Performance Evaluation of Asphalt Pavement Preservation Activities

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A 2-year research project was sponsored by the Nevada Department of Transportation (NDOT) and conducted by University of Nevada at Reno researchers to evaluate the long-term performance of asphalt pavement preservation activities that NDOT has implemented for the past 15 years. During this research project, 11 preservation activities were identified after several meetings with NDOT maintenance personnel. This study evaluated 847 field sections. The performance of the selected field sections was assessed on the basis of the pavement condition before and after treatment application. The analysis evaluated the likelihood of enhancing the pavement performance as well as the anticipated performance period for the various treatments. Benefit–cost ratios for the various treatments were also evaluated, given the pretreatment pavement condition, traffic level, and environmental conditions. A set of guidelines is provided to help select the most cost-effective preservation activities on the basis of the most favorable conditions with regard to environment, traffic, and conditions of the existing pavement (e.g., present serviceability index, international roughness index, rut depth, fatigue cracking, transverse cracking, and block cracking).

Maintenance of highway facilities is a critical step in the overall process of providing a safe and comfortable ride for the road users. The fundamental purpose of maintenance is to slow down the deterioration process to avoid significant failures. Typically, the cost of maintenance is 15% to 20% of the expected cost to repair the ultimate failure that will occur without the application of maintenance activities. For example, national data indicate that every $1 spent on maintaining the pavement surface saves $5 on major rehabilitation that would be required if the maintenance activities were not conducted. This concept holds true for all highway maintenance activities.

One difficult part of implementing a maintenance program is the estimation of the long-term performance of the various maintenance techniques. Attempts have been made over the past 30 years to develop generic models that can accurately predict the long-term performance of pavement maintenance activities. In most cases, performance has been predicted by theoretical modeling that did not use actual in-service pavement performance data. In the cases where modeling was performed on in-service data, models were generally developed as a function of pavement age alone to keep them simple, which drastically limited their application. Such simple models typically ignore the impact of important factors, such as the conditions of the existing pavement, traffic, materials properties, and environmental conditions.

It is well known that the main objective of a pavement maintenance activity is to maintain the current condition of the pavement or slow down the rate of deterioration. In this respect, it should be also recognized that maintenance activities are not intended to add to the structural capacity, but rather their long-term durability comes mainly from the conditions of the pavement that has received treatment. Hence, the notion that a generic model can be developed to predict the long-term performance of maintenance activities on a national scale is highly unrealistic. Consequently, realistic models predicting long-term performance of maintenance activities should be based on their performances under localized conditions.

Highway agencies should learn from the experience of their neighboring states in regard to what works and what does not work for certain type of pavements. Still, highway agencies should not assume validity of the performance of maintenance activities on their system when based solely on the performance from other states. This is because each state has unique materials, traffic volumes and composition, and environmental conditions that are not uniform even throughout its own roadway system.

OBJECTIVE

The overall objective of this study was to develop an effective pavement preservation program for Nevada's flexible pavements. The developed program is supposed to help the Nevada Department of Transportation (NDOT) to select the most effective preservation activity for a given roadway section. This objective was achieved by evaluating the long-term performance and cost-effectiveness of the various asphalt pavement preservation activities that NDOT has implemented for the past 15 years.

BACKGROUND

There are differences in the interpretation of pavement preservation terminology among local and state transportation agencies, causing inconsistencies and confusion within pavement preservation programs and how their effectiveness is being measured. From those problems and a review of literature, the Office of Asset Management at the U.S. Department of Transportation, FHWA, issued in 2005 guidance to clarify pavement preservation terminology (*1*).

Pavement preservation represents a proactive approach in maintaining existing highways. The FHWA guide listed three primary components of the pavement preservation program: minor rehabilitation (nonstructural), preventive maintenance, and some routine maintenance activities. For a treatment to be considered pavement

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preservation, it has to restore the functionality of the existing system, extend its service life, and yet not increase its structural capacity (*1*).

In 2004, Peshkin et al. developed a methodology for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements (*2*). The applicability of the methodology was tested using data from actual pavement projects. A plan for obtaining the data needed to support the proposed methodology was also developed to guide agencies into developing a preventive maintenance management system. The research provided information on the expected life of various maintenance techniques, such as crack filling and sealing (2 to 6 years); fog seals (1 to 2 years); slurry seals (3 to 5 years); scrub seals (1 to 3 years); microsurfacing (4 to 7 years); chip seals (4 to 7 years); and thin hot-mix asphalt (HMA) overlays (7 to 10 years).

In 2005, Galehouse et al. assessed the life extensions of pavements in Michigan as a result of the implementation of an integrated cost-effective system (*3*). An average of 7.5 years life extension was found for the thin HMA overlays, 5 years for slurry seals, 2 years for crack seals, and 4.5 years for chip seals.

In 2006, Labi et al. developed a methodology for comparing the long-term cost-effectiveness of microsurfacing and thin HMA by using three measures of effectiveness (*4*). Those measures were treatment service life, increase in average pavement condition, and area bounded by the performance curve. The international roughness index (IRI) was used as a performance indicator. Using pavement management data from Indiana, the researchers found that irrespective of the measure of treatment effectiveness considered and under all climatic and traffic loading conditions, microsurfacing is generally more cost-effective than thin HMA overlays (*4*).

Adams and Kang showed the essential characteristics of different pavement preservation programs along with the potential obstacles and barriers that highway agencies may face in establishing a pavement preservation program (*5*). The information was synthesized by reviewing programs at eight state transportation agencies. The study summarized the expected life of common pavement preservation techniques for some states as follows:

- Thin overlays. Michigan: 5 to 12 years; Ohio: 8 to 12 years.
- Microsurfacing. Michigan: 3 to 6 years; Ohio: 5 to 8 years.
- Crack sealing. California: 1 to 4 years; Michigan: up to 3 years; Ohio: 1 to 4 years.
- Chip seal. California: 3 to 6 years; Michigan: 3 to 7 years; Ohio: 5 to 8 years.
- Seal coat. Minnesota: 5 to 7 years.

The researchers concluded that development of a pavement preservation program requires the understanding of the concept of life extension.

IDENTIFICATION OF PAVEMENT PRESERVATION ACTIVITIES

The following preservation activities were identified after several meetings with the NDOT maintenance personnel, and they are defined and characterized in details in Working Paper 1, "Pavement Preservation Activity Documentation," submitted to NDOT Research Division in September 2007 (*6*):

- Chip seal. Consists of a layer of asphalt binder that is overlaid by a layer of embedded aggregate. The evaluated chip seals were made using SS-1, SS-1h, CSS-1, CSS-1h, and latex modified (i.e., LMCRS-2 or LMCRS-2h) emulsions.
- Sand seal. Consists of a layer of asphalt binder that is overlaid by a layer of sand (minus #4). The evaluated sand seals were made using RS-1, CRS-1, MS-1, or HFMS-1 emulsions.
- Scrub seal. Application of a polymer-modified emulsion to the pavement surface, with a sweep or squeegee of the binder, followed by an application of a sand layer (minus #4 sized volcanic cinders). The evaluated scrub seals were made using poly(methylphenyl)silane emulsions.
- Fog seal. A light application of slow setting asphalt emulsion diluted with water to the pavement surface. The evaluated fog seals were made using SS-1, SS-1h, CSS-1, or CSS-1h emulsions.
- Crack filling. Cleaning of cracks in the pavement surface and filling them with rubberized asphalt, rejuvenating agent, emulsion, or liquid asphalt (cutback). The hot-applied CRAFCO PolyFlex crack filler sealants Type 1, Type 2, and Type 3 were used depending on the climatic zone.
- Maintenance overlay cold mix (MO-CM). Patching application that consists of laying down cold-mix asphalt from a small paver followed by compaction using a small roller compactor. The evaluated cold mixes were manufactured with a CMS-2S asphalt emulsion with an AC-10 base asphalt.
- Machine patching paver laid plantmix (MP-PLP). Patching application that consists of laying down hot-mix asphalt from a small paver followed by compaction using a small roller compactor. The evaluated dense graded HMA mixes (maximum aggregate size of 1″) were manufactured with polymer-modified asphalt binders (PG64-28 and PG76-22 for northern and southern Nevada, respectively).
- Machine patching blade laid cold mix (MP-BLC). Restore surface lost to raveling, settlement, or other causes in which the vertical difference in pavement exceeds 1″ in a 10 ft length in any direction. The patching application consists of laying down a cold-mixture that is blade laid and machine placed. Machine patching may be a maximum of 2″ in thickness. No more than 300 yd^3 or 550 tons of bituminous material may be used in any 10-mi section. The cold evaluated mixes were manufactured with a CMS-2S asphalt emulsion with an AC-10 base asphalt.
- Machine patching blade laid plantmix (MP-BLP). Patching application that consists of laying down the HMA directly from the truck and the compaction is performed by a motor-grader. The evaluated dense graded HMA mixes (maximum aggregate size of 1″) were manufactured with polymer-modified asphalt binders (PG64-28 and PG76-22 for northern and southern Nevada, respectively).

PERFORMANCE OF PAVEMENT PRESERVATION ACTIVITIES

This effort concentrated on the performance evaluation of the previously identified preservation activities. Generally, the performance of a preservation activity can be defined as the improvement or holding of the condition of the pavement surface that the activity provided over a specific period. The improvement and holding depends on several factors, which include construction technique, materials characteristics, traffic, and environmental conditions at the specific site. To capture all these aspects, the following steps were followed:

1. Review of NDOT maintenance records. The 1990 to 2005 maintenance database provided detailed records of the date of application and type of pavement preservation treatment used on each

road, along with actual cost figures for labor, equipment, and materials. The database included more than 17,000 preservation activities over 15 years at various locations throughout the state and under different traffic levels.

2. Treatments selection for performance evaluation. Under each of the previously identified preservation activities, a representative number of field sections were selected. The selection criteria included road classification [state route (SR); U.S. route (US); and Interstate route (IR)]; section location (Districts 1, 2, and 3); section length (i.e., greater than 1 mi); and at least 5 years of performance before the application of another maintenance or major rehabilitation treatment. A total of 847 sections were selected and evaluated. Of note is that the same road segment may have received different treatments at different periods.

3. Analysis of NDOT pavement management system (PMS) data. Performance of the preservation activities in regard to improving and extending or to holding and maintaining the condition of the pavement surface was assessed through analysis of the PMS data. NDOT's PMS collects distress data, including cracking, rutting, bleeding, raveling, and surface roughness on an annual or biannual basis on the majority of the state's pavement system. This step involved matching the exact location of the selected field sections (using recorded beginning and ending mileposts) with its corresponding performance data in the PMS database.

Performance-Related Data

Pavement performance data, collected over time, provides the basis for assessing the actual performance of a pavement technology. Pavement roughness, rutting, and cracking represent the major components of NDOT's pavement conditions survey program.

The present serviceability index (PSI) is used to assess the long-term performance of the various maintenance activities that have been used by NDOT. The PSI is correlated with various pavement measurements (i.e., roughness, rutting, cracking, and patching) and provides an indication of the overall pavement condition. Currently, NDOT uses the following PSI equation for flexible pavements:

$$\text{PSI} = 5 \times e^{(-0.0041 \times \text{IRI})} - 1.38 \times \text{RD}^2 - 0.03 \times \sqrt{C + P} \qquad (1)$$

where

IRI = international roughness index (in./mi),
RD = rut depth (in.),
C = cracking (ft^2/1,000 ft^2), and
P = patching (ft^2/1,000 ft^2).

If the calculated PSI is less than 0, then a PSI of 0.10 is reported.

The PSI values range from 5 for a pavement with a very good condition to a value of 0 at the extreme low end for a pavement with a very poor condition. The terminal (or failure) serviceability (PSI) is the minimum level of serviceability the agency allows in design. NDOT pavements on US and IR are designed for a minimum PSI (terminal serviceability) of 2.5, while a terminal serviceability of 2.0 is used for SR.

Analysis Approach

The performance of the preservation activities for improving or maintaining the condition of the pavement surface are assessed based on the pavement condition before and after treatment application. Table 1 shows the objective of the treatment application as well as its expected performance based on the pavement condition (i.e., PSI) before and after treatment application, respectively, for different traffic levels (i.e., road classification). For example, if a chip seal was applied on a state route with a PSI value of 2.3, then the treatment purpose is to hold the current condition of the pavement surface from further deterioration. If the treated pavement exhibited a PSI value of 2.8 after treatment application and decreased to a PSI value of 2.5 after 3 years of service, and afterward to a PSI value of 2.3 in the following 2 years of service, then in regard to performance, the treatment improved and extended the pavement condition for 3 years and held it for 2 more years, with a total overall minimum performance of 5 years. Furthermore, if the PSI of the section continued to drop and reached the terminal value for state routes (i.e., 2.0) after 1.5 years, then the maximum pavement performance life is reported as 6.5 years (5 years to previous pavement condition plus 1.5 years to terminal serviceability). In summary, the performance of the chip seal for that specific pavement would be characterized as improve and extend, with an expected performance life of 5.0 to 6.5 years.

TABLE 1 Treatment Objective and Performance Based on PSI Ranges and Road Classification

Road Classification	PSI at Application	Treatment Application Objective	Treatment Performance
State route (SR)	2.0–2.5	Hold	Hold–maintain
	2.5–3.0	Improve–extend	Improve–extend
	3.0–4.2	Prevent	
U.S. route (US) and Interstate (IR)	2.5–2.8	Hold	Hold–maintain
	2.8–3.5	Improve–extend	Improve–extend
	3.5–4.2	Prevent	

The overall objective of this analysis was to address the following three questions:

1. Did the treatment enhance pavement performance?

This analysis identified the number of preservation activities that met or exceeded the anticipated treatment objective.

2. What is the anticipated performance period for the various preservation activities?

This analysis evaluated the expected performance life of various preservation activities in light of the pretreatment pavement condition, traffic level, and environmental condition.

3. What is the benefit–cost ratio of the various preservation activities?

Preservation activities should be scheduled to maximize their cost-effectiveness. However, it is difficult for most users to establish the level of distress when a particular treatment should be applied. This analysis looked into the benefit–cost ratio of a treatment given the pretreatment pavement condition, traffic level, and environmental condition.

Project-Level Analysis

Each selected section was identified by the combination of the county acronym, road classification, and beginning and ending mileposts. For example, a section ID of CL-SR164-6.4-9.2 refers to a section in

Clark County, SR 164, between mileposts 6.4 and 9.2. An alphabetical letter is added at the end of a section ID if the same section was subjected to the same treatment more than once. A total of 847 sections were evaluated in this research effort.

Figure 1 shows an example of the plots developed for each section by matching the field sections with their corresponding performance from the PMS database. Of note is that the yearly PSI values presented in Figure 1 correspond to the average of all the PSI values measured within each section. NDOT conducts yearly pavement distress survey for a 100-ft sample at the beginning and the end of each section and at each milepost between such limits.

In this paper, the project-level analysis is fully described through an example for chip seal application on state routes in NDOT District 1. Table 2 shows the section ID, the last PSI for the existing pavement before treatment application, treatment objective, treatment performance, number of years to reach the pretreatment pavement condition, expected performance life, and benefit of each preservation activity.

The treatment objective is identified by comparing the pretreatment PSI of the pavement with the PSI ranges in Table 1. The highlighted examples in Table 2 show that a chip seal was applied on section CL-SR164-6.4-9.2 with a pretreatment PSI of 2.3 with the objective to hold the pavement condition, while a chip seal was applied on section LN-SR321-0-5.11 with a pretreatment PSI of 2.6 with the objective to improve or extend the pavement condition.

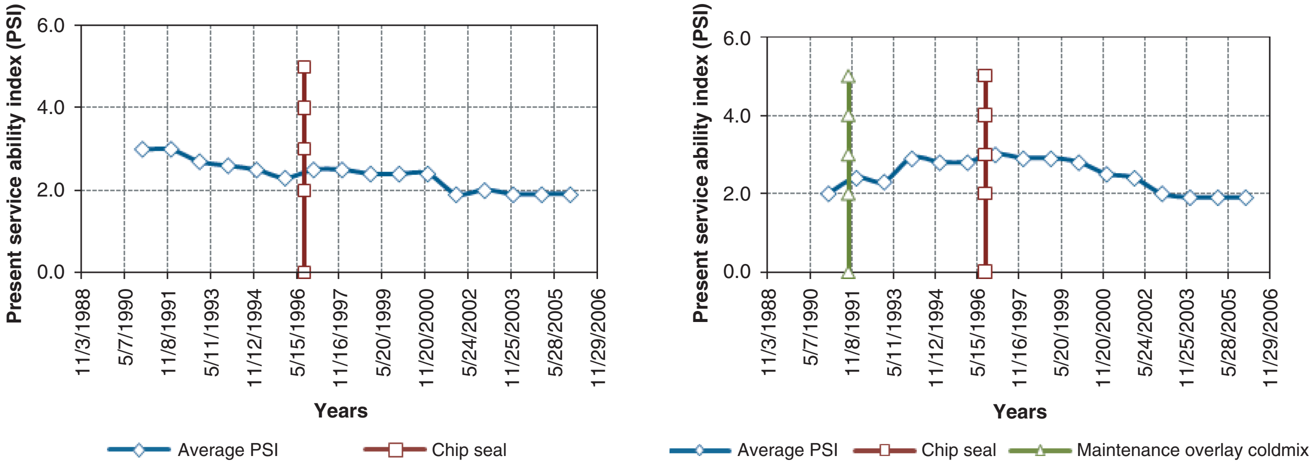
The treatment performance is evaluated according to the pavement PSI right after treatment application, number of years that the treatment improved or extended the pavement condition, number of years that the treatment held and maintained the existing pavement condition, and last PSI on record. The number of years that the pavement improved or extended or held or maintained the pretreatment pavement condition were identified by comparing the measured PSIs with the PSI ranges in Table 1. For example, the chip seal that was applied on section CL-SR164-6.4-9.2 held or maintained the pavement condition by exhibiting a PSI value of 2.5 right after treatment application and maintained the condition of the pavement for 3.9 years before it reached a PSI value of 1.9. However, the chip seal that was applied on section LN-SR321-0-5.11 improved or extended the pavement condition by exhibiting a PSI of 2.9 right after treatment application and decreased to a PSI of 2.5 after 3 years of service. Afterward, the pavement condition was held or maintained for 3 years before it reached a PSI value of 2.0, which happened to be the terminal serviceability for state routes.

The years to reach the pretreatment PSI values are the number of performance years from the time of treatment application to the time when the pavement reached similar conditions to pretreatment application. For example, it took 2.1 years for the chip seal that was applied on section CL-SR164-6.4-9.2 to deteriorate from a PSI of 2.5 right after treatment to the pretreatment PSI of 2.3. However, it took 2.3 years for the chip seal that was applied on section LN-SR321-0-5.11 to deteriorate from a PSI of 2.9 right after treatment to the pretreatment PSI of 2.6.

The expected performance life is provided in the form of an expected performance range in which the minimum value corresponds to the number of years to reach the pretreatment PSI value, and the maximum value corresponds to the number of years to reach the corresponding terminal serviceability of the road or the last recorded PSI value. In this case, the performance life of the chip seal that was applied on section CL-SR164-6.4-9.2 ranges from 2.1 to 3.9 years, while the performance life of the chip seal that was applied on section LN-SR321-0-5.11 ranges from 2.3 to 6.0 years.

The benefit (B) is defined as the area under the performance curve over the analysis period. Two cases may be encountered during the calculation of the benefit, depending on whether the PSI of the existing pavement (i.e., before treatment application) is higher or lower than the terminal serviceability of the corresponding road class (Figure 2). Whenever the pretreatment PSI is higher than the terminal serviceability, the future condition of the pavement without treatment application is extrapolated by extending a tangent of the same slope as that of the PSI curve of the last 3 years before treatment application.

The benefit–cost analysis is conducted using the area under the performance curve as the benefit (B, as mentioned earlier) and the actual total cost per lane mile (C). The total cost includes the cost for labor, materials, and equipment for each treatment activity. A higher benefit–cost ratio (referred to as B/C) for a given maintenance activity is associated with a higher benefit or a lower cost and indicates a better overall value for the treatment. Table 3 shows the benefit–cost ratio for the chip seal sections on state routes in NDOT District 1. The highlighted examples in Table 3 show that the chip seal that was applied on sec-



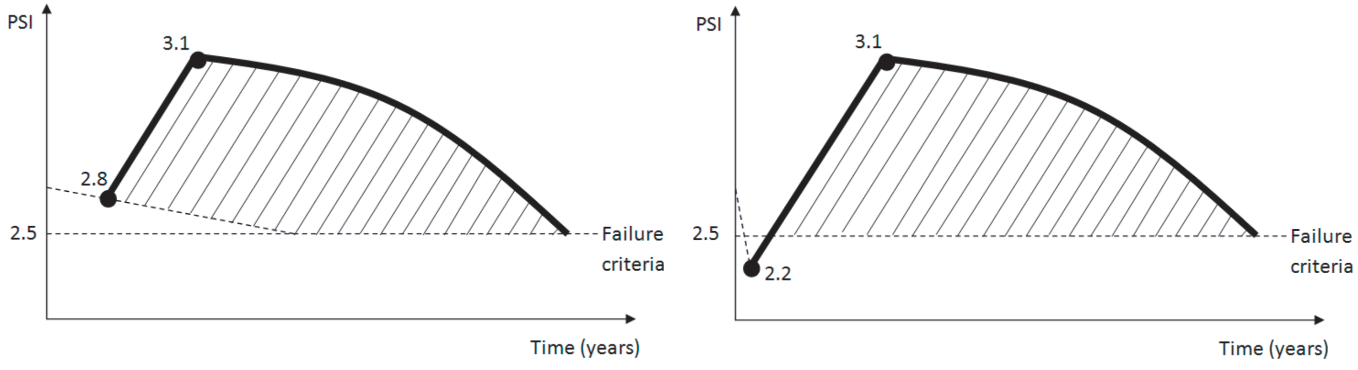
(a) (b)

FIGURE 1 PSI over the analysis period: (*a*) CL-SR164-6.4-9.2 and (*b*) ES-SR265-16-15.5.

TABLE 2 Project-Level Analysis for Chip Seals on State Routes in NDOT District 1

			Treatment Performance							
Section ID	PSI of Existing Pavement	Treatment Objective	PSI^a	Improve–Extend, Years (PSI > 2.5)	PSI^b	Hold, Years (PSI ≤ 2.5)	PSI^c	Years to Reach the Pretreatment PSI	Performance Range, Years	Benefit B^d
CL-SR165-0-3.8 A	1.9	Hold			2.3	4.1	1.9	2.0	2.0–4.1	1.7
CL-SR165-0-3.8 B	1.8	Hold	2.6	3.1	2.5	3.0	2.1	4.0	4.0–6.1	3.5
CL-SR165-6.5-33112 A	2.0	Hold			2.4	4.1	2.0	2.1	2.1–4.1	1.5
CL-SR165-6.5-33112 B	2.1	Hold			2.5	4.0	2.0	2.0	2.0–4.0	1.7
CL-SR168-19.3-23.82 A	2.5	Hold	2.8	3.1	2.5	4.0	2.0	3.9	3.9–7.1	3.8
CL-SR168-19.3-23.82 B	2.2	Hold	2.6	3.2	2.5	4.0	2.0	4.1	4.1–7.2	3.6
CL-SR168-8-11.2 A	2.3	Hold	2.6	3.2	2.5	5.0	2.0	3.9	3.9–8.2	3.6
CL-SR168-8-11.2 B	2.3	Hold	2.6	3.0	2.5	4.0	2.1	3.8	3.8–7.0	3.4
CL-SR168-4.7-8 A	2.6	Improve–extend	2.9	2.0	2.5	2.0	2.0	2.0	2.0–4.0	4.2
CL-SR168-4.7-8 B	1.9	Hold			2.5	4.2	1.9	2.0	2.0–4.2	2.1
CL-SR164-6.4-9.2	2.3	Hold			2.5	3.9	1.9	2.1	2.1–3.9	1.8
CL-SR164-5.5-14.6	2.3	Hold	2.8	3.0	2.5	3.0	2.4	3.7	3.7–6.0	3.6
CL-SR604-61-69.68	2.1	Hold			2.5	3.9	1.9	2.0	2.0–3.9	1.6
ES-SR265-8-10	2.3	Hold			2.5	3.9	1.9	2.0	2.0–3.9	1.8
ES-SR265-10-11	2.1	Hold			2.5	3.0	1.9	2.1	2.1–3.0	1.7
ES-SR265-15-17.5 A	1.9	Hold			2.2	3.0	1.9	2.0	2.0–3.0	1.6
ES-SR265-15-17.5 B	1.9	Hold			2.3	3.0	1.9	2.0	2.0–3.0	1.7
ES-SR265-13-15.5	2.8	Improve–extend	3	3.0	2.5	2.0	2.5	2.1	2.1–5.0	4.0
ES-SR266-30-31	1.9	Hold			2.5	2.0	1.9	2.0	2.0–2.0	1.7
ES-SR266-25-29.3	2.3	Hold	2.6	3.0	2.5	3.0	2.1	3.8	3.8–6.0	3.5
ES-SR266-19.76-26.95	2.2	Hold	2.6	3.0	2.5	3.0	2.1	4.1	4.1–6.0	3.7
ES-SR266-14-20.66	2.2	Hold	2.6	3.0	2.5	2.0	2.1	4.2	4.2–5.0	3.8
LN-SR321-0-5.11	2.6	Improve–extend	2.9	3.0	2.5	3.0	2.0	2.3	2.3–6.0	4.1
LN-SR319-50-54.5	2.0	Hold			2.4	3.5	2.0	1.6	1.6–3.5	1.5
LN-SR319-56-60	2.0	Hold			2.5	3.1	2.0	2.1	2.1–3.1	1.5
LN-SR319-60-66	2.7	Improve–extend	3.1	4.0	2.5	2.0	2.5	4.0	4.0–6.0	4.0
LN-SR319-63-70.91	2.8	Improve–extend	3.2	3.0	2.5	2.0	2.5	2.4	2.4–5.0	4.3

[a] PSI right after treatment application.
[b] PSI right after treatment application if treatment performance was only hold and maintain; otherwise 2.5 for SR and 2.8 for US or IR.
[c] Last PSI on record.
[d] Benefit in PSI × years.



(a) (b)

FIGURE 2 Area under performance curve: (*a*) Case 1 and (*b*) Case 2.

TABLE 3 Benefit–Cost Analysis for Chip Seals on State Routes in NDOT District 1

Section ID	Treatment Objective	Benefit, B (PSI × years)	Cost, C ($/lane mile)				Benefit–Cost Ratio, B–C $100 \times \frac{\text{PSI} \times \text{years}}{1{,}000\$/\text{lane mile}}$
			Labor	Materials	Equipment	Total	
CL-SR165-0-3.8 A	Hold	1.7	437	3,601	463	4,501	38
CL-SR165-0-3.8 B	Hold	3.5	1,227	3,508	1,224	5,959	59
CL-SR165-6.5-33112 A	Hold	1.5	573	3,660	540	4,773	31
CL-SR165-6.5-33112 B	Hold	1.7	1,037	3,862	178	4,895	35
CL-SR168-19.3-23.82 A	Hold	3.8	677	3,882	270	4,829	79
CL-SR168-19.3-23.82 B	Hold	3.6	745	4,744	185	5,674	63
CL-SR168-8-11.2 A	Hold	3.6	740	4,117	383	5,229	69
CL-SR168-8-11.2 B	Hold	3.4	740	4,117	383	5,229	65
CL-SR168-4.7-8 A	Improve–extend	4.2	740	4,117	383	5,229	80
CL-SR168-4.7-8 B	Hold	2.1	740	4,117	383	5,229	40
CL-SR164-6.4-9.2	Hold	1.8	740	4,117	383	5,229	34
CL-SR164-5.5-14.6	Hold	3.6	672	4,068	91	4,832	75
CL-SR604-61-69.68	Hold	1.6	672	4,068	91	4,832	33
ES-SR265-8-10	Hold	1.8	740	4,117	383	5,229	34
ES-SR265-10-11	Hold	1.7	740	4,117	383	5,229	33
ES-SR265-15-17.5 A	Hold	1.6	740	4,117	383	5,229	31
ES-SR265-15-17.5 B	Hold	1.7	740	4,117	383	5,229	32
ES-SR265-13-15.5	Improve–extend	4.0	740	4,117	383	5,229	77
ES-SR266-30-31	Hold	1.7	740	4,117	383	5,229	33
ES-SR266-25-29.3	Hold	3.5	740	4,117	383	5,229	67
ES-SR266-19.76-26.95	Hold	3.7	633	4,597	476	5,706	65
ES-SR266-14-20.66	Hold	3.8	347	4,844	382	5,572	68
LN-SR321-0-5.11	Improve–extend	4.1	347	4,844	382	5,572	74
LN-SR319-50-54.5	Hold	1.5	701	4,401	75	5,177	29
LN-SR319-56-60	Hold	1.5	674	3,890	302	4,866	31
LN-SR319-60-66	Improve–extend	4.0	740	4,117	383	5,229	77
LN-SR319-63-70.91	Improve–extend	4.3	1,326	3,114	810	5,251	82

tion CL-SR164-6.4-9.2 with an existing PSI of 2.3 with the objective to hold the pavement condition exhibited a benefit–cost ratio of 34, the chip seal that was applied on section LN-SR321-0-5.11 with an existing PSI of 2.6 with the objective of improve and extend the pavement condition exhibited a benefit–cost ratio of 74.

Performance Analysis of Chip Seals

Table 4 summarizes the number of sections with chip seals that met or exceeded the anticipated treatment objective. The data show a 58% and a 67% chance that the chip seal will enhance the pavement condition when applied to a pavement with the objective of holding or improving the pavement condition, respectively.

TABLE 4 Summary of Chip Seal Performance

Treatment Objective	Total Number of Sections	Treatment Performance, Number of Sections (percentage of total)	
		Improve–Extend	Hold–Maintain
Hold	65	38 (58)	27 (42)
Improve–extend	33	22 (67)	11 (33)
Prevent	24	24 (100)	0 (0)

Figure 3 shows the anticipated performance period in years for the chip seal by districts and road classifications. The error bars shown in the figures correspond to +/– one standard deviation of the data. As discussed earlier, the minimum performance period corresponds to the number of performance years from the time of treatment application to the time when the pavement reached similar conditions to pretreatment application. The maximum performance period corresponds to the number of performance years from the time of treatment application to the time when the pavement reached the terminal serviceability or to the time for the last PSI measured. Statistical analyses were conducted to help distinguish any significant differences in the treatments using a one-way analysis of variance (ANOVA) at a significance level (i.e., alpha value) of 0.05.

Figure 3 shows statistically similar performance periods for the chip seal in all three districts. However, the road classification was found to have a statistically significant impact on the performance periods of the chip seal. A higher performance period was observed for sections on SR with improve or extend performance when compared with that of sections on US and IR.

Figure 4 summarizes the benefit–cost ratio for the chip seal by district and road classification. The costs used to calculate the benefit–cost ratio are actual costs and do not account for the inflation rates. The

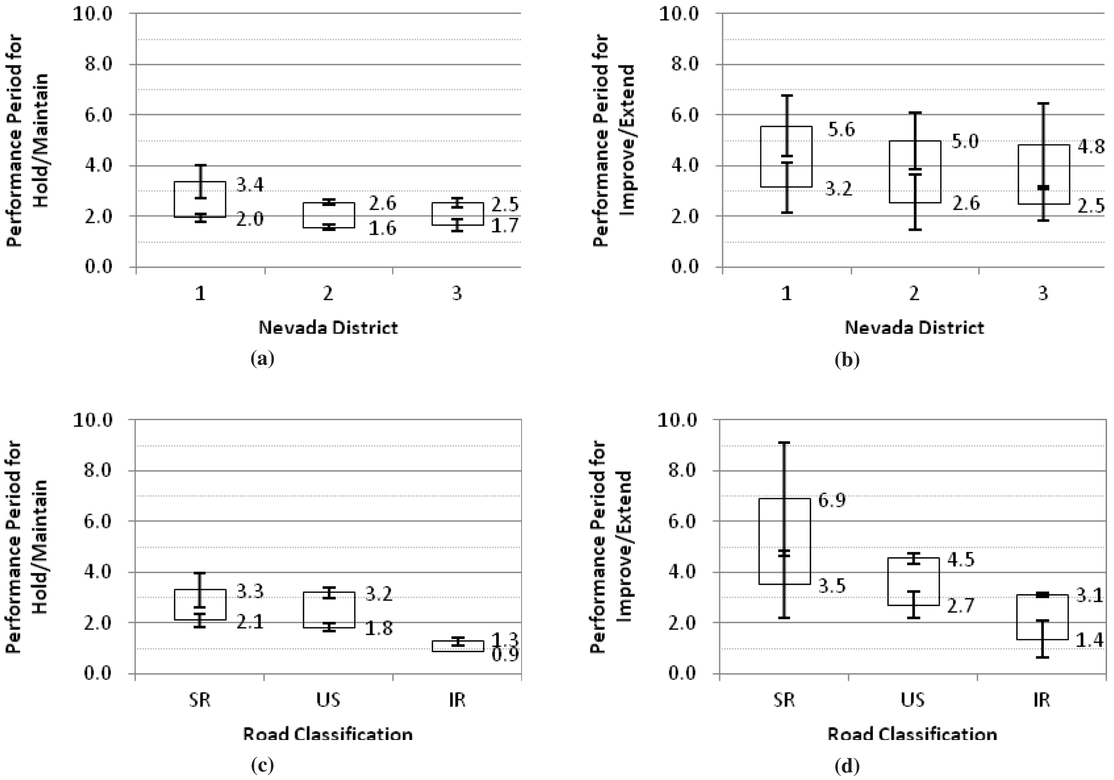


FIGURE 3 Performance period (years) for chip seal: (*a*) by Nevada district with hold–maintain performance, (*b*) by Nevada district with improve–extend performance, (*c*) by road classification with hold–maintain performance, and (*d*) by road classification with improve–extend performance.

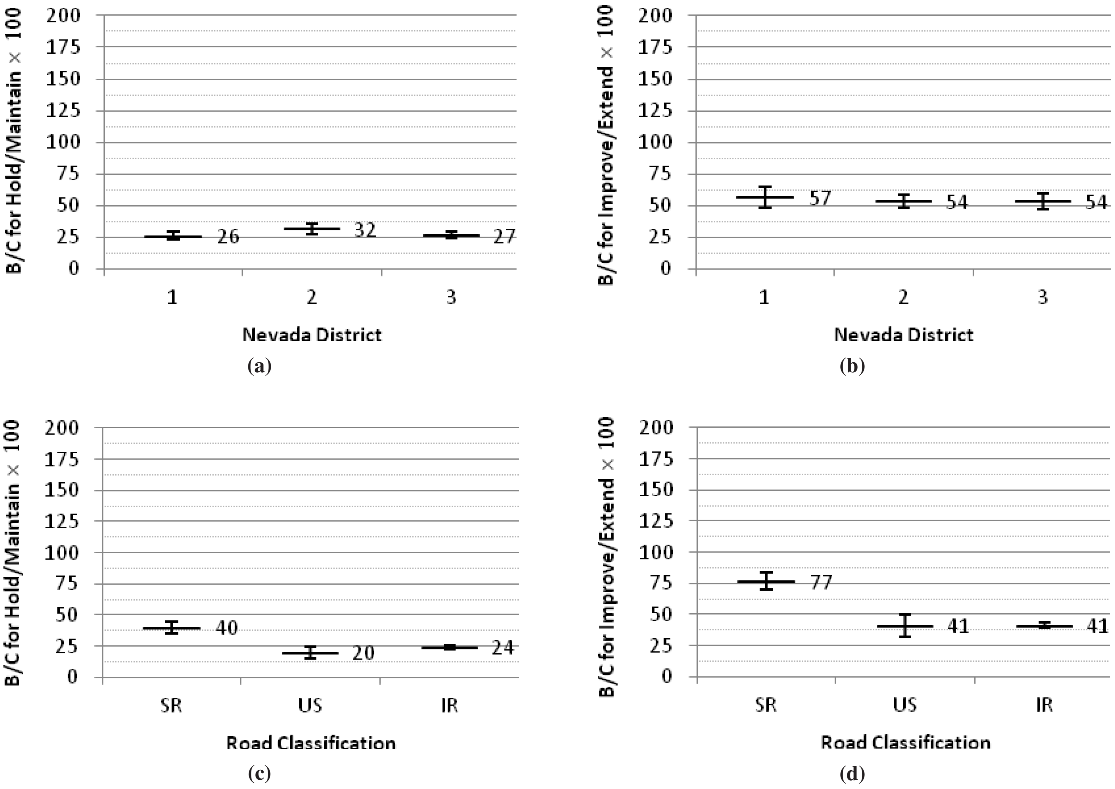


FIGURE 4 Benefit–cost ratio for chip seal: (*a*) by Nevada district with hold–maintain performance, (*b*) by Nevada district with improve–extend performance, (*c*) by road classification with hold–maintain performance, and (*d*) by road classification with improve–extend performance.

statistical analysis of the data using ANOVA (at the 5% significance level) reveals similar benefit–cost ratios for all three districts. Statistically, higher benefit–cost ratios were observed for chip seals applied on state routes when compared with US and IR roads. Additionally, the benefit–cost ratio of chip seal on the state route with hold and maintain performance was statistically similar to the benefit–cost ratio of chip seal on US and IR roads with improve and extend performance. In other words, the use of the chip seal on a US or IR road with an acceptable condition (i.e., 2.8 < PSI < 3.5) was as effective as the use of the chip seal on an SR with a relatively worse condition (i.e., PSI < 2.5).

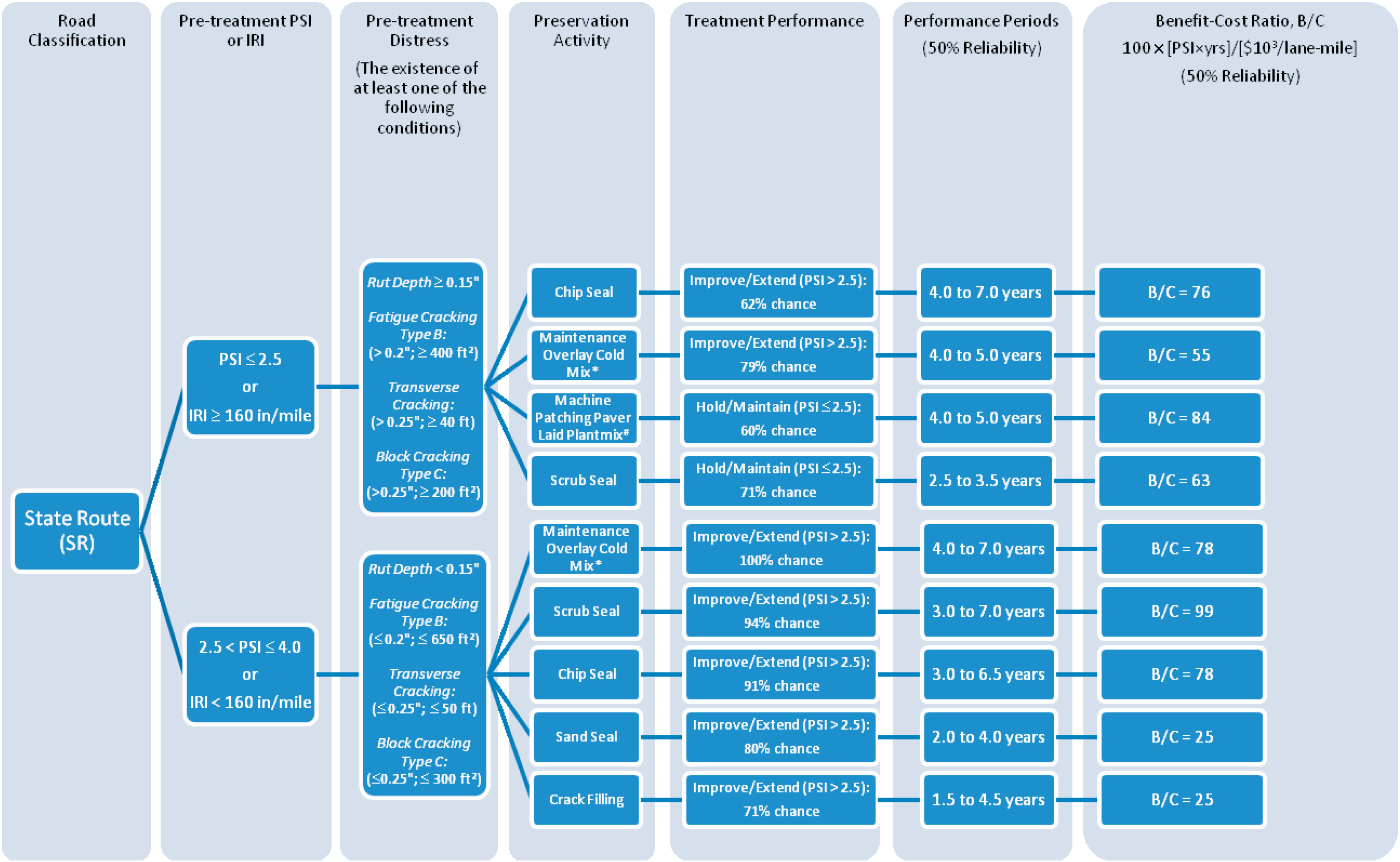
SUMMARY OF PERFORMANCE ANALYSIS

Similar analyses to the one presented for chip seals were performed for each of the evaluated pavement preservation treatments, and general conclusions were made. Table 5 summarizes the performance of the various preservation activities along with their pretreatment pavement condition, such as PSI, fatigue cracking, transverse cracking, block cracking, and rut depths. The average and standard deviation of the various distresses are reported for each preservation activity as a function of the treatment objective. The data in Table 5 show that

TABLE 5 Performance of Preservation Treatments

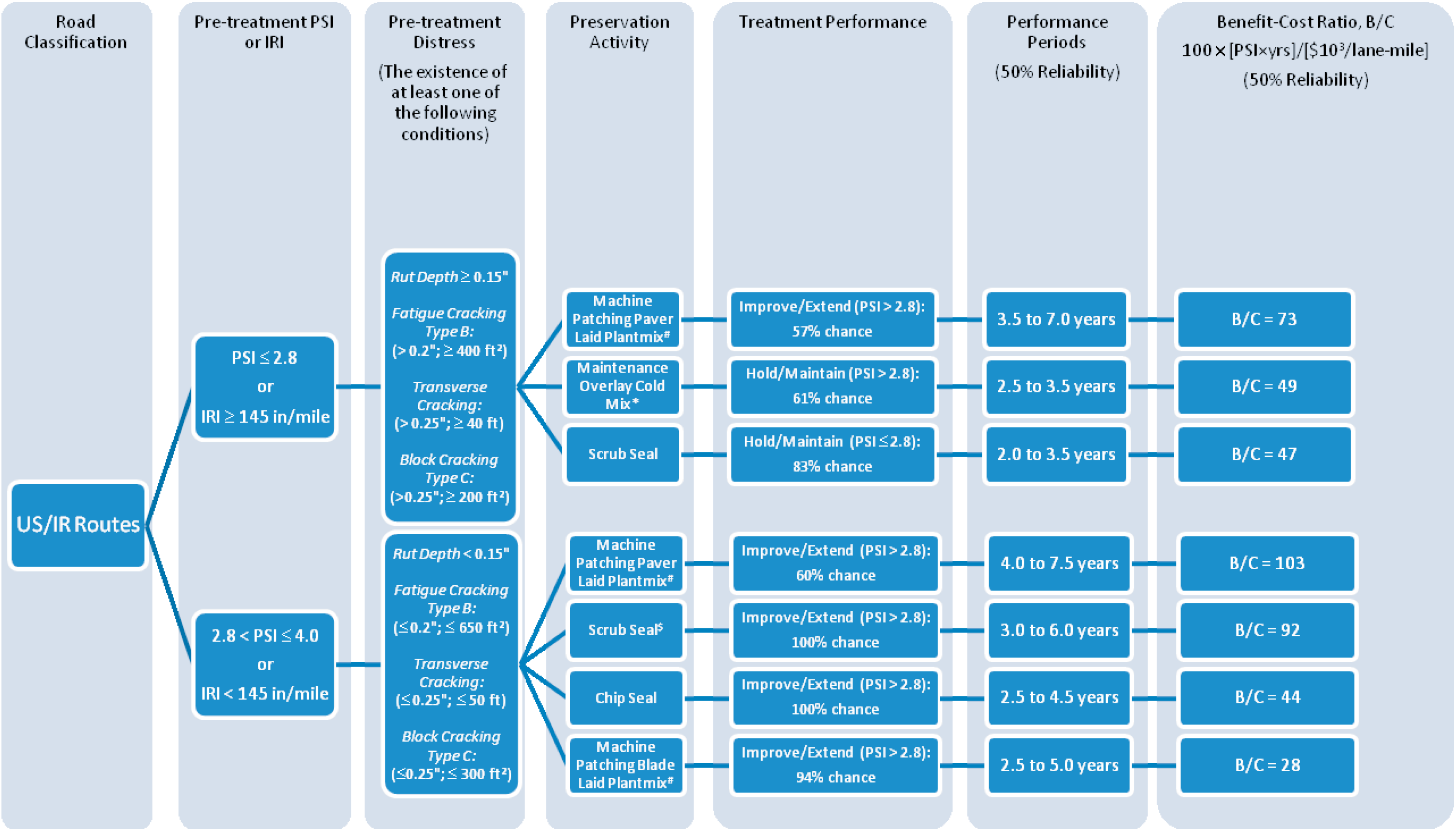
			Pretreatment Condition									
			Fatigue Cracking (ft^2)		Transverse Cracking (ft)		Block Cracking (ft^2)		Rut Depths (inch)		IRI (inch/mile)	
Treatment	Treatment Objective[a]	Treatment Performance	Average	SD	Average	SD	Average	SD	Average	SD	Average	SD
State Routes												
Chip seal	H–M	62% chance of I–E	537	48	46	2	269	15	0.16	0.01	181	10
	I–E	91% chance of I–E	456	24	37	2	218	13	0.13	0.01	147	9
Sand seal	H–M	75% chance of H–M	532	63	46	6	270	32	0.16	0.02	182	22
	I–E	80% chance of I–E	341	69	32	5	189	30	0.11	0.02	127	20
Scrub seal	H–M	71% chance of H–M	582	10	54	1	316	5	0.19	0.00	213	3
	I–E	94% chance of H–M	487	—	38	—	223	—	0.13	—	150	—
Fog/flush	H–M	100% chance of H–M	541	122	44	6	259	32	0.16	0.02	174	22
	I–E	92% chance of I–E	562	106	28	5	166	31	0.10	0.02	112	21
Crack filling	H–M	53% chance of H–M	568	43	46	4	271	24	0.16	0.01	182	16
	I–E	71% chance of I–E	383	49	32	3	189	0	0.11	0.01	127	14
MO-CM[b]	H–M	79% chance of I–E	438	57	45	5	267	27	0.16	0.02	180	18
	I–E	100% chance of I–E	324	27	33	3	194	16	0.12	0.01	130	11
MP-PLP[c]	H–M	60% chance of H–M	591	6	43	4	255	23	0.15	0.01	171	16
	I–E	—	—	—	—	—	—	—	—	—	—	—
MP-BLC[d]	H–M	53% chance of H–M	551	42	47	3	276	20	0.17	0.01	186	14
	I–E	100% chance of I–E	406	32	37	3	220	16	0.13	0.01	148	10
MP-BLP[e]	H–M	80% chance of I–E	494	30	51	4	303	26	0.18	0.02	204	18
	I–E	—	—	—	—	—	—	—	—	—	—	—
UR/IR Roads												
Chip seal	H–M	53% chance of H–M	487	62	41	4	241	24	0.15	0.01	162	16
	I–E	100% chance of I–E	360	45	30	3	174	19	0.11	0.01	117	13
Sand seal	H–M	56% chance of I–E	435	64	38	4	222	24	0.13	0.01	149	16
	I–E	—	—	—	—	—	—	—	—	—	—	—
Scrub seal	H–M	83% chance of H–M	576	18	43	2	255	10	0.15	0.01	172	7
	I–E	100% chance of I–E	389	77	41	28	242	166	0.15	0.10	163	112
Fog/flush	H–M	100% chance of H–M	620	38	37	5	220	31	0.13	0.02	148	21
	I–E	98% chance of I–E	574	59	26	5	152	27	0.09	0.02	102	18
Crack filling	H–M	66% chance of I–E	484	64	39	4	233	0	0.14	0.01	157	16
	I–E	95% chance of I–E	374	38	31	2	185	0	0.11	0.01	125	9
MO-CM[b]	H–M	61% chance of H–M	483	64	49	4	286	23	0.17	0.01	193	16
	I–E	—	—	—	—	—	—	—	—	—	—	—
MP-PLP[c]	H–M	57% chance of I–E	572	3	37	1	216	5	0.13	0.00	145	3
	I–E	60% chance of I–E	518	11	31	0	183	0	0.11	0.00	123	0
MP-BLC[d]	H–M	57% chance of I–E	461	70	41	6	240	35	0.15	0.02	162	23
	I–E	100% chance of I–E	374	14	34	1	199	8	0.12	0.01	134	6
MP-BLP[e]	H–M	62% chance of H–M	444	18	44	1	257	9			173	6
	I–E	94% chance of I–E	338	17	37	3	216	16	0.13	0.01	145	11

[a] H–M = hold–maintain, I–E = improve–extend.
[b] Maintenance overlay cold mix.
[c] Machine patching paver laid plantmix.
[d] Machine patching blade laid cold mix.
[e] Machine patching blade laid plantmix.



Notes: *Applied only in Districts 1 and 3
#Applied only in District 3

FIGURE 5 Recommended pavement preservation program for SR (# = applied only in District 3; * = applied only on US roads in Districts 1 and 3; $ = applied only on US roads).



Notes: $^{\#}$Applied only in District 3
*Applied only on US roads in Districts 1 and 3
$^{\$}$Applied only on US roads

FIGURE 6 Recommended pavement preservation program for US and IR road (# = applied only in District 3; * = applied only on US roads in Districts 1 and 3; \$ = applied only on US roads).

the lower the pretreatment PSI, the higher the reported pavement distresses and vice versa. For example, when chip seal was applied on the state route with the objective to hold and maintain (i.e., $2.0 < PSI < 2.5$) the pavement condition, an average fatigue cracking of 537 ft^2 was observed, while an average fatigue cracking of 456 ft^2 was observed when chip seal was applied to improve and extend (i.e., $2.5 < PSI < 3.0$) the pavement condition. Generally, the chance of improving and extending the pavement condition was higher when the pavement distresses were lower.

The following list summarizes the overall effectiveness of the various treatments based on their performance, chance of improving and extending the pavement condition, and benefit–cost ratio:

- Chip seals were effective on SR regardless of the pretreatment PSI level and on US and IR roads with a pretreatment PSI greater than 2.8. A higher benefit was found for chip seals applied to SR when compared with chip seals applied to US and IR roads.
- Sand seals were more effective on SR with a pretreatment PSI greater than 2.5. The effectiveness of sand seal on SR with a pretreatment PSI less than 2.5 was similar to its effectiveness on US road with a pretreatment PSI less than 2.8. Sand seals are not applied on IR.
- The effectiveness of scrub seals on SR with a pretreatment PSI greater than 2.5 was similar to its effectiveness on US roads with a pretreatment PSI greater than 2.8. A low benefit was found for the scrub seal when applied to SR and US roads with a pretreatment PSI less than 2.5 and 2.8, respectively. Scrub seals are not applied on IR roads.
- Fog seals had low benefits to the pavement performance on both SR as well as on US and IR roads. The greatest benefit of fog seals was found when they were applied to pavements with a pretreatment PSI greater than 2.5 and 2.8 for SR and for US and IR roads, respectively.
- Crack fillings were more effective when applied to SR when compared with US and IR roads, specifically when the pretreatment PSI was greater than 2.5.
- MO-CM was effective on both SR and US roads, with their highest benefit being on SR with a PSI greater than 2.5.
- MP-PLP was highly effective on both SR and US roads. However, of note is that the evaluated number of sections for the MP-PLP were relatively lower than were the evaluated number of sections for the other treatments.
- MP-BLC had low benefit to the pavement performance on both SR and US roads. The highest benefit was found when the MP-BLC was applied to pavements with a pretreatment PSI greater than 2.5 and 2.8 for SR and US roads, respectively.
- MP-BLP was more effective on SR when compared with the effect on US and IR roads. The effectiveness of MP-BLP on SR was similar to its effectiveness on US and IR roads with a pretreatment PSI greater than 2.8.

OVERALL RECOMMENDATIONS

From the analysis of the performance data on all of the evaluated preservation treatments, overall recommendations were made for pavement preservation programs on SR and on US and IR roads (Figures 5 and 6). The recommended preservation activities depend on the PSI value and the roughness of the road before treatment application, as well as the pavement condition in regard to rut depth, fatigue cracking, transverse cracking, and block cracking. The cracking classes, extent, and severity are defined in NDOT's *Flexible Pavements Distress Identification Manual* (*7*). The rut depths and the various cracking types reflect the structural condition of the pavement before the application of the maintenance activity. Of note is that PSI is highly influenced by the roughness of the road (IRI). However, a rutted and cracked pavement will result in a rough road, hence, a higher IRI value.

The recommended preservation activities are listed by preference based on the expected performance of the treatment after application, chance of the treatment to improve and extend the pavement condition, and the treatment benefit–cost ratio. Only the preservation activities with a benefit–cost ratio greater than 0.25 were included in the presented preservation programs.

Even though crack filling was found to be effective only on SR with a pretreatment PSI greater than 2.5, it is highly recommended and encouraged to apply crack filling when pavement cracks first develop, because timely treatment will help prevent further pavement deterioration.

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The Pavement Preservation Committee peer-reviewed this paper.