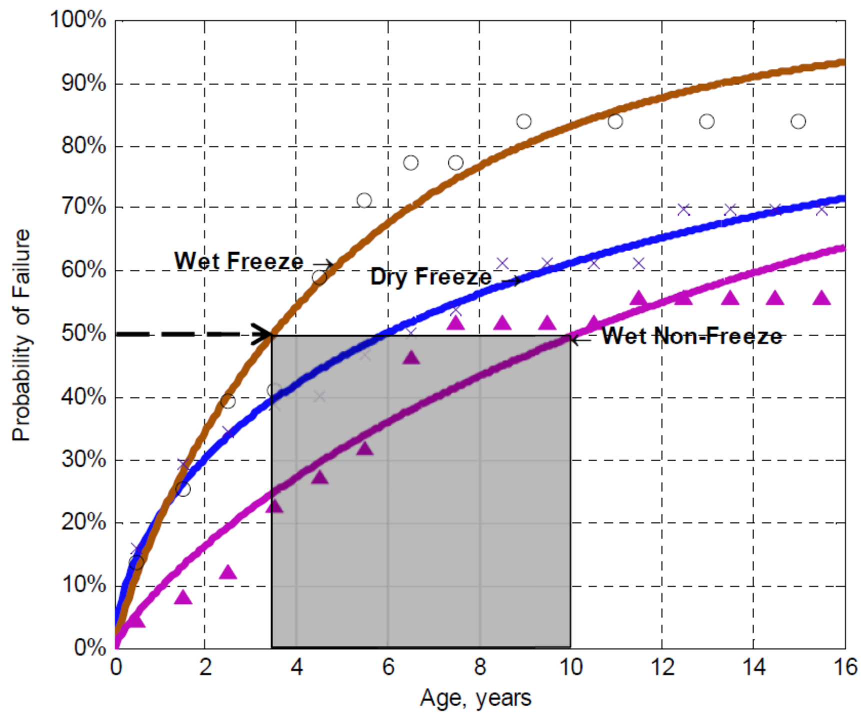


Figure 13. Age failure curves for chip seal treatments (Liu and Gharaibeh 2013).

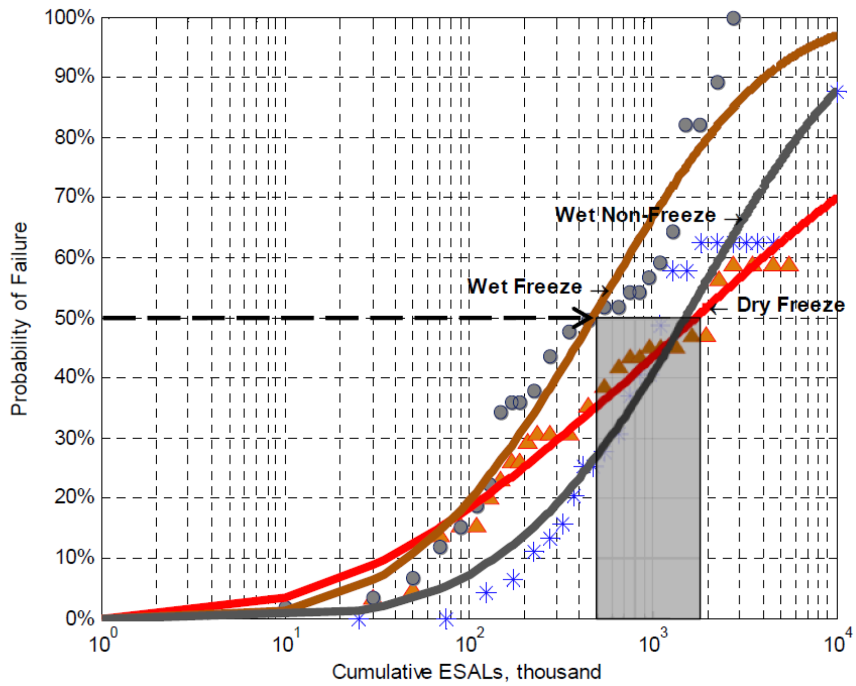


Figure 14. ESAL failure curves for chip seal treatments (Liu and Gharaibeh 2013).

Visible Chip Seal Distress

Visible chip seal distress includes oxidation, aggregate wear, aggregate polishing, bleeding, and aggregate loss (Gransberg 2007). Based on a literature review and agency survey conducted by Gransberg and James (2005), bleeding and raveling are the most common visible chip seal surface distresses.

- Bleeding—An excessive amount of binder appearing on the chip seal surface. Bleeding is caused by an excess amount of binder in proportion to the amount of aggregate or excessive aggregate embedment.
- Raveling—The loss of aggregate from the chip seal surface. Raveling occurs due to failure of the bond between the aggregate and binder.

The Gransberg 2007 chip seal distress model incorporates both bleeding and raveling, in that raveling leads to aggregate loss and bleeding leads to texture loss, both of which reduce the skid resistance of the pavement surface.

Summary

A number of national and state-level studies on predicting chip seal performance were reviewed according to engineering-based and qualitative-based performance measures. The reviewed studies indicated the use of visual surface ratings in a combined distress index, accompanied by pavement performance prediction equations, as the primary method for predicting chip seal performance. A summary of scheduled chip seal performance models is provided in table 7.

Table 7. Summary of chip seal performance prediction methods.

Reference	Performance Equation
Romero and Anderson (2005)	$SN = -0.3815\ Age + 59.4487$ ($R^2 = 0.01$)
Romero and Anderson (2005)	$SN\ (\%) = 1.9176\ Age - 1.2403$ ($R^2 = 0.83$)
Roque, Anderson, and Thompson (1991)	$MTD = 0.096 - 0.125\ EAR$ ($R^2 = 0.71$)
Transport New Zealand (1981)	$Td1 = 0.07 \times ALD \times logYd + 0.9$ (R^2 unknown)
Morian, Gibson, and Epps (1998)	$PRS = 45.26 + 4.37\ Age + 9.79\ IC - 9.21\ SA + 10.43\ SG$ ($R^2 = 0.31$)
Li and Kazmierowski (2004)	$PCI = 10 \times (0.1 \times RCI)^{0.5} \times DMI \times 0.962$ ($R^2 = 0.96$)
Peshkin, Hoerner, and Zimmerman (2004)	Models determined using pavement condition data or user provided equations in Microsoft Excel tool.
Liu, Hossain, and Miller (2009)	$IRI = 3.97091 + 0.8932\ Initial\ IRI + 2.87797\ Age + 1.29244\ Class$ ($R^2 = 0.87$) $RD = 0.03621 + 0.76501\ Initial\ RD - 0.00404\ Class$ ($R^2 = 0.74$) $TCR = -0.0765 + 0.7833\ Initial\ TCR + 0.0175\ Age + 0.0561\ Class$ ($R^2 = 0.63$) $FCR = -0.24839 + 0.49664\ Initial\ FCR + 0.00008\ ESAL + 0.15381\ Class$ ($R^2 = 0.53$)
Hein and Rao (2010)	$PCR_{fair} = 88.058 - 1.3704 \times Age$ ($R^2 = 0.22$) $PCR_{good} = 93.381 - 2.0178 \times Age$ ($R^2 = 0.38$) $PCR_{all} = 90.082 - 1.6146 \times Age$ ($R^2 = 0.25$)
Rajagopal (2010)	$PCR_{61\ to\ 65} = -7.2265\ Age + 92.666$ ($R^2 = 0.75$) $PCR_{66\ to\ 70} = -4.7031\ Age + 93.059$ ($R^2 = 0.60$) $PCR_{71\ to\ 75} = -4.6069\ Age + 94.745$ ($R^2 = 0.74$) $PCR_{76\ to\ 80} = -4.0023\ Age + 94.229$ ($R^2 = 0.53$) $PCR_{81\ to\ 85} = -4.9661\ Age + 95.511$ ($R^2 = 0.60$) $PCR_{86\ to\ 90} = -3.9791\ Age + 95.873$ ($R^2 = 0.71$)
Morian et al. (2011)	$S = -0.027 \times Life^2 - 0.0179 \times Life + 1$ ($R^2 = 0.98$)
Liu and Gharaibeh (2013)	$POF_{dry\ freeze} = 1 - e^{-(Age/10.92)^{0.60}}$ ($R^2 = 0.98$) $POF_{wet\ freeze} = 1 - e^{-(Age/5.25)^{0.89}}$ ($R^2 = 0.96$) $POF_{wet\ non\text{-}freeze} = 1 - e^{-(Age/15.69)^{0.84}}$ ($R^2 = 0.92$)
Liu and Gharaibeh (2013)	$POF_{dry\ freeze} = 1 - e^{-(ESAL/3.73)^{2.57}}$ ($R^2 = 0.97$) $POF_{wet\ freeze} = 1 - e^{-(ESAL/2.93)^{3.99}}$ ($R^2 = 0.94$) $POF_{wet\ non\text{-}freeze} = 1 - e^{-(ESAL/3.43)^{4.79}}$ ($R^2 = 0.95$)

CHAPTER 3. SURVEY OF AGENCY CHIP SEAL PRACTICES

Introduction

A survey of agency practices and performance measures was conducted on chip seal pavements. The agency survey was sent to the Pavement Management Engineer at each U.S. State Highway Agency and Canadian Provincial Government. The following provides a summary of the survey results, with more detailed discussions presented in Appendix B. In total, thirty-seven agencies responded to the survey, thirty-one (or sixty-two percent) U.S. State Highway Agencies, and six (or sixty percent) Canadian Provincial Governments. The survey that was sent to the highway agencies is presented in Appendix A.

Chip Seal Use

Of the thirty-seven responding agencies, nineteen agencies indicated that chip seals were a minor activity, sixteen indicated that it was a major activity, and two indicated that chip seals were not used (see figure 10).

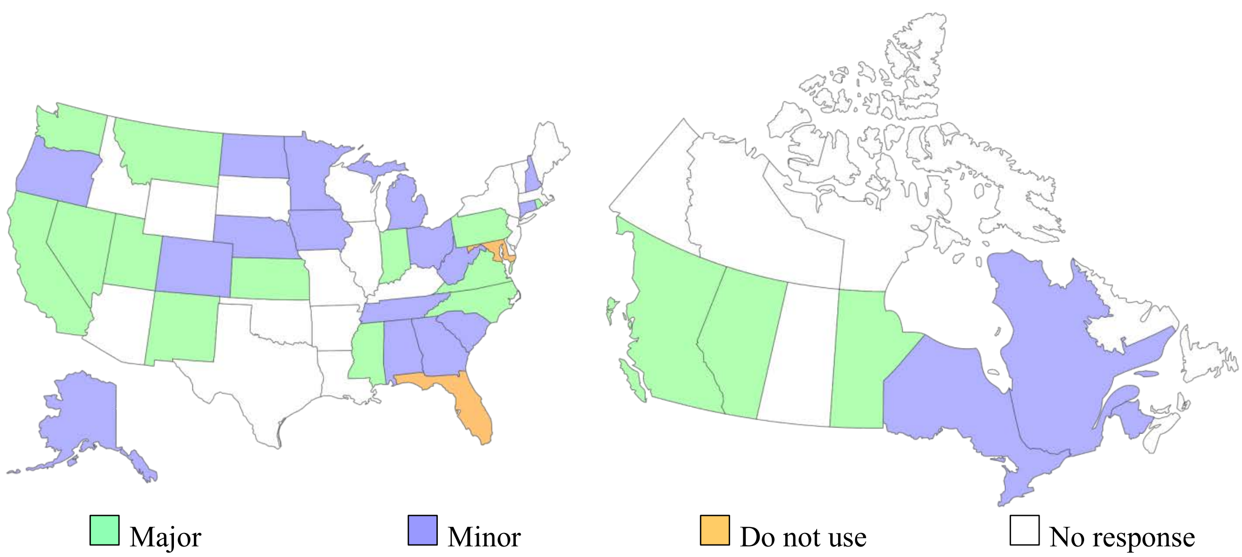
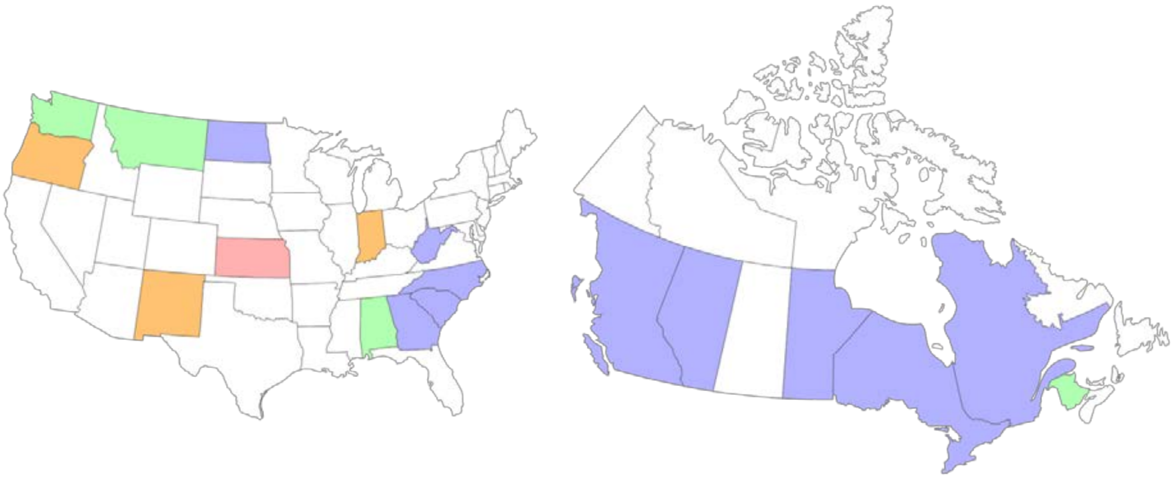
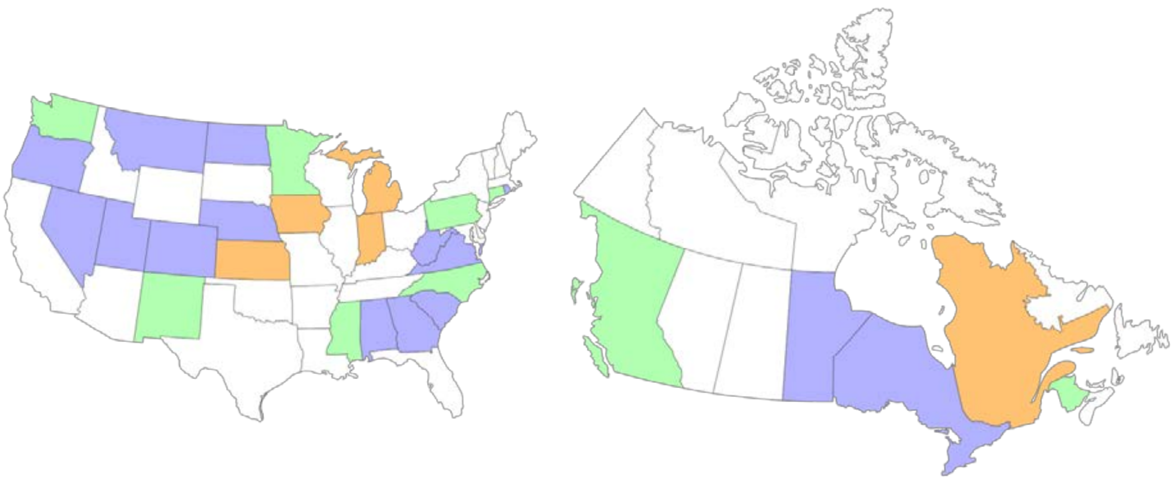


Figure 15. Level of chip seal use.

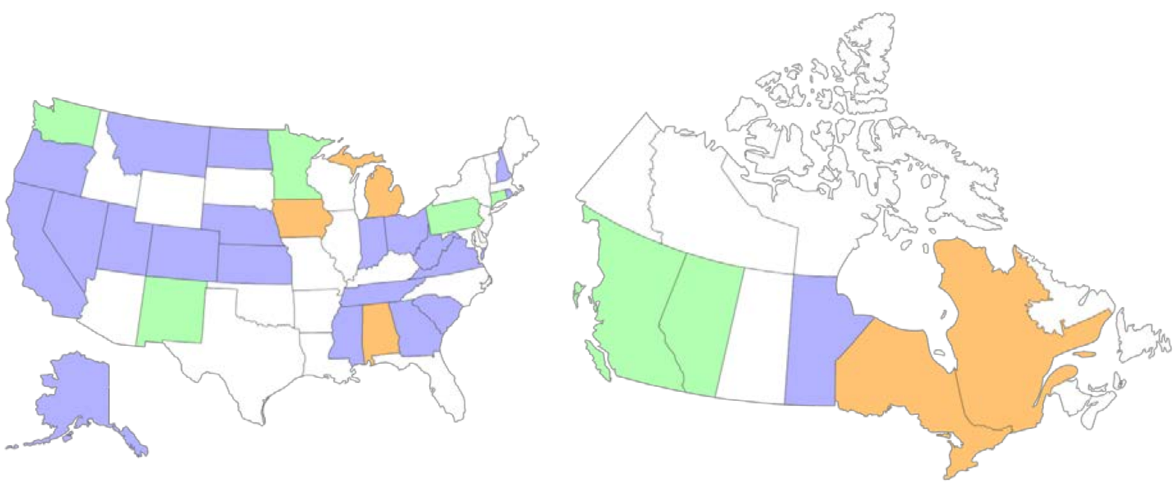
A general assessment of chip performance by chip seal pavement type is shown in figure 11. The pavement types include (1) new construction – chip seal over aggregate base, (2) chip seal of an existing chip seal pavement, and (3) chip seal of an existing asphalt pavement. For all three pavement types, the majority of agency responses indicated that chip seals have "good" performance.



a. Chip seal over aggregate base.



b. Chip seal over existing chip seal.



c. Chip seal over existing asphalt pavement.

Excellent Good Fair Poor No response/not applicable

Figure 16. Performance—chip seal over existing asphalt pavement.

Of the thirty-five agencies that use chip seals, eighteen agencies (fifty-one percent) indicated that chip seals are used for new construction, twenty-nine agencies (eighty-three percent) indicated that chip seals are applied to existing chip seal pavements, and thirty-three agencies (ninety-four percent) indicated that chip seals are applied to existing asphalt pavements. This indicates that the majority of agencies are using chip seal treatments as part of their pavement preservation program.

Chip Seal Design and Material Selection

The majority of responding agencies (nineteen) have no formal chip seal design method, eight agencies use an agency-developed method, five agencies use the McLeod or modified McLeod method, four agencies base the chip seal design on past performance, and one agency uses the Asphalt Institute MS-19 method (AI 2009).

The most predominant binder type used is CRS-2P (twenty-one agencies), followed by CRS-2 (seven agencies), HFRS-2P (four agencies), AC 15P and CRS-2H (two agencies each), and AC 5, AC 10, AC 20, CRS-1H, and CRS-1P (one agency each).

For aggregate gradation, the eight agencies each indicated the use of 0.5 inch uniformly graded and 0.375 inch uniformly graded aggregate, followed by 0.5 inch minus well-graded (three agencies), 0.625 inch minus well-graded and 0.375 inch minus well-graded (two agencies each), and 0.625 inch uniformly graded (one agency).

Finally, tables 8 and 9 summarize the number of chip seal courses (single, double, or triple) used for new construction and preservation activities by functional classification, respectively. For new construction, except for the interstate and dependent on functional classification, there is a relatively even distribution between single (five to seven agencies) and double (five to eight agencies) chip seals. However, for preservation treatments, the majority of agencies use a single chip seal application.

Table 8. Typical number of chip seal courses—new construction.

Course Type	Number of Agencies						
	Interstate	**Arterial (Urban)**	**Arterial (Rural)**	**Collector (Urban)**	**Collector (Rural)**	**Local (Urban)**	**Local (Rural)**
Single	5	5	7	6	7	7	6
Double	2	5	5	5	6	5	8
Triple	0	0	0	0	1	0	1

Table 9. Typical number of chip seal courses—preservation/rehabilitation.

Course Type	Number of Agencies						
	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
Single	11	13	22	15	23	15	25
Double	2	2	4	2	7	3	4

Chip Seal Pretreatment Activities

Table 10 summarizes agency pretreatment activities prior to chip seal application, as well as treatments that are typically applied after chip seal application. Cells containing a check mark (✓) indicate that the agency, as needed, includes the pretreatment activity prior to chip seal application. Twenty-four agencies include crack sealing, fourteen agencies include pre-leveling, and twenty-seven agencies include patching prior to chip seal application (applied on an as-needed basis). Fourteen agencies also indicated that a fog seal or sand seal is typically placed after chip seal application.

Table 10. Pretreatment activities prior to chip seal application.

Agency	Pretreatment Applications				Treatment after Chip Seal Application
	Crack Seal	Prelevel	Patching	Other	
Alabama		✓	✓	Milling	None
Alaska	✓		✓		None
Alberta	✓		✓	Spray patching; localized rut fill	None
British Columbia	✓	✓	✓	Geotextile for reflective cracking	None
California	✓		✓	Localized dig outs & repair	Typically fog seal & sand cover
Colorado	✓		✓		None
Connecticut	✓	✓	✓		None
Georgia	✓	✓	✓		Typically sand seal
Indiana	✓		✓		Typically fog seal
Iowa		✓	✓		Fog seal
Kansas					None
Manitoba	✓		✓		None
Michigan	✓			Microsurfacing for rut filling	Fog seal is encouraged
Minnesota	✓		✓		Fog seal

Table 10. Pretreatment activities prior to chip seal application (continued).

Agency	Pretreatment Applications				Treatment after Chip Seal Application
	Crack Seal	Prelevel	Patching	Other	
Mississippi	✓	✓	✓		None
Montana	✓				None
Nebraska	✓		✓		None
Nevada	✓		✓		Fog seal
New Brunswick		✓	✓	Pulverize existing surface, adding granular material, ditching - as required	Fog seal on dry surfaces where heavy traffic is expected; Microsurfacing to improve ride quality where heavy traffic is expected
New Hampshire	✓	✓	✓	Remove pavement markings by scarification	None
New Mexico	✓		✓	Sweeping	None
North Carolina	✓		✓	Crack seal & patch 1-2 years before chip seal	None
North Dakota			✓	Sweeping/cleaning	None
Ohio			✓		Often fog seal, sometimes a couple weeks later, sometimes a year or two later
Ontario					None
Oregon	✓		✓		Fog seal on occasion
Pennsylvania		✓	✓		None
Quebec		✓			None
Rhode Island	✓				Sometimes paver placed elastomeric surface treatment
South Carolina	✓	✓	✓		None
Tennessee				Usually none but may do crack sealing or patching.	Usually fog seal or microsurfacing/ thin-lift asphalt
Utah	✓	✓	✓		Flush coat
Virginia				Case by case basis	None
Washington	✓	✓	✓		Choke stone & fog seal
West Virginia	✓	✓	✓		Fog seal & microsurfacing are being tried

Chip Seal Project Selection

Table 11 includes a summary of survey responses related to chip seal project selection. Survey respondents were asked to identify the maximum AADT and any other criteria (i.e., pavement condition, climate, steep grades, turning motion, functional classification, and speed) used for selecting a roadway for a chip seal application. As available, table 11 also includes the condition level used in the chip seal project selection process. The following summarizes agency chip seal project selection criteria.

- The AADT requirements range from a minimum of 750 vehicles per day to a maximum of 20,000 vehicles per day. The more common AADT levels include less than 5,000 AADT (six responses) and less than 10,000 AADT (eight responses), with five agencies indicating no AADT limit.
- Pavement condition is used by twenty-seven agencies in the project selection process. Twenty-one agencies use some form of pavement condition (e.g., condition index, crack severity). Nine agencies specified rut depth and four agencies specified base failures as pavement segments that are not eligible for chip seal application.
- Ten agencies indicated that pavement sections containing steep (or extremely steep) grades and intersection (or heavy turning movements) are excluded from chip seal application.
- Thirteen agencies indicated that chip seals are not applied in urban areas.
- Eight agencies indicated that chip seals are not applied to interstate or freeway pavements.

In addition, agencies were asked to identify the method used for determining the timing of chip seal applications. Agencies were asked to choose between (1) observed pavement condition, (2) predetermined cycle, (3) performance prediction models, or (4) other. Thirty agencies indicated that the timing of chip seal application was based on the observed pavement condition; thirteen agencies indicated it was based on a predetermined cycle; and five agencies indicated the use of performance prediction models. These responses are shown in table 12.

Table 11. Chip seal project selection criteria.

Agency	Maximum AADT (two-way)	Other Limiting Considerations					
		Condition	Climate	Steep Grades	Turning Motion	Functional Class	Speed
Alabama	< 500 (new) < 5,000 (preservation)						
Alaska	< 1,000	No excessive rutting	Non Coastal				
Alberta	< 20,000				Avoid intersections	No urban areas	
British Columbia	< 5,000	No excessive rutting	✓	✓	Avoid switchbacks & busy intersections	Avoid freeways	
California	< 30,000	No base failure, severe distress		No steep grades	Avoid sharp curves		
Colorado	< 10,000	No excessive rutting			✓		
Connecticut	< 5,000	No base failure, excessive rutting, and wheelpath cracking				No curb & sidewalk, mainly rural roads	
Georgia	< 4,000 & < 200 trucks/day	No base failure, excessive rutting			Avoid industrial areas & intersections	No interstate or urban roadways	< 55 mph
Indiana	< 10,000	No base failure, extensive surface distress				No towns with curb & gutter	
Iowa	< 1,500						
Kansas	No limit	Must have sound structure				No interstate	
Manitoba	No limit	No excessive rutting	✓				
Michigan	< 5,000					No freeways	
Minnesota	< 20,000						
Mississippi	< 2,000	No excessive rutting, fatigue cracking	✓			No urban areas	< 55 mph
Montana	No limit						
Nebraska	< 2,000						
Nevada	< 10,000			✓			
New Brunswick	No limit						
New Hampshire	< 10,000	No excessive rutting		No stopping on steep grades	Avoid heavy turning movements & signalized intersections	No interstate or divided highways	

Table 11. Chip seal project selection criteria (continued).

Agency	Maximum AADT (two-way)	Other Limiting Considerations					
		Condition	Climate	Steep Grades	Turning Motion	Functional Class	Speed
New Mexico	No limit (non-interstate only)			✓		No high volume urban areas	No high speed roadways
North Carolina	< 10,000[1]					No interstate or major US routes	
North Dakota	< 10,000					No interstate or interregional routes	
Ohio	< 2,500 (& < 250 trucks)	No excessive bleeding, rutting, and in fair to good condition				Only two lane rural roads	
Ontario	< 750					Only collector or arterials	
Oregon	< 5,000	Low severity cracking only	Non Coastal	No steep grades > 2000 AADT	Avoid unless AADT < 2,000	No urban areas	
Pennsylvania	< 20,000 (typically < 1,500)			No stopping on steep grades	Avoid heavy truck traffic		
Quebec	< 1,000			No extremely steep grades			
Rhode Island	[2]					only on minor arterials & below	
South Carolina	< 5,000						
Tennessee	< 750	Stable asphalt, address oxidation					
Utah	< 10,000	Fair to good condition					
Virginia	< 2,000					Only primary & secondary roads	
Washington	< 10,000	No highly distressed pavements		✓	Avoid intersections and turn areas	No urban interstate and city streets	
West Virginia	< 1,000		✓	No extremely steep grades	✓	Only on non-urban collector & lower routes	

[1] Use polymer modified emulsion for higher AADT levels.
[2] Based on functional class.

Table 12. Method for determining chip seal timing.

Agency	Pavement Condition[1]	Predetermined Cycle	Performance Model	Comments
Alabama	✓			
Alaska	✓			
Alberta	CI			Also based on pavement age
British Columbia	A, L, Ride, T	✓		
California	A, Rut			
Colorado	A, L, Ride, Rut, T		✓	
Connecticut	CI, Rut			Also based on funding level, treatment cost, & benefit-cost
Georgia	✓			
Indiana	F, Ride, Rut	✓		
Iowa	✓			
Kansas	A		See Eq. 5 – 8	
Manitoba	✓			
Michigan	Ride			
Minnesota	✓	✓		
Mississippi	A, Ride, Rut	✓		
Montana	✓	✓		
Nebraska		✓		
Nevada	✓			Benefit-cost
New Brunswick	✓		✓	
New Hampshire	Rut	✓		
New Mexico	A, B, F, L, T, R, Ride, Rut	✓		
North Carolina	B, CI, F, R, Rut	✓		Some divisions use timed cycles, most use pavement condition
North Dakota		✓		
Ohio	B, CI, Rut			
Ontario		✓		
Oregon	A, L, R, T	✓		Predetermined cycle used for planning, due to limited funds prioritize based on pavement condition
Pennsylvania	A, B, F, L, T, R, Rut, Ride	✓		
Quebec	A, L, Ride, Rut			
Rhode Island	A, CI, L, Rut, T			

Table 12. Method for determining chip seal timing (continued).

Agency	Pavement Condition[1]	Predetermined Cycle	Performance Model	Comments
Tennessee	CI			
Utah	✓			
Virginia	✓			
Washington	✓			
West Virginia	A, B, CI, L, T, R, Ride		✓	

A – alligator cracking; B – bleeding; CI – combined condition index; F – friction; L – longitudinal cracking; R – raveling/weathering; Ride – roughness; Rut – rut depth; and T – transverse cracking.

Pavement Condition Assessment

Table 13 provides a summary of the pavement condition assessment practices of the responding agencies. Agencies were asked to identify the condition survey method (manual/windshield, semi-automated, or fully automated), distress identification procedure (agency-developed, LTPP *Distress Identification Manual*, or other), and whether or not friction testing, rut depth, and roughness testing were also conducted. It should be noted that several agencies indicated that multiple condition survey methods and distress identification methods are used. For the most part, this is due to either the agency transitioning from manual to semi- or fully automated data collection procedures, the condition survey method type is dependent on functional classification, or the agency distress method is based on both agency and LTPP *Distress Identification Manual* procedures.

Twenty-five of the responding agencies conduct a combination of manual (nine agencies), manual and semi-automated (six agencies), and manual and fully automated (ten agencies) condition surveys, three agencies conduct only semi-automated condition surveys, and eight agencies conduct only fully automated condition surveys. In relation to quantifying surface distress, twenty-three agencies use an agency-based method, four agencies use the LTPP *Distress Identification Manual*, six agencies use a combination of both an agency-based and the LTPP *Distress Identification Manual*, one agency uses the pavement quality index (PQI) method, and one agency uses AASHTO methods. In addition to surface distress, eight agencies assess surface friction and sixteen agencies collect rut depth and roughness data.

Table 13. Pavement condition practices.

Agency	Condition Survey Method[1]	Distress Method[2]	Additional Data Collected		
			Friction	Rut Depth	Roughness
Alabama	M, S	A	✓	✓	✓
Alaska	M, F	A			
Alberta	M	A			
British Columbia	M	A		✓	✓
California	M	A			
Colorado	S	A, L		✓	✓
Connecticut	M, F	A, L		✓	
Georgia	F	A			
Indiana	M, F	A	✓		✓
Iowa	F	L	✓	✓	✓
Kansas	F	AASHTO		✓	✓
Manitoba	M	A			
Michigan	M, S	A		✓	✓
Minnesota	M, F	A		✓	✓
Mississippi	M, F	L		✓	✓
Montana	M, F	A	✓	✓	✓
Nebraska	M, S	A, L			
Nevada	M	A			
New Brunswick	M	A			
New Hampshire	M, S	A		✓	
New Mexico	F	A			
North Carolina	M	A	✓		✓
North Dakota	F	A			
Ohio	M	A			
Ontario	M, F	A		✓	✓
Oregon	M, S	A, L	✓	✓	✓
Pennsylvania	F	A			
Quebec	M	A	✓	✓	✓
Rhode Island	M, F	L			
South Carolina	M, S	PQI			
Tennessee	S	L[3]			
Utah	F	A, L	✓	✓	✓
Virginia	F	A			
Washington	S	A	✓	✓	✓
West Virginia	M, F	A, L		✓	✓

[1] M = manual/windshield; S = semi-automated; F = fully automated.
[2] A = agency-developed; L = LTPP *Distress Identification Manual*; PQI = pavement quality index.
[3] Slightly modified for crack width (high severity > 1/2 in).

Chip Seal Performance Life

Tables 14 through 16 provide a summary of the reported use of chip seal pavements by functional class and performance life for chip seal new construction, chip seals of existing chip seal pavements, and chip seals of existing asphalt pavements, respectively. On average, new construction chip seal performance life ranged from 5.6 years (urban arterial routes) to 7.8 years (rural local routes); chip seal of existing chip seal pavements range from 6.0 years (urban arterial routes) to 7.5 years (rural local routes); and chip seal of existing asphalt pavements range from 6.5 years (urban arterial routes) to 7.4 years (urban collector and rural local routes). Figure 12 provides a comparison of average performance life by functional class, and shows that, on average, chip seal performance life is slightly greater on rural routes than on urban routes, which would be expected.

Table 14. Chip seal performance life—new construction.

Statistic	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
No. of Agencies[1]	3 (10)	5 (16)	8 (26)	5 (16)	12 (39)	6 (19)	12 (39)
Minimum	6	3	3	5	3	5	3
Maximum	7	7	9	8	10	7	20
Average	6.7	5.6	6.5	6.6	6.6	6.2	7.8
Std. Deviation	0.6	1.7	1.8	1.5	2.3	1.0	5.0

[1] Values shown in parenthesis represent the percent of responding agencies.

Table 15. Chip seal performance life—over existing chip seal pavement.

Statistic	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
No. of Agencies[1]	3 (10)	5 (16)	13 (42)	7 (23)	17 (55)	8 (26)	17 (55)
Minimum	5	5	4	4	4	4	4
Maximum	7	7	11	8	10	7	15
Average	6.6	6.0	6.5	6.3	6.6	6.1	7.5
Std. Deviation	1.0	1.0	1.8	1.5	1.8	1.1	3.1

[1] Values shown in parenthesis represent the percent of responding agencies.

Table 16. Chip seal performance life—over existing asphalt pavement.

Statistic	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
No. of Agencies[1]	2 (6)	6 (19)	15 (48)	8 (26)	18 (58)	8 (26)	16 (52)
Minimum	5	5	5	6	5	6	5
Maximum	7	8	15	10	17	10	17
Average	6.6	6.5	7.3	7.4	7.3	7.1	7.4
Std. Deviation	1.4	1.0	2.5	1.3	2.7	1.2	2.9

[1] Values shown in parenthesis represent the percent of responding agencies.

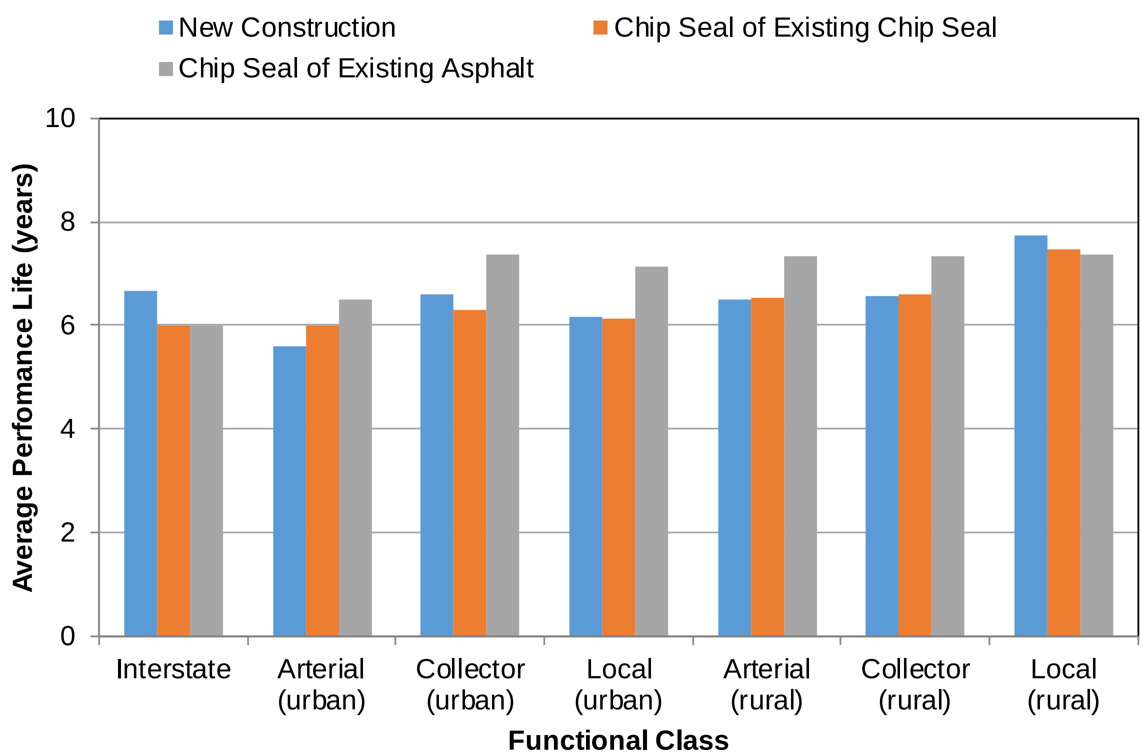


Figure 17. Performance life by functional class.

Summary

An online agency survey of chip seal practices and performance was sent to all U.S. and Canadian highway agencies. The following provides a summary of the survey results from the thirty-one U.S. State Highway Agencies and the six Canadian Ministries of Transportation that responded to the survey.

- **Chip seal application**. Eighteen of the responding agencies use chip seals for new construction, twenty-nine apply chip seals to existing chip seal pavements, and thirty-three apply chip seals to existing asphalt pavements.
- **Design method**. While nineteen agencies have no formal chip seal design method, seventeen agencies either use an agency-developed method, the McLeod or modified McLeod method, past performance, or the Asphalt Institute MS-19 procedure.
- **Materials**. The predominant binder type is CRS-2P (twenty-one agencies) and the majority of agencies use either a 0.5 inch (eight agencies) or 0.375 inch (eight agencies) uniformly graded aggregate. In addition, for new construction, both single and double course chip seals are used, while the majority of agencies use a single chip seal application for preservation activities.
- **Pretreatment activities**. The majority of agencies include crack sealing (twenty-four agencies), pre-leveling (fourteen agencies), and patching (twenty-seven agencies), on an as-needed basis, prior to chip seal application.
- **Post chip seal treatments.** Fourteen agencies indicate that fog seals or sand seals were applied after the chip seal application.
- **Project selection.** Project selection is based on AADT, pavement condition, grade steepness, functional classification, and the presences of intersections, heavy truck turning movements, and urban areas.
- **Chip seal timing**. Thirty agencies indicate that chip seal timing is based on observed pavement condition (e.g., cracking, rutting, roughness), thirteen agencies base treatment application on a predetermined cycle, and five agencies use a performance prediction model based on pavement condition.
- **Pavement condition assessment.** Nine agencies conduct a manual or windshield pavement condition survey, nine agencies conduct a manual and/or semi-automated pavement condition survey, and eighteen agencies conduct a manual and/or fully automated pavement condition survey.
- **Chip seal performance life.** The reported chip seal performance life range includes:
  - New construction: 5.6 to 7.8 years.
  - Chip seal over existing chip seal: 6.0 to 7.5 years.
  - Chip seal over existing asphalt: 6.5 to 7.4 years.

CHAPTER 4. WSDOT PAVEMENT CONDITION AND PERFORMANCE MODELING TECHNIQUES

Introduction

State Highway Agencies (SHA) continually seek to develop, refine, and modify pavement performance prediction models to improve their overall ability to effectively manage their pavement network. The level of sophistication, data requirements, and modeling techniques can vary significantly depending on the specific needs and capabilities of the SHA.

Pavement performance can be modeled according to individual pavement sections or groups of pavements with similar characteristics (referred to as families). Reliable performance prediction models are a critical element in pavement management systems. Specifically, performance prediction models are used to:

- Estimate future pavement conditions.
- Identify the appropriate timing for pavement preservation and rehabilitation activities.
- Identify the most cost-effective treatment strategy for pavements on the network level.
- Estimate statewide pavement preservation and rehabilitation needs required to address agency-specified goals, objectives, and constraints.
- Demonstrate the consequences of different pavement investment strategies and funding scenarios.
- Plan future pavement programs.

The performance prediction models serve as the cornerstone in guiding highway agencies to make more informed decisions regarding the preservation and rehabilitation of the pavement network. Thus, it is important that the prediction models are not only reliable but also reflect the actual pavement performance. The more accurately the performance prediction models reflect agency-specific deterioration patterns, the less likely that the pavement management system is to misrepresent future condition levels or the impacts of various construction programs.

WSDOT Pavement Condition Data Collection

WSDOT has been conducting pavement condition surveys since the late 1960s because of a priority programming (RCW 47.05) mandated by the Washington State Legislature. This early priority programming mandate required WSDOT to base the selection of pavement rehabilitation projects according to need. This law is still in existence today, although in 1993 a change was initiated requiring pavement rehabilitation projects selection based on lowest life cycle cost, and in 2002 required the inclusion of preservation.

Pavement surface condition data have been collected on 100 percent of the state highway network every other year from 1960 to 1988, and every year from 1989 to present. Table 17 describes the core program performance indicators collected during the WSDOT pavement condition data collection survey.

Table 17. WSDOT asphalt-surfaced pavement core program distress types (WSDOT 1992).

Distress	Unit of Measure	Severity
Alligator cracking	feet (per each wheelpath)	Low: < 0.25 in crack width Medium: spalled High: spalled and pumping
Longitudinal cracking	feet	Low: < 0.25 in crack width Medium: > 0.25 in crack width High: spalled
Transverse cracking	Count per 100 ft segment length	Low: < 0.25 in crack width Medium: > 0.25 in crack width High: spalled
Raveling[1]	feet	Low: slightly aged/slightly rough Medium: moderately rough, pitted High: deeply pitted and very rough
Flushing[1]	feet	Low: slight Medium: moderate High: severe
Patching	feet (per each wheelpath)	Low: chip seal patch Medium: blade patch High: full depth patch
Rut depth	inch	Averaged over segment length
IRI	inch/mile	Average over segment length

[1] Distress data has not been collected from 2008 to present.

In 1991, WSDOT purchased a South Dakota DOT Type II profiler for collecting longitudinal and transverse profile to determine rut depth, faulting, and IRI. In 1999, WSDOT purchased its first automated pavement condition van and evaluates the collected data using trained personnel at computer workstations (i.e., semi-automated) for quantifying pavement distress (IRI, rut depth, and faulting are processed automatically through vendor-supplied computer software). WSDOT has also been conducting friction testing since 1968 (Corsello 1993). Friction testing is conducted on 50 percent of the state highway system each year (Northwest, Olympic, and Eastern Regions in even years and North Central and Southwest Regions in odd years) in accordance with ASTM E274 using a ribbed tire.

As of 2011, due to funding restrictions WSDOT has modified its process for analyzing pavement condition on chip seal designated roadways[1]. The new process includes collecting pavement condition data on all state highways. However, for chip seal designated routes, the assessment of pavement distress (i.e., cracking, patching) and calculation of PSC are not conducted. Profile data for determining rut depth and IRI are processed each year along with the remainder of the pavement network. Table 18 provides a summary of the WSDOT historical pavement condition data collection practice for chip seal pavements.

Table 18. WSDOT historical pavement condition data collection practice.

Year	Video Images	Distress Rating	IRI	Rut
1969-1991	Not collected	All roadways, biennially	Not collected	All roadways biennially
1991[1]-1998	Not collected	All roadways, biennially	All roadways, biennially	All roadways, biennially
1999[2]-2010	All roadways, annually	All roadways, annually	All roadways, annually	All roadways, annually
2011-2012	All roadways, annually	Not conducted	All roadways, annually	All roadways, annually
2013	Western WA and NHS in Eastern WA	Not conducted	Western WA and NHS in Eastern WA	Western WA and NHS in Eastern WA
2014	All roadways, annually	Not conducted	All roadways, annually	All roadways, annually

[1] South Dakota Type II profiler.
[2] Pathway Services, Inc., PathRunner automated data collection van (profile and video images).

[1] Within the WSPMS each roadway segment is assigned a designated pavement type. Chip seal (or BST) designated roadways are pavement segments consisting of BST over aggregate base, BST over BST(s), and asphalt concrete pavement (ACP) segments that are preserved using BST applications.

WSDOT Pavement Performance Prediction

Pavement performance prediction is conducted within the Washington State Pavement Management System (WSPMS) using the core program pavement distresses (table 17) to calculate the PSC. PSC is calculated using equation 24 (Kay, Mahoney, and Jackson 1993).

$$PSC = 100 - 15.8 \times (EC)^{0.5} \quad \text{(Eq. 26)}$$

where:

PSC = pavement structural condition.

EC = equivalent alligator, longitudinal, and transverse cracking, and patching.

= $ACEC + LCEC + TCEC + PTEC$

$ACEC$ = alligator cracking component of equivalent cracking.

= $0.13\ (AC1)^{1.35} + 0.445\ (AC2)^{1.15} + AC3$

$AC1$ = percent of low severity alligator cracking

$AC2$ = percent of medium severity alligator cracking

$AC3$ = percent of high severity alligator cracking

$LCEC$ = longitudinal cracking component of equivalent cracking.

= $0.13\ (0.1\ LC1)^{1.35} + 0.445\ (0.1\ LC2)^{1.15} + 0.16AC3$

$LC1$ = percent of low severity longitudinal cracking

$LC2$ = percent of medium severity longitudinal cracking

$LC3$ = percent of high severity longitudinal cracking

$TCEC$ = transverse cracking component of equivalent cracking.

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

$TC1$ = number of low severity transverse cracks

$TC2$ = number of medium severity transverse cracks

$TC3$ = number of high severity transverse cracks

$PTEC$ = patching component of equivalent cracking.

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

$PT1$ = percent of chip seal patching

$PT2$ = percent of blade and full-depth patching (score deduct is limited to no more than 45 points)

PSC is based on a scale from 0 to 100, with 100 indicating no or insignificant distress. Within the WSPMS a best-fit curve of PSC versus pavement surface age is developed using the Levenberg-Marquardt nonlinear least squares solution (Pierce et al. 2004). The general form of the PSC performance prediction equation includes:

$$PSC = C - m \times Age^{p} \qquad \text{(Eq. 27)}$$

where:

PSC = Pavement structural condition.
C = Model constant (maximum value of approximately 100).
m = Slope coefficient.
P = Exponent that controls the degree of curvature of the performance curve.

The best-fit model is characterized by the highest R^2 value and the lowest root mean square error (Pierce et al. 2004). In the event of a relatively new pavement surface (less than three condition ratings) the WSPMS applies a standard (or default) equation based on pavement type, surfacing depth, and geographical location (also referred to as a family curve). Performance equations for IRI and rut depth are determined through simple linear regression. Table 19 provides a summary of pavement condition and threshold values for PSC, IRI, and rut depth.

Table 19. WSDOT pavement condition thresholds.

Condition	PSC	IRI (in/mi)	Rut (in)
Very Good	80 – 100	< 96	< 0.24
Good	60 – 79	96 – 170	0.24 – 0.41
Fair	40 – 59	171 – 220	0.42 – 0.58
Poor	20 – 39	221 – 320	0.59 – 0.74
Very Poor	0 – 19	> 320	> 0.74

The pavement condition and pavement performance models summarized in this chapter will be used in the evaluation or possible development of new pavement performance models to characterize chip seal performance.

CHAPTER 5. PROPOSED PERFORMANCE MEASURES

Introduction

To improve the acceptance and implementation of the proposed chip seal performance measure, it is important that the identified measure be able to reflect in-service performance, utilizes currently available data or data that can be readily obtained, and that it accurately identifies the most appropriate treatment timing. Furthermore, the performance measure should be developed using a data set that represents the full range of pavement segment scenarios (e.g., different climate regions, traffic volumes). All data included in the development of the performance measures must be reliable for the performance measure to be applicable. Thus, the data must be measured accurately without bias and collected in a consistent manner over time. Furthermore, for any utilized data, it must agree with engineering logic; that is, it must have the proper characteristics to make it a sensible choice for inclusion in the given performance measure.

Evaluation of Chip Seal Performance Measures

As described in Chapter 2, a number of chip seal performance prediction models were identified. However, none of the identified performance prediction models adequately address raveling, which has been identified as one of the leading chip seal distress types. In addition, a number of the identified performance models were based on existing pavement condition data (e.g., rut depth, IRI) that may not adequately reflect optimum timing for chip seal application.

Recommendations for Further Evaluation

Based on the results of the Phase I study and discussion with WSDOT, the proposed performance measures for chip seal pavements should include a measure of surface cracking (e.g., longitudinal cracking, fatigue cracking, patching) and/or PSC, and pavement surface macrotexture. At this time WSDOT has chosen to delay the evaluation of chip seal performance measures until additional pavement condition data can be collected and evaluated. Once sufficient data is available, the evaluation process outlined in the work plan can be used for the development and evaluation of performance measures for chip seal pavements.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). 1993. *Guide for Design of Pavement Structures.* American Association of State Highway and Transportation Officials, Washington, DC.

Asphalt Institute (AI). 2009. *Basic Asphalt Emulsion Manual.* MS-19. Asphalt Institute, Lexington, KY.

Corsello, P. 1993. *Evaluation of Surface Friction Guidelines for Washington State Highways.* Report No. WA-RD 312.1. Washington State Department of Transportation, Olympia, WA.

Flintsch, G. W., E. de Leon, K. K. McGhee, and I. L. Al-Qadi. 2003. "Pavement Surface Macrotexture Measurement and Application." *Transportation Research Record 1860.* Transportation Research Board, Washington, DC.

Gransberg, D. D. 2008. *Evaluate TXDOT Chip Seal Binder Performance Using Pavement Management Information System and Field Measurement Data San Antonio District*. Interim Research Report No. 3. University of Oklahoma, Norman, OK.

Gransberg, D. D. and D. M. B. James. 2005. *Chip Seal Best Practices.* NCHRP Synthesis 342. Transportation Research Board, Washington, DC.

Hall, J. W., K. L. Smith, L. Titus-Glover, J. C. Wambold, T. J. Yager, and Z. Rado. 2009. *Guide for Pavement Friction*. NCHRP Web-Only Document 108. Transportation Research Board, Washington, DC.

Hein, D. K., and S. Rao. 2010. "Rational Procedures for Evaluating the Effectiveness of Pavement Preservation Treatments." *Compendium of Papers from the First International Conference on Pavement Preservation*, Newport Beach, California, USA.

Huang, B. and Q. Dong. 2009. *Optimizing Pavement Preventive Maintenance Treatment Applications in Tennessee (Phase I).* Final Report. Tennessee Department of Transportation, Knoxville, TN.

Huang, R. 2012. *New Technologies for Pavement Evaluation, TxDOT 3-D Pavement Survey Technology.* Presentation, 86th Annual Transportation Short Course at Texas A&M University. Texas Department of Transportation, Austin, TX.

Kay, R. K., J. P. Mahoney, and N. C. Jackson. 1993. *The WSDOT Pavement Management System—A 1993 Update.* Report No. WA-RD 274.1. Washington State Department of Transportation, Olympia, WA.

Laurent, J., J. F. Hebert, D. Lefebvre, and Y. Savard. nd *High-Speed Network Level Road Texture Evaluation using 1mm Resolution Transverse 3D Profiling Sensors Using a Digital Sand Patch Model.* Pavemetrics, Quebec, Canada.

Li, N. and T. Kazmierowski. 2004. "Impact of Performance Measures on Pavement Asset Management in Canada." *Proceedings, 6th International Conference on Managing Pavements.* Queensland Department of Main Roads, Brisbane, Queensland, Australia.

Liu, L., and N. G. Gharaibeh. 2013. "Survival Analysis of Thin Overlay and Chip Seal Treatments Using the Long-Term Pavement Performance Data." Paper No. 13-0826. *TRB 92nd Annual Meeting Compendium of Papers*. Transportation Research Board, Washington, DC.

Liu, L., M. Hossain, and R. Miller. 2009. "Modeling of Chip Seal Performance on Kansas Highways." *Proceeding of the 2009 Mid-Continent Transportation Research Symposium*, Ames, IA.

Morian, D. A., G. Wang, D. Frith, and J. Reiter. 2011. *Analysis of Completed Monitoring Data for the SPS-3 Experiment.* Transportation Research Board Annual Meeting, Paper No. 11-2516. Transportation Research Board, Washington, DC.

Morian, D. A., S. D. Gibson, and J. A. Epps. 1998. *Maintaining Flexible Pavements—The Long Term Pavement Performance Experiment SPS-3 5-Year Data Analysis.* Report No. FHWA-RD-97-102. Federal Highway Administration, Washington, DC.

National Highway Institute (NHI). 2013. *Pavement Preservation: Preventive Maintenance Treatment, Timing, and Selection.* NHI Course No. 131115. Federal Highway Administration, Washington, DC.

Ohio Department of Transportation (ODOT). 2004. *Pavement Condition Rating System.* Ohio Department of Transportation, Columbus, OH.

Peshkin, D. G., T. E. Hoerner, and K. A. Zimmerman. 2004. *Optimal Timing of Pavement Preventive Maintenance Applications*. NCHRP Report 523. Transportation Research Board, Washington DC.

Pierce, L. M., N. Sivaneswaran, K. Willoughby, and J. Mahoney. 2004. "Mining PMS Data to Evaluate the Performance of New Hot Mix Asphalt Pavement Design Practices." *Proceedings, Sixth International Conference on Managing Pavements, Brisbane, Australia.* Queensland Department of Main Roads, Brisbane, Australia.

Rada, G. R., D. J. Jones, J. T. Harvey, K. A. Senn, and M. Thomas. 2013. *Guide for Conducting Forensic Investigations of Highway Pavements.* NCHRP Report 747. Transportation Research Board, Washington, DC.

Rajagopal, A. 2010. *Effectiveness of Chip Sealing and Micro Surfacing on Pavement Serviceability and Life*. Final Report. Ohio Department of Transportation, Columbus, OH.

Romero, P. and D. I. Anderson. 2005. *Life Cycle of Pavement Preservation Seal Coats.* Report No. UT-04.07. Utah Department of Transportation, Salt Lake City, UT.

Roque, R., D. Anderson, and M. Thompson. 1991. "Effect of Material, Design, and Construction Variables on Seal Coat Performance." *Transportation Research Record 1300*. Transportation Research Board, Washington, DC.

Seneviratne, P. N. and J. M. Bergener. 1994. *Effects of Aggregate Seal Coats on Skid Index Numbers & Accident Rates of Low Volume Roads in Utah*. Utah Department of Transportation, Salt Lake City, UT.

Sengoz, B., A. Topal, and S. Tanyel. 2012. "Comparison of Pavement Surface Texture Determination by Sand Patch Test and 3D Laser Scanning." *Periodica Polytecnica,* Volume 56, No 1. Budapest University of Technology and Economics, Budapest, Turkey.

Shuler, S., A. Lord, A. Epps-Martin, and D. Hoyt. 2011. *Manual for Emulsion-Based Chip Seals for Pavement Preservation.* NCHRP Report 680. Transportation Research Board, Washington, DC.

Testa, D. M. and M. Hossain. 2014. *Kansas Department of Transportation 2014 Chip Seal Manual.* Report No. K-TRAN: KSU-09-8. Kansas Department of Transportation, Topeka, KS.

Tighe, S., N. Li, L. Falls, and R. Haas. 2000. "Incorporating Road Safety into Pavement Management." *Transportation Research Record 1699*. Transportation Research Board, Washington, DC.

Transit New Zealand (TNZ). 1981. *Standard Test Procedure for Measurement of Texture by the Sand Circle Methods*. TNZ T/3, Wellington, New Zealand.

Utah Department of Transportation (UDOT). 2009. *Pavement Preservation Manual – Part 4 Pavement Condition Modeling with dTIMS.* Office of Asset Management. Utah Department of Transportation, Salt Lake City, UT.

Vilaca, J. L., J. C. Fonesca, A. C. M. Pinho, and E. Freitas. 2010. "3D Surface Profile Equipment for the Characterization of the pavement texture – TexScan". *Megatronics 20.* Elsevier Ltd., London, England.

Washington State Department of Transportation (WSDOT). 1992. *Pavement Surface Condition Rating Manual*. Washington State Department of Transportation, Olympia, WA.

Washington State Department of Transportation (WSDOT). 2014. *Gray Notebook*. Edition 52. Washington State Department of Transportation, Olympia, WA.

APPENDIX A: AGENCY SURVEY QUESTIONS

QUESTIONNAIRE

Dear Survey Recipient,

Applied Pavement Technology, Inc. (APTech) is conducting a study for the Washington State Department of Transportation (WSDOT) to define/develop performance measures for chip seal pavements. The purpose of this questionnaire is to identify state highway agencies that use chip seal performance measures, how these measures were developed, and how they are used in practice.

This survey is being sent to the pavement management engineer or the person who is responsible for pavement rehabilitation and preservation practices at each US State Highway Agency and Canadian Provincial Government. If you are not the appropriate person at your agency to complete this questionnaire, please forward this to the correct person.

The results of the study will be incorporated into the final research report. APTech will identify, evaluate, summarize, and, as appropriate, develop applicable chip seal performance measures for review by WSDOT. Applicable procedures will be evaluated using WSDOT pavement management data and through limited field studies. Upon completion of this 2-year study, WSDOT will evaluate and consider adopting the most applicable chip seal performance measure for possible inclusion into the Washington State Pavement Management System.

Please compete and submit this survey by **July 31, 2014**. We estimate that it should take no more than 20 minutes to complete. If you have any questions or problems related to this questionnaire, please contact Linda Pierce at 505.796.6101 or lpierce@appliedpavement.com.

Questionnaire Instructions

- If you are unable to complete the questionnaire at a single sitting, you can return to the questionnaire at any time by reentering through the survey link as long as you access the questionnaire through the same computer. Reentering the survey will return you to the last completed question.
- Survey navigation is conducted by selecting the “prev” (previous) or “next” button at the bottom of each page.

Definitions

- Arterial—Street or roadway that provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.
- AADT—Average annual daily traffic (two-way).
- Chip seal—a layer of asphalt binder overlaid with a layer of embedded aggregate.
- Collector—Street or roadway that provides a less highly developed level of service at a lower speed for shorter distances by collecting traffic from local roads and connecting them with arterials.
- Fog seal—Application of binder sprayed on top of the existing surface.
- Local—All roads not defined as arterials or collectors; primarily provides access to land with little or no through movement.

Thank you for your time and expertise in completing this important questionnaire.

General Information

1. Respondent details:

   Name: ______________________________
   Title: ______________________________
   Agency: ______________________________
   E-mail: ______________________________
   Phone: ______________________________

2. What is the level of chip seal use by your agency?

   ☐ Major activity
   ☐ Minor activity
   ☐ Do not use (thank you for your time in completing this questionnaire)

3. How would you rate the performance of your chip seal pavements?

	Chip Seal over Aggregate Base (New Construction)	Chip Seal over Existing Chip Seal	Chip Seal over Existing Asphalt Pavement
Excellent	☐	☐	☐
Good	☐	☐	☐
Fair	☐	☐	☐
Poor	☐	☐	☐

   Additional comments: ______________________________

4. How is chip seal performance life defined by your agency?

   ☐ Time until pavement condition returns to the level immediately prior to chip seal application.
   ☐ Time until pavement reaches a specified condition threshold.
   ☐ Time since last chip seal application.

   Other (please specify): ______________________________

5. What is the typical performance life of your chip seal pavements?

Functional Class	Chip Seal over Aggregate Base	Chip Seal over Existing Chip Seal	Chip Seal over Existing Asphalt Pavement
All	_____ years	_____ years	_____ years
Interstate	_____ years	_____ years	_____ years
Arterial (urban)	_____ years	_____ years	_____ years
Arterial (rural)	_____ years	_____ years	_____ years
Collector (urban)	_____ years	_____ years	_____ years
Collector (rural)	_____ years	_____ years	_____ years
Local (urban)	_____ years	_____ years	_____ years
Local (rural)	_____ years	_____ years	_____ years

6. What is the maximum AADT (two-way) for which a chip seal can be applied?

   ☐ <500 AADT
   ☐ < 1,000 AADT
   ☐ < 2,000 AADT
   ☐ < 5,000 AADT
   ☐ <10,000 AADT
   ☐ < 20,000 AADT
   ☐ No limit

   Other (please specify): ____________________

7. Are there additional factors that impact your decision for using chip seals (select all that apply)?

   ☐ Exiting pavement condition (please describe):____________________
   ☐ Climate conditions (please describe): ____________________
   ☐ Steep grades (please describe): ____________________
   ☐ Turning motions (please describe): ____________________
   ☐ Functional classification (please describe): ____________________
   ☐ Posted speed limit (please describe): ____________________

   Other (please specify): ____________________

8. What chip seal design methods do you use?

   ☐ Kearby method
   ☐ Asphalt Institute method (MS-19)
   ☐ McLeod Method
   ☐ Agency developed method
   ☐ Modified Kearby method
   ☐ Sand patch testing
   ☐ Based on past performance
   ☐ No formal design method

   Other (please specify): ____________________

9. What binder type do you normally use (select all that apply)?

   ☐ AC 2.5
   ☐ AC-5 latex
   ☐ AC 10
   ☐ AC15-5TR
   ☐ AC 40
   ☐ CRS-1H
   ☐ CRS-2
   ☐ CRS-2P
   ☐ HFRS-2P
   ☐ AC 5
   ☐ AC 10
   ☐ AC 15P
   ☐ AC20
   ☐ CRS-1
   ☐ CRS-1P
   ☐ CRS-2H
   ☐ HFRS

   Other (please specify): ____________________

10. What aggregate gradation do you typically use (select all that apply)?

- ☐ 5/8 in uniformly graded
- ☐ 1/2 in uniformly graded
- ☐ 3/8 in uniformly graded
- ☐ 5/8 in minus well-graded
- ☐ 1/2 in minus well graded
- ☐ 3/8 in minus well graded

Other (please specify): ______________________________

11. What is the typical number of courses used?

	New Construction		Preservation	
Functional Class	**Single**	**Double**	**Single**	**Double**
All	☐	☐	☐	☐
Interstate	☐	☐	☐	☐
Arterial (urban)	☐	☐	☐	☐
Arterial (rural)	☐	☐	☐	☐
Collector (urban)	☐	☐	☐	☐
Collector (rural)	☐	☐	☐	☐
Local (urban)	☐	☐	☐	☐
Local (rural)	☐	☐	☐	☐

Other (please specify):

12. What methods do you use to characterize the existing pavement condition of chip seal pavements (select all that apply)?

- ☐ Manual or windshield surface distress survey
- ☐ Semi-automated surface distress survey
- ☐ Fully automated surface distress survey
- ☐ Friction testing
- ☐ Rut depth
- ☐ Roughness

Other (please specify): ______________________________

13. What pavement condition rating methodology do you use?

- ☐ Agency developed
- ☐ Long-Term Pavement Performance Distress Identification Manual
- ☐ Pavement Condition Index (ASTM 6433)

Other (please specify): ______________________________

14. Prior to chip sealing, what pretreatment applications are typically used (select all that apply)?

- ☐ Crack sealing
- ☐ Preleveling (or level-up)
- ☐ Patching
- ☐ Geotextile for retarding reflective cracking

Other (please specify): ______________________________

15. Do you require additional treatment application after chip seal placement (e.g., fog seal, microsurfacing)?

    ☐ Yes (please specify): ____
    ☐ No

16. What method do you use to identify when a chip seal treatment should be applied (select all that apply)?

    ☐ Based on observed pavement condition
    ☐ Based on predetermined cycle (e.g. age)
    ☐ Based on performance prediction model

    Other (please specify): ____

17. If chip seal treatment timing is based on pavement condition, which distress type(s) and trigger value(s) are used to determine treatment timing (select all that apply)?

    ☐ Longitudinal cracking (trigger value =__________)
    ☐ Alligator cracking (trigger value =__________)
    ☐ Transverse cracking (trigger value =__________)
    ☐ Raveling/weathering (trigger value =__________)
    ☐ Bleeding (trigger value =__________)
    ☐ Rut depth (trigger value =__________)
    ☐ Roughness (trigger value =__________)
    ☐ Friction (trigger value =__________)
    ☐ Combined condition index (trigger value =__________)

    Other (please specify): ____

18. If your agency uses performance measures/models for determining chip seal application timing, do you have any reports, manuals, guidelines, and so on that document your process?

    ☐ Yes
    ☐ No

    If yes, could you please send a copy to Linda Pierce at lpierce@appliedpavement.com?

19. Would you be interested in receiving a copy of the survey results?

    ☐ Yes
    ☐ No

Thank you for your time.

APPENDIX B: SUMMARY OF AGENCY SURVEY RESPONSES

A survey of US Highway Agencies and Canadian Provincial Governments was conducted in order to determine agency performance measures for chip seal pavements. The survey was sent to all pavement management engineers at each state and provincial highway agency. In total, thirty-seven agencies (thirty-one US and six Canadian highway agencies) responded to the survey. The following provides a summary of the survey responses.

Agencies responding to the survey include:

- Alabama DOT
- Alaska DOT & Public Facilities
- Alberta Transportation
- British Columbia Transportation & Infrastructure
- California DOT
- Colorado DOT
- Connecticut DOT
- Florida DOT
- Georgia DOT
- Indiana DOT
- Iowa DOT
- Kansas DOT
- Manitoba Infrastructure & Transportation
- Maryland State Highway Administration
- Michigan DOT
- Minnesota DOT
- Mississippi DOT
- Montana DOT
- Nebraska Department of Roads
- Nevada DOT
- New Brunswick Transportation & Infrastructure
- New Hampshire DOT
- New Mexico DOT
- North Carolina DOT
- North Dakota DOT
- Ohio DOT
- Ontario Ministry of Transportation
- Oregon DOT
- Pennsylvania DOT
- Quebec Ministry of Transportation
- Rhode Island DOT
- South Carolina DOT
- Tennessee DOT
- Utah DOT
- Virginia DOT
- West Virginia DOT
- Washington State DOT

Table B1. Level of chip seal use.

Agency	Activity Level
Alabama	Minor activity
Alaska	Minor activity
Alberta	Major activity
British Columbia	Major activity
California	Major activity
Colorado	Minor activity
Connecticut	Minor activity
Georgia	Minor activity
Indiana	Major activity
Iowa	Minor activity
Kansas	Major activity
Manitoba	Major activity
Michigan	Minor activity
Minnesota	Minor activity
Mississippi	Major activity
Montana	Major activity
Nebraska	Minor activity
Nevada	Major activity

Agency	Activity Level
New Brunswick	Minor activity
New Hampshire	Minor activity
New Mexico	Major activity
North Carolina	Major activity
North Dakota	Minor activity
Ohio	Minor activity
Ontario	Minor activity
Oregon	Minor activity
Pennsylvania	Major activity
Quebec	Minor activity
Rhode Island	Major activity
South Carolina	Minor activity
Tennessee	Minor activity
Utah	Major activity
Virginia	Major activity
West Virginia	Minor activity
Washington	Major activity

Table B2. General assessment of chip seal pavement performance.

Agency	Chip Seal over Aggregate Base	Chip Seal over Existing Chip Seal	Chip Seal over Existing Asphalt Pavement
Alabama	Excellent	Good	Fair
Alaska	Not applicable	Not applicable	Good
Alberta	Good	Not applicable	Excellent
British Columbia	Good	Excellent	Excellent
California	Not applicable	Not applicable	Good
Colorado	Not applicable	Good	Good
Connecticut	Not applicable	Excellent	Excellent
Georgia	Good	Good	Good
Indiana	Fair	Fair	Good
Iowa	Not applicable	Fair	Fair
Kansas	Poor	Fair	Good
Manitoba	Good	Good	Good
Michigan	Not applicable	Fair	Fair
Minnesota	Not applicable	Excellent	Excellent
Mississippi	Not applicable	Excellent	Good
Montana	Excellent	Good	Good
Nebraska	Not applicable	Good	Good
Nevada	Not applicable	Good	Good
New Brunswick	Excellent	Excellent	Not applicable
New Hampshire	Not applicable	Not applicable	Good
New Mexico	Fair	Excellent	Excellent
North Carolina	Good	Excellent	Not applicable
North Dakota	Good	Good	Good
Ohio	Not applicable	Not applicable	Good
Ontario	Good	Good	Fair
Oregon	Fair	Good	Good
Pennsylvania	Not applicable	Excellent	Excellent
Quebec	Good	Fair	Fair
Rhode Island	Not applicable	Good	Good
South Carolina	Good	Good	Good
Tennessee	Not applicable	Not applicable	Good
Utah	Not applicable	Good	Good
Virginia	Not applicable	Good	Good
West Virginia	Good	Good	Good
Washington	Excellent	Excellent	Excellent
Not applicable/no response	17	6	2
Excellent	4	9	7
Good	10	15	21
Fair	3	5	5
Poor	1	0	0

Table B3. General assessment of chip seal pavement performance—additional comments.

Agency	Additional Comments
Alabama	Chip seal over existing asphalt performance is fair because of application/construction issues. Chip seals placed on aggregate bases are NOT the final surface on any state maintained route. The chip seals placed on aggregate bases are used to seal the aggregate base prior to asphalt placement. Chip seals placed over aggregate bases where the chip seal is the final wearing layer are used primarily on low volume local (County) routes.
Alberta	No chip seals on existing chip seal pavements.
British Columbia	Some bases on new constructions are not well compacted lending to failed seal coat areas.
California	Also use asphalt rubber chip seal as a stress absorbing membrane interlayer.
Connecticut	No chip seal over aggregate base is used; very limited use overall.
Georgia	We do not typically chip seal of existing asphalt pavement, but if we do, we level first.
Indiana	We rarely chip seal over an aggregate base.
Iowa	We do not place chip seals on aggregate bases.
Kansas	Do not use "New Construction" but the counties use it some.
Manitoba	Majority of chip seals are over asphalt pavement are as a preservation treatment.
New Brunswick	Performance depends on level of truck traffic. Do almost no chip seal over asphalt.
New Hampshire	We do apply chip seals directly over aggregate bases and have yet to re-apply a chip seal over another chip seal that has reached the end of its service life.
North Carolina	We do not usually put chip seals over existing HMA.
North Dakota	Only one short segment of roadway has had a chip seal over aggregate base. Limited experience with the technique.
Ontario	Have done limited chip seal projects in the past but we do carry out a large amount of surface treatments each year. Typically we use surface treatments for low volume road, which is considered to be chip seal by your definition. For collector/arterial road, we will only use chip seal over existing asphalt as preventive maintenance.
Oregon	We have very few BST roads left. They were old oil mat roads and are pretty rough. Most have been paved over.
Pennsylvania	We don't chip directly over aggregate.
Quebec	In the last 20 years, we used only chip seal over aggregate base.
Rhode Island	We do not chip seal over aggregate base.
Tennessee	We only use chip seal over existing asphalt pavement.
Utah	15 percent of our Interstate surface area is chip sealed, 40 percent of the remaining NHS is chip sealed, 70 percent of the non-NHS roads with AADT > 1000 are chip sealed, and 95 percent of the non NHS roads with AADT < 1000 are chip sealed.

Table B4. Agency chip seal performance life definition.

Agency	Definition of Chip Seal Performance
Alabama	Time since last chip seal.
Alaska	Time until pavement condition returns to the level immediately prior to chip seal.
Alberta	Time until pavement reaches a specified condition threshold.
British Columbia	Time until pavement condition returns to the level immediately prior to chip seal. Time until pavement reaches a specified condition threshold.
California	Time until pavement reaches a specified condition threshold.
Colorado	Time until pavement reaches a specified condition threshold.
Connecticut	Time until pavement reaches a specified condition threshold.
Georgia	Time until pavement reaches a specified condition threshold.
Indiana	Time until pavement reaches a specified condition threshold.
Iowa	Time since last chip seal.
Kansas	Time until pavement condition returns to the level immediately prior to chip seal.

Table B4. Agency chip seal performance life definition (continued).

Agency	Definition of Chip Seal Performance
Manitoba	Time until pavement reaches a specified condition threshold.
Michigan	Time until pavement condition returns to the level immediately prior to chip seal.
Mississippi	Time since last chip seal.
Montana	Time since last chip seal.
Nebraska	Time until pavement condition returns to the level immediately prior to chip seal.
Nevada	Time until pavement reaches a specified condition threshold.
New Brunswick	Time since last chip seal.
New Hampshire	Time since last chip seal.
North Carolina	Time until pavement reaches a specified condition threshold. Time since last chip seal.
North Dakota	Time since last chip seal.
Ohio	Time until pavement reaches a specified condition threshold.
Ontario	Time since last chip seal.
Oregon	Time since last chip seal.
Pennsylvania	Time since last chip seal.
Quebec	Time until pavement reaches a specified condition threshold.
Rhode Island	Time until pavement reaches a specified condition threshold.
Tennessee	Time until pavement condition returns to the level immediately prior to chip seal.
Utah	Time until pavement condition returns to the level immediately prior to chip seal. Time since last chip seal.
Virginia	Time until pavement reaches a specified condition threshold.
West Virginia	Time until pavement reaches a specified condition threshold.
Washington	Time since last chip seal.

Table B5. Typical performance life of chip seal over aggregate base.

Agency	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
Alaska	7	5	7	5	7	5	3
Alberta	—	—	—	—	—	—	10
British Columbia	—	3	3	5	5	5	5
Connecticut	—	—	7	—	7	—	—
Georgia	—	—	—	—	—	—	20
Kansas	—	—	—	—	3	—	3
Manitoba	10	10	10	10	10	10	10
Montana	6	6	7	8	10	7	12
North Carolina	—	—	9	—	10	—	12
North Dakota	—	7	7	7	7	7	7
Ontario	—	4	4	4	4	4	4
Oregon	—	—	—	—	8	—	—
Quebec	8	8	8	8	8	8	8
South Carolina	—	—	—	—	6	6	6
Washington	5	7	7	8	8	7	7
West Virginia	—	—	—	—	3		3
Count	5	8	10	8	14	9	14
Average	7.2	6.3	6.9	6.9	6.9	6.6	7.9
Std. Deviation	1.9	2.3	2.1	2.0	2.4	1.8	4.7

Table B6. Typical performance life of chip seal of existing chip seal.

Agency	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
British Columbia	—	5	5	5	5	5	5
Colorado	6	6	6	6	6	6	
Georgia	—	—	—	—	—	—	12
Indiana	6	6	6	6	6	6	6
Iowa	—	—	—	—	5	—	5
Kansas	—	—	4	4	4	4	4
Manitoba	10	10	10	10	10	10	10
Michigan	—	—	5	—	5	—	5
Mississippi	—	—	6	—	6	—	—
Montana	6	6	7	8	10	7	12
Nebraska	—	—	5	6	6	7	7
Nevada	—	—	7	—	—	—	7
New Brunswick	—	—	—	—	7	—	10
North Carolina	—	—	11	—	10	—	15
North Dakota	—	7	7	7	7	7	7
Ohio[1]	—	—	7	—	7	—	7
Ontario	—	4	4	4	4	4	4
Oregon	—	—	6	—	8	—	—
Pennsylvania	—	—	—	—	5	—	5
Rhode Island	—	—	8	—	8	—	8
South Carolina	—	—	—	—	6	6	6
Virginia	—	5	7	6	7	6	7
Washington	5	7	7	8	8	7	7
West Virginia	—	—	—	—	5	—	5
Count	6	10	18	12	22	13	22
Average	6.3	6.1	6.6	6.3	6.6	6.2	7.3
Std. Deviation	1.9	1.7	1.8	1.8	1.8	1.6	2.9

[1] Two-lane roadways only.

Table B7. Typical performance life of chip seal of existing asphalt pavement.

Agency	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
Alberta	—	—	15	—	17	—	17
British Columbia	—	5	5	7	7	7	7
Colorado	10	10	10	10	10	10	10
Connecticut	—	—	7	—	7	—	—
Indiana	7	7	7	7	7	7	7
Iowa	—	—	—	—	5	—	5
Kansas	—	6	6	6	6	6	6
Manitoba	10	10	10	10	10	10	10
Michigan	—	—	5	—	5	—	5
Minnesota	6	6	6	6	6	6	6
Mississippi	—	—	6	—	6	—	—
Nebraska	—	—	5	6	6	7	7
Nevada	—	—	7	—	—	—	7
New Hampshire	—	8	8	8	10	10	10
North Dakota	—	7	7	7	7	7	7
Ohio[1]	—	—	7	—	7	—	7

Table B7. Typical performance life of chip seal of existing asphalt pavement (continued).

Agency	Interstate	Arterial (Urban)	Arterial (Rural)	Collector (Urban)	Collector (Rural)	Local (Urban)	Local (Rural)
Ontario	—	5	5	5	5	5	5
Oregon	—	—	6	—	8	—	—
Pennsylvania	—	—	—	—	5	—	5
Rhode Island	—	—	8	—	8	—	8
South Carolina	—	—	—	—	6	6	6
Tennessee	—	—	10	10	6	—	6
Virginia	—	6	8	7	8	7	8
Washington	5	7	7	8	8	7	7
West Virginia	—	—	—	—	7	—	7
Count	7	11	21	13	24	13	22
Average	6.9	6.8	7.4	7.2	7.4	7.2	7.4
Std. Deviation	2.3	1.8	2.4	1.8	2.6	1.8	2.7

[1] Rural two-lane roadways only.

Table B8. Maximum AADT (two-way) for which a chip seal can be applied.

Agency	Maximum AADT (two-way)
Alabama	< 500 (new); < 5,000
Alaska	< 1,000
Alberta	< 20,000
British Columbia	< 5,000
California	< 30,000
Colorado	< 10,000
Connecticut	< 5,000
Georgia	< 4,000 & < 200 trucks/day
Indiana	< 10,000
Iowa	< 1,500
Kansas	No limit
Manitoba	No limit
Michigan	< 5,000
Minnesota	< 20,000
Mississippi	< 2,000
Montana	No limit
Nebraska	< 2,000
Nevada	< 10,000

Agency	Maximum AADT (two-way)
New Brunswick	No limit
New Hampshire	< 10,000
New Mexico	Non-interstate only
North Carolina	< 10,000[1]
North Dakota	< 10,000
Ohio	< 2,500 & < 250 trucks
Ontario	< 750
Oregon	< 5,000
Pennsylvania	< 20,000 (typically < 1,500)
Quebec	< 1,000
Rhode Island	Based on functional class
South Carolina	< 5,000
Tennessee	< 750
Utah	< 10,000
Virginia	< 2,000
Washington	< 10,000
West Virginia	< 1,000

Table B9. Additional decision factors for chip seal application.

Agency	Condition	Climate	Steep Grades	Turning Motion	Functional Class	Speed
Alabama	✓					
Alaska	Rut depth	Non coastal				
Alberta	Condition index, friction or icing issues			Avoid intersections	No urban areas	
British Columbia	Rut depth	✓	✓	Avoid switchbacks & busy intersections	Avoid freeways	
California	Base failure, severe distress		No steep grades	Avoid sharp curves		
Colorado	Rut depth			✓		
Connecticut	Base failure, rutting, non-wheelpath cracking				No curb & sidewalk, mainly rural roads	
Georgia	Rut depth, base failure			Avoid industrial areas & intersections	No interstate or urban roads	< 55 mph
Indiana	Base failure, surface distress				No towns with curb & gutter	
Kansas	Sound structure, IRI				No interstate	
Manitoba	Rut depth, IRI	✓				
Michigan	Condition Indices				No freeways	
Mississippi	Rut depth, fatigue cracking, IRI	✓			No urban areas	< 55 mph
Nevada	✓		✓			
New Brunswick	Visual inspection			Improve friction		
New Hampshire	Rut depth		Stopping on steep grades	Avoid heavy turning movements & signalized intersections	No interstate or divided highways	
New Mexico	✓		✓		No high volume urban areas	No high speed roadways
North Carolina	✓				No interstate or major US routes	
North Dakota	✓				No interstate, interregional routes	
Ohio	Bleeding, rutting, fair to good condition				Only two lane rural roads	
Ontario					Only collectors or arterials	
Oregon	Low severity cracking	Non Coast	No steep grades > 2000 AADT	Avoid unless AADT < 2,000	No urban areas	
Pennsylvania			Stopping on steep grades	Avoid truck traffic		

Table B9. Additional decision factors for chip seal application (continued).

Agency	Condition	Climate	Steep Grades	Turning Motion	Functional Class	Speed
Quebec			No extremely steep grades			
Rhode Island	✓				Minor materials & below	
South Carolina	✓					
Tennessee	Stable asphalt, address oxidation					
Utah	Fair to good condition					
Virginia	✓				Only primary & secondary roads	
Washington	Highly distressed		✓	Intersections and turn areas	No urban interstate and city streets	
West Virginia	Condition Index	✓	No extremely steep grades	✓	Non-urban collector & lower routes	

Table B10. Additional decision factors for chip seal application—additional comments.

Agency	Additional Comments
Alberta	Performance life is defined as time between the chip seal and next rehabilitation. We consider a chip seal to last "indefinitely".
California	Depends on the funding level.
Montana	Treatment plans allow for 6-7 years for chip seals. Budget, traffic and studded tires determine if chip seals occur at this frequency or longer.
New Brunswick	7 to 8 years.
New Mexico	The time the life of the pavement is extended.
North Carolina	Some divisions use a timed approach, others use condition.
Ontario	Usually reapply surface treatment every 4 to 8 years. If single surface treatment, every 4 years; if double surface treatment every 6 years.
South Carolina	Research project currently underway to define performance life cycle on all preservation treatments.
Tennessee	Not specified. We expect 6 years (untopped) or 10 years (topped).
Utah	It really isn't tracked.

Table B11. Chip seal design methods.

Agency	No formal method	Asphalt Institute MS-19	McLeod Method	Agency developed method	Based on past performance	Comments
Alabama	✓					
Alaska	✓			✓		
Alberta	✓					Contractor design
British Columbia			✓	✓		
California	✓					
Connecticut					✓	
Georgia	✓					
Indiana			✓	✓		Based on McLeod
Iowa	✓					
Kansas				✓		
Manitoba			✓			
Michigan	✓		✓			
Minnesota						Modified McLeod
Mississippi	✓					
Montana	✓					
Nebraska				✓	✓	
Nevada	✓					
New Brunswick					✓	
New Hampshire	✓					
New Mexico	✓					
North Carolina				✓		
North Dakota	✓					Professional experience
Ohio	✓					
Ontario			✓			Modified McLeod, UK Road Note 39, and French Alogen methods
Oregon	✓				✓	
Pennsylvania				✓		
Quebec	✓					
Tennessee	✓					
Utah	✓					
Virginia		✓				
West Virginia				✓		
Washington	✓					
Total	19	1	5	8	4	

Table B12. Chip seal binder types.

Agency	AC				CRS					HFRS	HFRS-2P
	5	10	15P	20	1H	1P	2	2H	2P		
Alabama							✓	✓	✓		
Alaska							✓		✓		✓
Alberta							✓		✓		
California			✓								
Colorado							✓		✓	✓	✓
Georgia		✓						✓			
Iowa									✓		
Kansas					✓						
Minnesota									✓		
Mississippi									✓		
Montana									✓		
Nebraska									✓		
Nevada						✓			✓		
New Hampshire									✓		
New Mexico	✓			✓							
North Carolina							✓				
North Dakota									✓		✓
Ohio									✓		
Ontario									✓		
Oregon			✓						✓		✓
Pennsylvania									✓		
Quebec							✓		✓	✓	
South Carolina									✓		
Tennessee									✓		
Utah									✓		
Virginia							✓				
Washington									✓		
Total	1	1	2	1	1	1	7	2	21	2	4

Table B13. Chip seal binder types—additional comments.

Agency	Additional Comments
Alabama	PG 58-22, PG 64-22, RC 250, RC 800, MC 800, CRS 2HP, and CRS-2l.
Alberta	HF-150S or -250S for graded seals (used for AADT <1000).
British Columbia	HF-150P + Antistrip.
California	PG grades asphalt, modified binder, polymer modified asphaltic emulsion.
Connecticut	PG58-28 with 10% crumb rubber added (wet process).
Georgia	CRS-2L
Indiana	INDOT spec AE 90 S, which is similar to HFRS 2P.
Manitoba	HF-150 polymer or unmodified c/w anti-strip agent.
Michigan	CSEA and CRS-2M.
Nevada	PG70-22TR
New Brunswick	HFMS-2, HP200/HP200(P), HF100S/HF100S(P), HF150S/HF150S(P), HF250S/HF250S(P), and MS-2.
New Hampshire	Neat PG 58-28 modified with 18% crumb rubber.
Utah	LMCRS-2.
West Virginia	RS2

Table B14. Typical aggregate gradation.

Agency	Uniformly Graded			Well-Graded		
	5/8 in	1/2 in	3/8 in	5/8 in	1/2 in	3/8 in
Alaska		✓			✓	
Alberta			✓		✓	✓
British Columbia				✓		
California		✓	✓			
Georgia		✓				
Indiana			✓			
Nevada		✓				
New Hampshire		✓	✓			
New Mexico		✓	✓			
North Dakota						✓
Quebec	✓	✓	✓	✓	✓	
Virginia			✓			
Washington		✓	✓		✓	
Total	1	8	8	2	3	2

Table B15. Chip seal binder types—additional comments.

Agency	Additional Comments
Alberta	Chip seal is 10 mm uniformly graded; graded aggregate seal is 10 mm well graded; double seal is 12.5 mm well (double seal is for use on aggregate base on low volume roads).
California	Our specs also include 5/16-in and 1/4-in aggregate.
Manitoba	100 percent passing 1/2 in sieve and well-graded.
Michigan	Base Course: 3/8 in – 90-100, #4 – 0-10, #8 – 0-5, #200 – 2 percent maximum; Top Course: 1/4 in – 85-100, #8 – 0-10, #200 – 2 percent maximum.
Minnesota	3/8 in minus, prefer a single size.
Mississippi	3/8 in and 5/8 in, unsure about grading.
Montana	≤ 10,000 AADT – 3/8 in minus; > 10,000 AADT – 1/2 in minus.
New Brunswick	9.5mm, 12.5mm, 10.0mm, 19.0mm uniformly graded.
New Hampshire	1/2 in used as bottom coarse for double chip seal, and 3/8" is used for single chip seals, asphalt rubber chip seals, and top coarse for double chip seals.
New Mexico	Aggregates are generally crushed rock passing the ⅜ inch sieve. The material should also contain very little material passing the number 10 sieve. To limit dust and to ensure proper coating of the aggregate, the amount of fines (material passing the No. 200 sieve) should be limited to 1 to 2 percent. Dirty aggregates containing should be thoroughly washed prior to stockpiling to remove minus number 40 sieve materials.
Ontario	Chip Seals: Uniformly graded; bottom chip 6 to 10mm (or Class 1 aggregates as per OPSS.PROV 1006), top chip 2 to 5mm; Surface Treatment: Graded aggregates; most common Class2 aggregates (graded material with 100% passing 16.0mm sieve), also some Class6 aggregates (100% passing 13.2mm sieve) (Reference OPSS.PROV 1006).
Pennsylvania	AASHTO #8, 1.0 percent wash test.

Table B16. Number of chip seal courses by functional class—new construction.

Agency	Interstate	Arterial (urban)	Arterial (rural)	Collector (urban)	Collector (rural)	Local (urban)	Local (rural)
British Columbia	—	D	D	D	D	D	D
Colorado	S	S	S	S	S	S	S
Georgia	—	—	—	—	—	—	D
Indiana	S	S	S	S	S	S	—
Kansas	—	—	—	—	D	—	D
Manitoba	D	D	D	D	D	D	D
Montana	S	S	S	S	S	S	S
Nebraska	—	—	S	S	S	S	S
Nevada	—	—	S	—	—	—	S
North Dakota	S	S	S	S	S	S	S
Ontario	—	D	D	D	D	D	D
Quebec	D	D	D	D	D	D	D
South Carolina	—	—	—	—	S	S	—
Virginia	S	S	S	S	S	S	S
West Virginia	—	—	—	—	T	—	T
Washington	—	D	D	D	D	D	D
Single	5	5	7	6	7	7	6
Double	2	5	5	5	6	5	8
Triple	0	0	0	0	1	0	1

S = single chip seal; D = double chip seal; T = triple chip seal.

Table B17. Number of chip seal courses by functional class—preservation.

Agency	Interstate	Arterial (urban)	Arterial (rural)	Collector (urban)	Collector (rural)	Local (urban)	Local (rural)
Alberta	S	—	S	—	S	—	S
British Columbia	—	S	S	S	S	S	S
California	S	S	S	S	S	S	S
Colorado	S	S	S	S	S	S	S
Connecticut	—	—	S	—	D	—	S
Georgia	—	—	—	—	—	—	S
Indiana	S	S	S	S	S	S	S
Iowa	—	—	—	—	S	—	S
Kansas	—	—	S	S	S	S	S
Manitoba	S	S	S	S	S	S	S
Michigan	D	D	D	D	D	D	D
Minnesota	S	S	S	S	S	S	S
Mississippi	—	—	S	—	S	—	—
Montana	S	S	S	S	S	S	S
Nebraska	—	—	S	S	S	S	S
Nevada	—	—	S	—	—	—	S
New Brunswick	—	—	—	—	D	—	S
New Hampshire	—	S	S	S	D	D	D
North Carolina	—	—	D	—	D	—	S

S = single chip seal; D = double chip seal.

Table B17. Number of chip seal courses by functional class—preservation (continued).

Agency	Interstate	Arterial (urban)	Arterial (rural)	Collector (urban)	Collector (rural)	Local (urban)	Local (rural)
North Dakota	S	S	S	S	S	S	S
Ohio	—	—	S	—	S	—	—
Ontario	—	S	S	S	S	S	S
Oregon	—	—	S	—	S	—	—
Pennsylvania	—	—	—	—	S	—	S
Quebec	D	D	D	D	D	D	D
Rhode Island	—	—	S	—	S	—	S
South Carolina	—	—	—	—	S	S	S
Tennessee	—	—	—	—	S	—	S
Utah	S	S	S	S	S	S	S
Virginia	S	S	S	S	S	S	S
West Virginia	—	—	D	—	D	—	D
Washington	S	S	S	S	S	S	S
Single	11	13	22	15	23	15	25
Double	2	2	4	2	7	3	4

S = single chip seal; D = double chip seal.

Table B18. Number of chip seal courses by functional class —additional comments.

Agency	Additional Comments
Alabama	Typical new construction where the chip seal is the final wearing layer is a double chip seal. Preservation is typically a single chip seal, but recently has seen the use of cape seals and triple seals.
Alaska	Depends on region, most use single chip seal applications.
Alberta	Double chip seals are only used directly over aggregate base; otherwise all are single chip seals.
New Mexico	We nearly always use a single chip seals.
North Carolina	We do single and double chip seals. Selection is made by local divisions.
Tennessee	Used only on low volume roads unless with overlay, single chip seal applied.
West Virginia	Triple chip seals for new construction.
Washington	A choke and fog seal is typically applied.

Table B19. Methods for characterizing existing pavement condition.

Agency	Manual or windshield	Semi-automated	Fully automated	Friction testing	Rut depth	Roughness
Alabama	✓	✓		✓	✓	✓
Alaska	✓		✓			
Alberta	✓					
British Columbia	✓				✓	✓
California	✓					
Colorado		✓			✓	✓
Connecticut	✓		✓		✓	
Indiana	✓		✓	✓		✓
Iowa			✓	✓	✓	✓
Kansas			✓		✓	✓
Manitoba	✓					
Michigan	✓	✓			✓	✓
Minnesota	✓		✓		✓	✓
Mississippi	✓		✓		✓	✓
Montana	✓		✓	✓	✓	✓
Nebraska	✓	✓				
Nevada	✓					
New Brunswick	✓					
New Hampshire	✓	✓			✓	
New Mexico			✓			
North Carolina	✓			✓		✓
North Dakota			✓			
Ohio	✓					
Ontario	✓		✓		✓	✓
Oregon	✓	✓		✓	✓	✓
Pennsylvania			✓			
Quebec	✓			✓	✓	✓
Rhode Island	✓		✓			
South Carolina	✓	✓				
Tennessee		✓				
Utah			✓	✓	✓	✓
Virginia			✓			
West Virginia	✓		✓		✓	✓
Washington		✓				
Total	24	9	16	8	16	16

Table B20. Pavement condition rating methodology.

Agency	Agency Developed	LTPP Distress Identification Manual	Other
Alabama	✓		
Alaska	✓		
Alberta	✓		
British Columbia	✓		
California	✓		
Colorado	✓	✓	
Connecticut	✓	✓	
Georgia	✓		
Indiana	✓		
Iowa		✓	
Kansas			AASHTO
Manitoba	✓		
Michigan	✓		
Minnesota	✓		
Mississippi		✓	
Montana	✓		
Nebraska	✓	✓	
Nevada	✓		
New Brunswick	✓		
New Hampshire	✓		
New Mexico	✓		
North Carolina	✓		
North Dakota	✓		
Ohio	✓		
Ontario	✓		
Oregon	✓	✓	Based heavily on LTPP
Pennsylvania	✓		
Quebec	✓		
Rhode Island		✓	
South Carolina			Pavement Quality Index
Tennessee			Crack width (high severity > 1/2 in)
Utah	✓	✓	
Virginia	✓		
West Virginia	✓	✓	
Washington	✓		
Total	29	9	

Table B21. Pretreatment applications.

Agency	Crack Seal	Prelevel	Patch	Other
Alabama		✓	✓	Milling
Alaska	✓		✓	
Alberta	✓		✓	Spray patching; localized rut fill
British Columbia	✓	✓	✓	Geotextile for retarding reflective cracks
California	✓		✓	Localized digouts and repair.
Colorado	✓		✓	
Connecticut	✓	✓	✓	
Georgia	✓	✓	✓	
Indiana	✓		✓	
Iowa		✓	✓	
Manitoba	✓		✓	
Michigan	✓			Micro rut filling if necessary
Minnesota	✓		✓	
Mississippi	✓	✓	✓	
Montana	✓			
Nebraska	✓		✓	
Nevada	✓		✓	
New Brunswick		✓	✓	Pulverize existing surface, adding granular material, ditching (as required)
New Hampshire	✓	✓	✓	Scarify pavement markings
New Mexico	✓		✓	Sweeping
North Carolina	✓		✓	Crack seal & patch 1 to 2 years before chip seal
North Dakota			✓	Sweeping/cleaning
Ohio			✓	
Oregon	✓		✓	
Pennsylvania		✓	✓	
Quebec		✓		
Rhode Island	✓			
South Carolina	✓	✓	✓	
Tennessee				Usually none but may do crack sealing or patching.
Utah	✓	✓	✓	
Virginia				Case by case basis
West Virginia	✓	✓	✓	
Washington	✓	✓	✓	
Total	24	14	27	

Table B22. Pretreatment applications—additional comments.

Agency	Additional Comments
California	Typically follow with a flush coat which includes a fog seal and sand cover.
George	We use a final course of sand seal typically.
Indiana	Typically fog seal all chip seals.
Iowa	Fog seal.
Michigan	Fog seal is not "required" but it is encouraged.
Minnesota	All our fog sealed.
Nevada	Fog seal.
New Brunswick	Fog seal on dry surfaces where heavy traffic is expected; Microsurfacing to improve ride quality where heavy traffic is expected.
Ohio	It's not required, but we often fog seal our chip seals, sometimes a couple weeks later, sometimes a year or two later.
Oregon	Fog seal on occasion, but not always.
Rhode Island	Sometimes we use a paver-placed elastomeric surface treatment to create a stress absorbing membrane interlayer.
Tennessee	Usually the chip seal will be topped with a fog seal, Microsurface, or thin-lift asphalt.
Utah	Flush coat.
West Virginia	Not required for all applications but we are trying fog seals and have done 1 Microsurfacing.
Washington	Typically place a choke stone and fog seal.

Table B23. Methods for identifying when a chip seal treatment should be applied.

Agency	Observed pavement condition	Predetermined cycle	Performance prediction model
Alabama	✓		
Alaska	✓		
Alberta	✓		
British Columbia	✓	✓	
California	✓		
Colorado	✓		✓
Connecticut	✓		✓
Georgia	✓		
Indiana	✓	✓	
Iowa	✓		
Kansas	✓		✓
Manitoba	✓		
Michigan	✓		
Minnesota	✓	✓	
Mississippi	✓	✓	
Montana	✓	✓	
Nebraska		✓	
Nevada	✓		
New Brunswick	✓		✓
New Hampshire	✓	✓	
New Mexico	✓	✓	
North Carolina	✓	✓	
North Dakota		✓	

Table B23. Methods for identifying when a chip seal treatment should be applied (continued).

Agency	Observed pavement condition	Predetermined cycle	Performance prediction model
Ohio	✓		
Ontario		✓	
Oregon	✓	✓	
Pennsylvania	✓	✓	
Quebec	✓		
Rhode Island	✓		
Tennessee	✓		
Utah	✓		
Virginia	✓		
West Virginia	✓		✓
Washington	✓		
Total	31	13	5

Table B24. Additional decision factors for chip seal application—additional comments.

Agency	Additional Comments
Alberta	Will also depend on pavement age. A pavement may score high enough to warrant a chip seal but if it's older than 12 years a case needs to be made and if other indicators such as ride or strength show that rehabilitation will be required in the near future it will not get a seal coat.
North Carolina	Some divisions use timed cycle, most use annual condition survey.
Ohio	The following criteria defines when we should choose a chip seal: traffic < 2500, trucks <250, and rural two lane roadways. However, many of our Districts oppose using chip seals.
Oregon	While time is used for planning, funds are limited enough that we have to defer some projects, so we use condition to prioritize.
South Carolina	Research project underway to develop tool to assist with determining "right treatment on the right road at the right time"

Table B25. Distress type(s) and trigger value(s) for determining chip seal treatment timing.

Agency	Longitudinal Cracking	Alligator Cracking	Transverse Cracking	Block Cracking	Raveling/ Weathering	Bleeding	Rut Depth	Roughness	Friction	Combined Condition Index
Alberta	✓				✓					35 [1,2]
British Columbia	< 0.40 in	Minimal	< 0.40 in		Minimal		< 0.40 in	✓		
California		< 10 percent[3]					< 0.50 in			
Colorado	✓	✓	✓				✓	✓		
Connecticut	> 5.5[4]		5.0 – 6.8[5]				< 0.50 in			✓
Georgia	✓	✓	✓		✓		✓			
Indiana							< 0.25 in	< 130 in/mi	< 25	
Kansas		✓								
Manitoba	✓		✓							
Michigan[6]							< 0.13 in	< 107 in/mi		
Mississippi	[7]	None	[7]				< 0.25 in	< 240 in/mi		
Nevada[8,9]		> 0.20 in, ≥ 400 ft^2; ≤ 0.20 in, ≤ 650 ft^2	> 0.25 in, ≥ 40 ft^2; ≤ 0.25 in, ≤ 50 ft^2	> 0.25 in, ≥ 200 ft^2; ≤ 0.25 in, ≤ 300 ft^2			≥ 0.15 in; < 0.15 in	≥ 160 in/mi; < 160 in/mi		
New Hampshire							< 0.50 in			
New Mexico	< 0.25 in	Low severity	< 0.25 in		no loose aggregate	None	< 0.38 in	✓	✓	
North Carolina					✓	Spot repair	< 0.50 in		< 37	65 – 85[2]
Ohio						None	< 0.25 in			66 – 80[2]
Oregon	Low severity	Low severity	✓		aggregate lose & snow plow damage					
Pennsylvania	✓	✓	✓		✓	✓	✓	✓	✓	
Quebec	< 25 percent	< 20 percent					< 0.60 in	> 250 in/mi		
Rhode Island[2]	50 – 70 if ride score ≥ 65	> 70 if ride score ≥ 65	> 70 If ride score ≥ 65, then 70 – 90	50 - 75				≥ 65		70 – 85
Tennessee										< 3.5[10]
Utah[2,11]		≥ 50 (level 2)[12,13] ≥ 75 (all others)[12]	≥ 70 (all others)[14]				≥ 50 (level 2)[13] ≥ 70 (all others)	≥ 30 (level 2)[13] ≥ 70 (all others)		
West Virginia[14]	4	4	3.5		✓	✓		3.5		✓

[1] Score also based on age, AADT, surface texture, and foreign material (AT 2000).
[2] Scale 0 (poor) to 100 (excellent). Utah DOT - 50 is considered to be unacceptable condition.
[3] Multiple interconnected cracks in the wheel path.
[4] 1-9 (no cracking) scale; value corresponds to 1,700 ft/mi of wheelpath cracking.
[5] 1-9 scale; value corresponds to a full-width crack spacing of 16 to 50 ft.
[6] Remaining Service Life > 5 yrs (double) > 6 yrs (single); Distress Index < 30 (double); < 25 (single); (MIDOT 2014).
[7] < 15 percent total cracking.
[8] For State routes, top value for segments with PSI ≤ 2.5; bottom value for segments with 2.5 < PSI ≤ 4.0 (Hajj, Loria, and Sebaaly 2009).
[9] For US & Interstate routes, top value for segments with PSI ≤ 2.8; bottom value for segments with 2.8 < PSI ≤ 4.0 (Hajj, Loria, and Sebaaly 2009).
[10] Scale 0 to 5 (excellent).
[11] At least 6 years since last treatment.
[12] Wheel path cracking index.
[13] Level 2 roadways - AADT < 1,000.
[14] Environmental cracking index that includes transverse, longitudinal, and block cracking.