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Literature Review on Performance, Best Practices, and Training Needs for Chip Seals, Slurry Surfacing, and Cape Seals

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REPORT 19-32

LITERATURE REVIEW ON PERFORMANCE, BEST PRACTICES, AND TRAINING NEEDS FOR CHIP SEALS, SLURRY SURFACING, AND CAPE SEAL

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16. Abstract

The objective of this study is to document the performance, best practices, and training needs of various pavement preservation treatments, accounting for the factors that affect the performance of the treatments. Treatments covered in this document include chip seals, slurry seals, microsurfacing, and cape seals.

The literature review in this report covers local, national, and international practices. The information gathered from the various studies was cross-referenced with similar reports for accuracy and to obtain common consensus for each of the treatments being evaluated. Performance data, along with the development of best construction practices for specific treatment types, will aid transportation agencies in becoming familiar with pavement management systems. With this knowledge, the use of these systems will aid in the tracking and maintenance of road networks. Within this literature review is a section that discusses pavement management systems (PMSs) used. Pavement management systems in California include StreetSaver and PaveM; StreetSaver is most commonly used by local agencies and PaveM is utilized by Caltrans.

The performance of chip seals, slurry surfacing, and cape seals was researched, including identification of the factors affecting performance of each treatment type, as well as observations and data from agencies who have documented the performance and behavior of treatments over several years.

The last topic covered was identifying training needs for the preservation treatments presented. This section of the document sets out the training and knowledge required to facilitate improved and more reliable performance of preservation treatments.

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EXECUTIVE SUMMARY

Pavement preservation provides a means for maintaining and improving the functional condition of an existing pavement segment through application of a preventative and responsive set of treatments that impede deterioration or correct isolated pavement defects. It also means, in simpler terms, deferring costly pavement rehabilitation or reconstruction to a later time. While pavement preservation is not expected to increase the structural capacity of the pavement, it can lead to improved performance (slowed cracking, reduced weathering, attenuated degradation, and other performance benefits), longer service life, and reduced life cycle costs (LCC). In this light, the Federal Highway Administration (FHWA) defines pavement preservation as “work that is planned and performed to improve or sustain the condition of the road but does not add capacity or structural value.”

The objective of this study is to document the performance, best practices, and training needs of various pavement preservation treatments, accounting for the factors that affect the performance of the treatments. Treatments covered in this document include chip seals, slurry seals, microsurfacing, and cape seals. This objective will be accomplished through a series of tasks that include the following.

- **Literature review**. From the literature review and survey of local agencies in California, as well as national documents, the performance of each treatment type and existing performance models will be identified.

- **Best practices**. Construction best practices for each of the treatments will also be identified.

- **Performance models**. These models will be developed as a part of the overall study. By inputting data into the performance models, the researchers expect to identify the benefits of selected preservation treatments. Data collected from selected local agencies will be used to accomplish this task using an approach developed as a part of NCHRP Project 14-33.

- **Training materials**. Using the results of the literature review, training materials will be developed to help local agencies understand how to design and construct chip seals, slurry seals, and cape seals. The training materials will include not only technical presentations, but also a training module for the best construction practices, as well as sample specifications for each of the treatments.

- **Dissemination of information**. This task will consist of the widespread distribution of this information throughout California and is expected to aid agencies in determining the most cost-effective and efficient treatment for their maintenance and rehabilitation projects.

The literature review in this report covers local, national, and international practices. The information gathered from the various studies was cross-referenced with similar reports for accuracy and to obtain common consensus for each of the treatments being evaluated.

Performance data, along with the development of best construction practices for specific treatment types, will aid transportation agencies in becoming familiar with pavement management systems. With this knowledge, the use of these systems will aid in the tracking and maintenance of road networks. Within this literature review is a section that discusses pavement management systems (PMSs) used. Pavement management systems in California include StreetSaver and PaveM; StreetSaver is most commonly used by local agencies and PaveM is utilized by Caltrans.

The performance of chip seals, slurry surfacing, and cape seals was researched, including identification of the factors affecting performance of each treatment type, as well as observations and data from agencies who have documented the performance and behavior of treatments over several years. It should be noted that there was significantly more data available on chip seal treatments compared to the other treatment types.

The best practices for chip seals, slurry surfacing, and cape seals include information on the advantages and disadvantages of each treatment, as well as when certain treatments should and should not be used. The best practices from various local, national, and international agencies also include construction and methodology procedures and techniques to ensure an effective treatment application.

The last topic covered was identifying training needs for the preservation treatments presented. This section of the document sets out the training and knowledge required to facilitate improved and more reliable performance of preservation treatments.

I. INTRODUCTION

BACKGROUND

State agencies across the nation are exploring techniques to maintain their road infrastructure, and the use of pavement management systems and preservation treatments are the answer. Pavement management systems (PMS) are utilized to determine the most effective pavement preservation strategy to maintain and improve an agency's pavement condition. Most agencies have adopted some sort of PMS to determine the best time, treatment, and cost data available to improve their networks. A widely-used pavement management system used by local agencies in the State of California is MTC StreetSaver.

Currently, performance models are used to determine the pavement condition over time and the increased lifespan when treatments are used. With data from StreetSaver, performance models for pavement preservation treatments can be created and updated over time with the introduction of new materials, equipment, and practices. The different types of pavement treatments needed for different sections of road in each agency depend on the traffic levels, the weather conditions, and the current road condition prior to treatment. Knowledge of these factors that affect pavement condition is necessary to determine the best treatment for the given section of road. This necessary knowledge calls for the training of individuals in various aspects of pavement management and maintenance.

The three components that make up a pavement preservation program are preventive maintenance, minor repairs, and routine maintenance activities. These components aid in planning an effective approach to extend pavement service life, improve surface condition and safety, and provide an efficient and cost-effective approach to extend the service life of a pavement.[1] Agencies are beginning to focus on implementing pavement preservation programs to ensure the longevity of pavement service life, ride quality, and safety factors. Cost-effective improvements are primarily found by utilizing the best preservation methods to correct minor distresses in order to extend the overall service life of a roadway.[2]

Problems associated with current pavement management strategies include:[3]

- Differences between the pavement condition data collected,
- Disparities in the pavement maintenance choices,
- Lack of current and past pavement condition data available,
- Determination of deferred maintenance effects, and
- Use of traffic volume data.

Uniform guidelines for data collection would help agencies utilize the data specific to their region to determine the condition of their road network system. Uniform guidelines would also allow agencies to identify what is affecting roads in their system and determine to what extent these factors cause the roadways to deteriorate.

REPORT OBJECTIVES

The objective of this report is to document the performance of the selected preservation treatments utilized for rehabilitation and maintenance projects. This literature review will concentrate on the most widely used treatments, including chip seals, slurry surfacing, and cape seals. This review includes the following:

- Literature research on different treatments to provide information necessary to determine the effectiveness and service life of each treatment,
- Performance curves for each preservation treatment to help demonstrate the effectiveness and service life duration,
- Best construction practices for the preservation treatments, and
- Training needs identified by agencies.

ORGANIZATION OF REPORT

The remaining report is organized as follows:

- Chapter 2 details the **performance** of chip seals, slurry seals, microsurfacing, and cape seals. This chapter includes a discussion of factors affecting performance and results and reports conclusions formed by various agencies on the performance of the different treatment types. In addition, this section includes performance models formulated by agencies and other sources.
- Chapter 3 summarizes the **best construction practices** for each type of treatment based on the various conditions found to influence the overall performance of the treatment. The best practices outline the details of each surface preparation, when to use a specific treatment type and when not to use it, and the environmental and climate conditions in which the treatment needs to be applied for the best results.
- Chapter 4 covers the **training** requirements and information necessary for the successful application of treatments.
- Chapter 5 of this report summarizes the overall **conclusions** for each treatment type and **recommendations** to agencies for each treatment based on the specific conditions outlined for treatments.
- Chapter 6, the reference list, includes the **sources** used to formulate this literature review and analysis.
- Appendix A includes details on performance measurement methods utilized by MTC and Caltrans.
- Appendix B provides further detailed information on the performance of treatments

and the factors that affect specific pavement preservation treatments. This section is organized according to the order in which the topics are introduced throughout the report.

- Appendix C details the questions used for the survey, which are discussed in Chapter 4. This survey consisted of 17 questions distributed to agencies by the City and County Pavement Improvement Center (CCPIC).

II. PERFORMANCE OF PAVEMENT PRESERVATION TREATMENTS

The performance of a treatment is an important aspect that is considered in the overall decision-making process and assessment of its effectiveness over time. This chapter discusses the most common treatments used by various local agencies in California, which include:

- Chip Seals
- Slurry Seals
- Microsurfacing
- Cape Seals

The need to predict and understand the performance of treatments for ensuring cost-effective choices leads the authors to focus on the following aspects for each treatment.

- Pavement management systems (PMS)
- Identifying the benefits of preservation treatments through performance jumps and life extension determined from PMS
- Factors affecting performance
- Performance of the treatment
- Advantages and disadvantages of each treatment

By recognizing the key controllable treatment risk factors, incorporating procedures to control these factors, and incorporating a feedback or monitoring mechanism, agencies can improve and better manage the performance of pavement preservation treatments.

COMMON PAVEMENT MANAGEMENT SYSTEMS

The performance models created for past, present, and future conditions of pavements are developed based on various parameters such as climate region, prior pavement condition, environment, average traffic conditions, project design, and materials. These factors are important in determining the overall performance of each pavement preservation or maintenance treatment. As important as these factors are, just as important is keeping track of the data. For this reason, a good pavement management system is useful.

The most common pavement management systems used in California are the MTC StreetSaver and the Caltrans PaveM systems. Each agency uses different performance measures to classify the condition of their roadway networks. For StreetSaver, the Pavement Condition Index (PCI) is used, while for the Caltrans system, individual distresses are used. Each system is briefly discussed in the following sections.

MTC's StreetSaver

MTC's StreetSaver assists agencies in determining the most cost-effective options available for maintenance and rehabilitation projects. This PMS utilizes the pavement condition index (PCI) to classify the pavement condition of different roadways based on the distress observations recorded by surveyors and raters for their sections. The PCI can be determined using the approach set out in Appendix A. The MTC StreetSaver program can also establish budget scenarios based on the needs and required schedules of an agency, as well as projecting the pavement conditions possible with the given budget. These functions allow for the best treatments for the current pavement conditions and projections of the conditions over time. Figure 1 shows the PCI values from 0–100 and their corresponding pavement condition ratings.

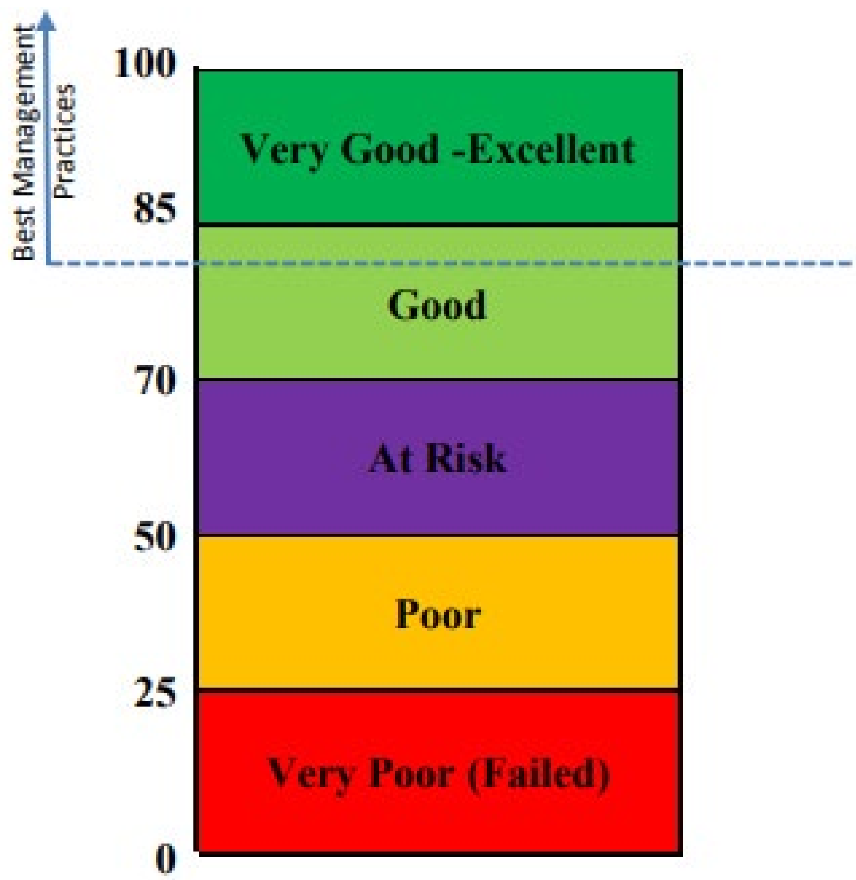

Figure 1. StreetSaver Pavement Condition Index Classifications

Source: County of Riverside Transportation Department. *Pavement Management Report*, Riverside, CA: 2014.

This program aids in the determination of the pavement condition; however, it is not entirely accurate, as each agency has a network of roads whose conditions are dependent on different factors. A significant factor mentioned by the County of Riverside in its "Pavement Management Report" is the application timing of the treatment. As shown in Figure 2, the pavement deterioration corresponds with age while Figure 3 details the deterioration trends with and without treatment.[4]

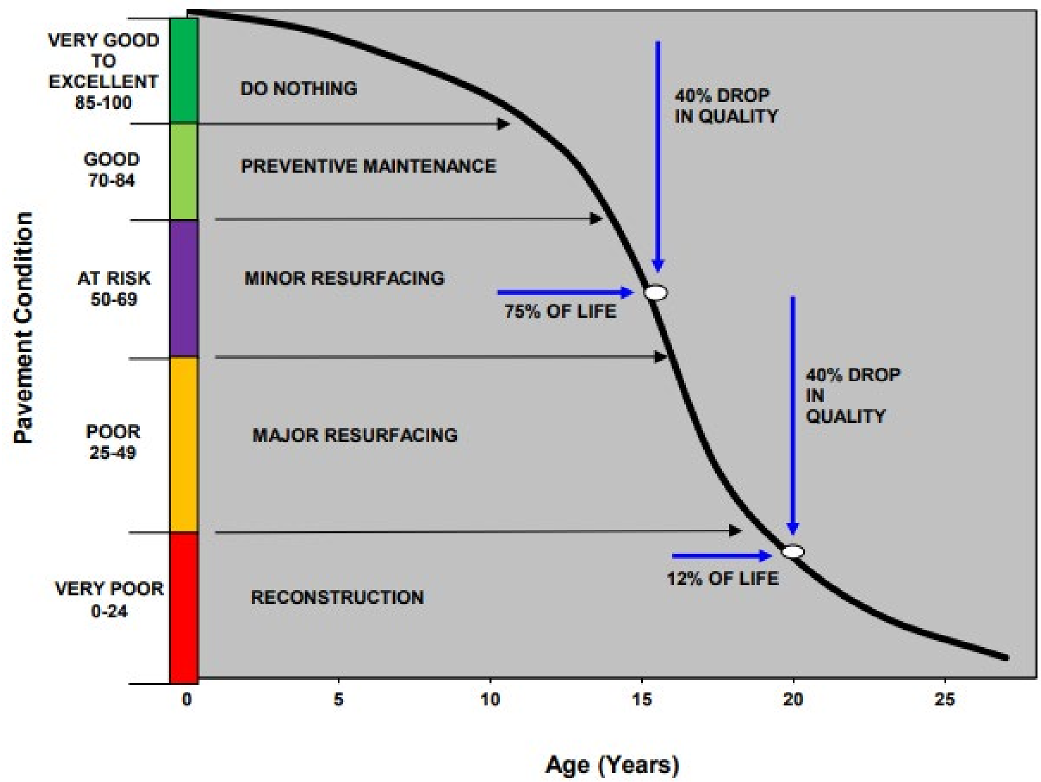

Figure 2. Pavement Deterioration Curve

Source: County of Riverside Transportation Department. *Pavement Management Report*, Riverside, CA: 2014.

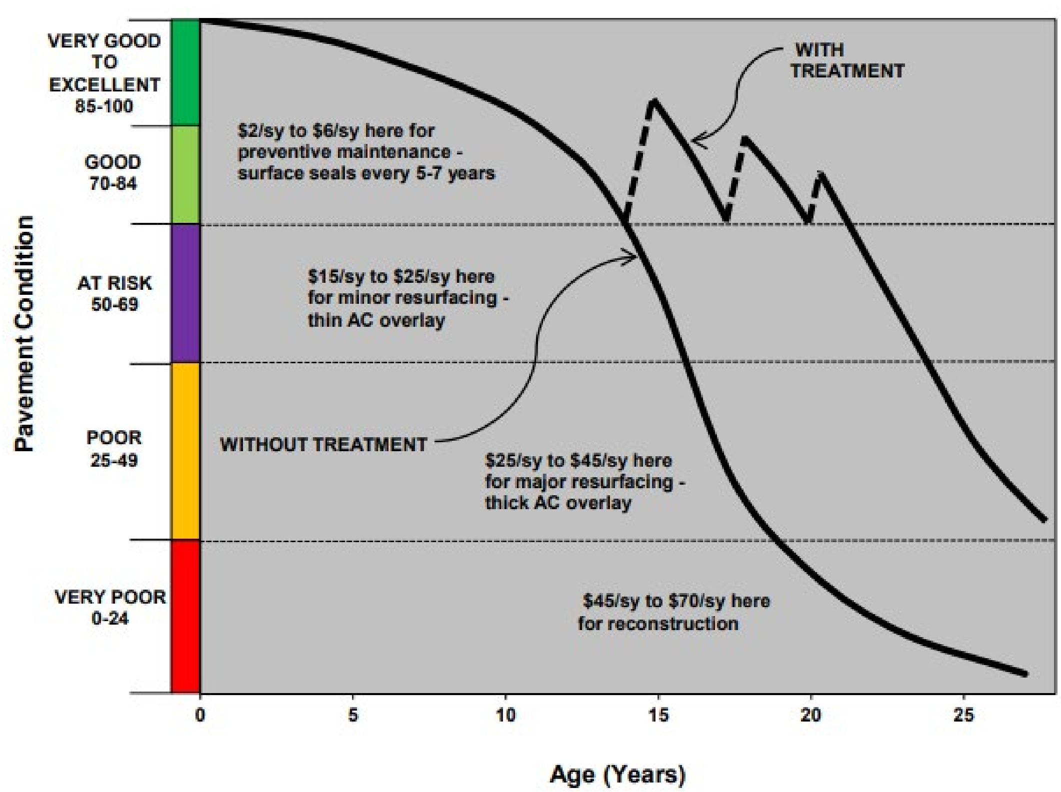

Figure 3. Pavement Deterioration Curve with and without Treatment

Source: County of Riverside Transportation Department. *Pavement Management Report*, Riverside, CA: 2014.

Caltrans PaveM

PaveM is utilized by Caltrans to recommend cost-efficient scenarios that pertain to improving pavement performance. In 2015, Caltrans invested in new technology, the automated pavement condition survey (APCS), which provides pavement condition data to support the models used in PaveM for each type of pavement, using the traffic, weather, and pavement thickness. The program is comparable to MTC's StreetSaver, as it produces the best scenarios to meet specific guidelines set by agencies.[5] Figure 4 shows an APCS vehicle model used to collect data for PaveM, while Figure 5 is an example of the PaveM system's IRI versus Time graph, showing a gradual deterioration over time.

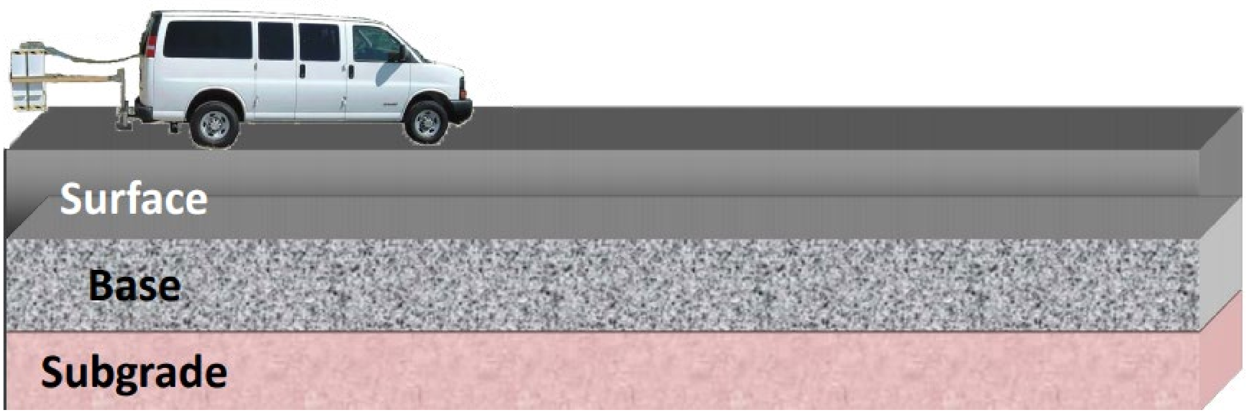

Figure 4. APCS Vehicle Used to Collect PaveM Data

Source: Tavares T., Bhullar J., Office of Planning and Programming. Office of Pavement Management and Performance. 2015 State of the Pavement Report, California Department of Transportation Division of Maintenance. 2015. 1–33.

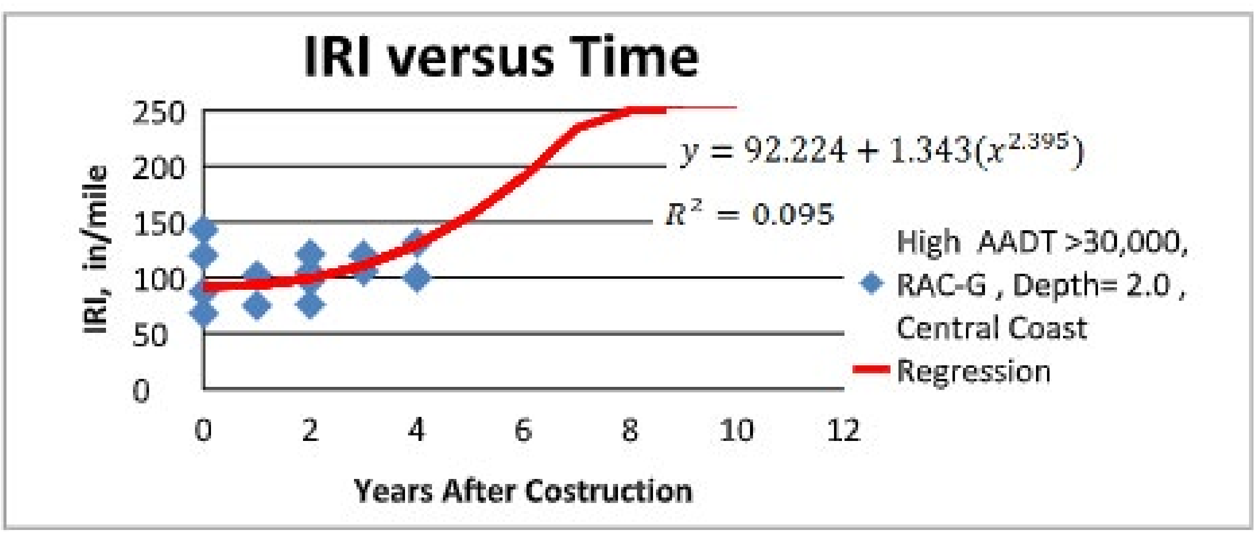

Figure 5. IRI vs. Time

Source: Ceja N., Hicks G. R., Cheng D. Development of Performance Models for Rubberized Asphalt Concrete Using Caltrans Data-Work Order 2. Sacramento, CA: Department of Resources Recycling and Recovery, 2014. 1–86.

Other Pavement Management Systems

Less common PMSs or related systems that are used by other California agencies include MicroPaver, with accompanying subsystems of FoxPro PCR 5.1, UCPRC PCR, and iVision. These pavement database systems vary in the data available, the data collected from pavements, and the systems' capabilities. The most commonly collected category of data for FoxPro PCR 5.1, UCPRC PCR, and iVision is the international roughness index (IRI).[6]

BENEFITS OF PAVEMENT PRESERVATION TREATMENTS

Background

Pavement preservation provides a means for maintaining and improving the functional condition of an existing pavement segment through application of a preventative and responsive set of treatments that slow deterioration or correct isolated pavement defects. It also means, in simpler terms, deferring costly pavement rehabilitation or reconstruction to a later time. While pavement preservation is not expected to increase the structural capacity of the pavement, it can lead to improved performance (slower cracking, reduced weathering, and attenuated degradation) and provide other performance benefits, promoting longer service lives and reduced life cycle costs (LCC). In this light, the Federal Highway Administration defines pavement preservation as work that is planned and performed to improve or sustain the condition of the road but does not add traffic capacity or structural value.[7]

The key component of pavement preservation is preventive maintenance, which can extend the useful life of the roadway in a cost-effective manner. Preventive maintenance is not directly associated with a specific treatment; rather, it is associated with the condition of the pavement when the preventative treatment is applied. When a treatment is applied in a timely manner, it is expected to have a positive effect on pavement performance in one or more of the following ways:[8]

- Preventing or slowing down infiltration of moisture and incompressible materials. This includes treatments such as crack or joint seals, membrane seals, and certain patches.

- Providing protection against aging and oxidation of bituminous surfaces. This includes items such as surface seals for asphalt surfaces.

- Restoring surface integrity. This includes surface seals and partial or full depth slab repairs.

- Improving surface texture. This includes surface seals, thin asphalt overlays and diamond grinding.

- Reducing pavement roughness. This includes thin asphalt overlays and diamond grinding.

These effects are measurable and should be reflected in the overall models of pavement performance. For example, Figure 6 illustrates the successful application of preventive maintenance treatments and their effect on a typical performance curve. The expected effects include improved overall performance in comparison to pavement performance without treatment, as well as a delayed need for rehabilitation if the pavement with preservation treatment will reach a rehabilitation threshold over time.

While the effects of preservation are easy to illustrate and are not overly controversial, their implementation and measured benefits are not as easy to quantify. There are several reasons for this situation, including the following points.

- There remain questions about the effect of preservation on commonly used measures of pavement performance, such as ride and cracking or pavement condition index (PCI).

- Where preservation has been practiced, it has not always been included as part of the pavement management systems used by highway agencies. As such, for modeling purposes, it has not always been possible to distinguish between pavements that have and have not received preservation treatments.

- In most agencies, the practice of preservation has not always been consistent from district to district. It has also varied over time as the interests of managers and funding providers have changed.

- The benefits of preservation are highly variable. Some of the benefits are affected by existing pavement condition, treatment type, material quality and consistency, quality of construction and workmanship, environment, and traffic. Variations in these factors could have a serious negative effect on the treatment benefits or the road performance.

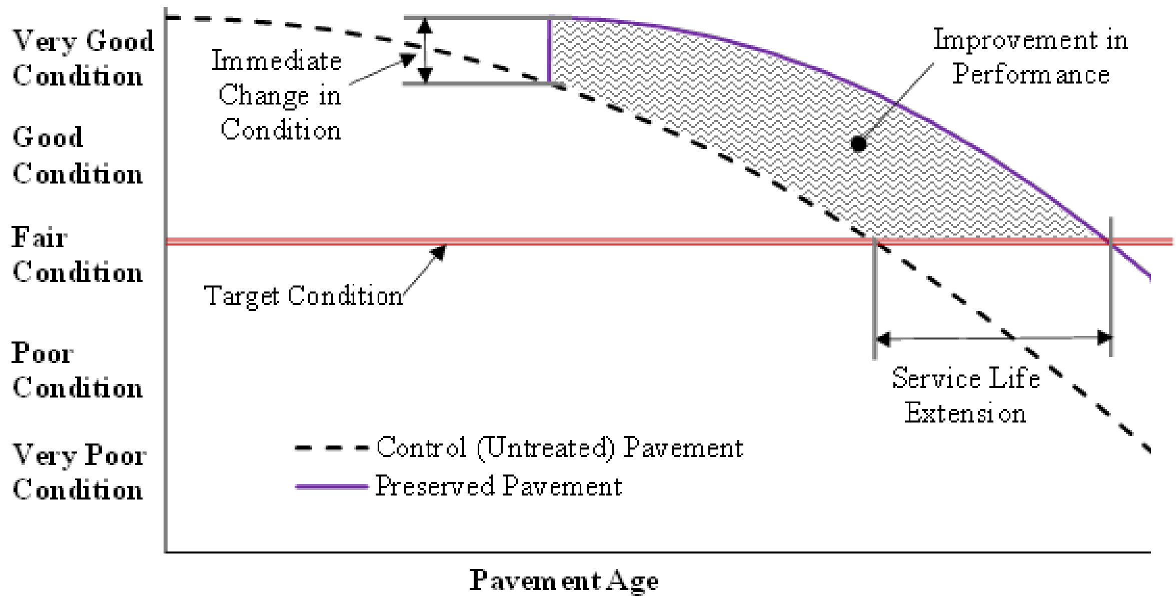

Figure 6. Anticipated Effect on Pavement Performance of a Single Preservation Treatment

Source: Rada G. R., Bryce J. M., Hicks G. R., Visintine B. A., Cheng D. Pavement Performance Measures that Consider the Contributions of Preservation Treatments, Final Report, NCHRP Report 858, Washington, D.C.: Transportation Research Board, National Academy of Sciences, 2018.

Because of the above reasons, the authors saw a clear need to identify, develop and implement a common set of pavement performance measures that could adequately measure the effect of preservation on pavement performance, service life, and life-cycle costs. To accomplish this goal, the current generation of performance measures needed to be evaluated to determine whether they could, in their current state, capture the effects of preservation treatments—or whether new measures must be developed. Although many highway agencies use performance measures, these measures are generally not used to assess the effectiveness and benefits of pavement preservation or to measure the contributions of preservation to changes in performance, service life and LCC. Incorporating these measures in pavement and/or asset management systems would provide a means for selecting the right preservation treatment at the right time, thereby better optimizing the allocation of resources.

Performance Jump and Life Extension

The report NCHRP 858 documents and presents the results of a study of pavement performance measures that consider the contributions or benefits of pavement preservation including ride, cracking, rutting and PCI.[9] Findings from a literature review and survey of highway agencies determined that the most common performance measures for asphalt pavements included ride, cracking, and rutting, and for concrete pavements the measures included ride, faulting, and cracking.[10] A framework for identifying the benefits or effects of preservation treatments was established, and then data from the long-term performance program and state highway agencies were used to evaluate the applicability of this framework. The results demonstrated that the recommended performance measures captured the benefits of preservation treatments on pavement performance.

This report had the objective to identify and/or develop pavement performance measures that consider the contributions of preservation to changes in performance, service life, and LCC. Some of the findings include: Individual distress, composite indexes and cost-based measures were identified to evaluate the effectiveness of preservation treatments. Individual distress types were roughness, cracking and rutting for asphalt pavements and roughness, cracking and faulting for concrete pavements.

- Many composite indexes were supplied by agencies, and these were evaluated as part of this research.
- A framework using performance measures to evaluate the effectiveness of preservation treatments was identified, validated and tested.
- A framework for evaluating the effects of preservation treatments on pavement performance was successfully demonstrated using both Long-Term Pavement Performance (LTPP) data and data from state highway agencies. It was found that:
    - The individual pavement condition measures recommended can capture the effects of preservation treatments on pavement performance.
    - Composite index measures captured the immediate effect of preservation but did not necessarily support the development of models that captured changes in long-term performance. Because the composite indexes are composed of many distresses, and each distress is affected differently by preservation (as demonstrated in this NCHRP report 858), it is not expected that most composite indexes will capture these changes in performance. However, because they successfully capture the effects of preservation in some cases, composite indexes should still be evaluated on a case-by-case basis as agencies are working to implement the measures.
- The data required to support the implementation of performance measures that capture the effects of preservation do exist, albeit often in many different locations. For example, many agencies collect some or all the data required to implement the measures. The LTPP database also has data that can be used to implement the measures, and further, if data are not directly available, many literature sources exist that can support implementation.
- The analytical methods required to support the development of models for implementation of the measures are outlined in the guide document which is an appendix to NCHRP report 858. Given that measured pavement condition data include considerable variation (e.g., measurement errors) and other issues, these methods are required to be somewhat more complicated than basic statistics. However, the guide document thoroughly discusses several of the techniques used to analyze the data during the conduct of this research.

Throughout the conduct of this research, it was found that the implementation of performance measures that capture the effect of preservation can enhance pavement management practices. Given that performance measures are integral to several decision processes within pavement management (e.g., treatment selection or project prioritization), if the measures do not adequately capture preservation, the resulting decisions will not reflect good business practice and will not reflect an improved LCC. Accordingly, efforts should be undertaken by every agency to implement the methods and recommendations developed as part of this research.

A guide was prepared to help implement the findings of this stud.. Though the study was aimed at state highway agencies, it should also be applied by local agencies if frequently using the PCI as the performance measure. The guide includes the following:

- A step-by-step procedure, including flowcharts and examples, for establishing the initial performance jump and long-term performance for each of the applicable treatments.

- Step-by-step procedures, including flowcharts and examples, for incorporating into an agency's business practice the effects of preservation treatments on pavement performance, service life, and LCC.

This approach will be utilized in the next phase of the project using data from selected cities and counties to identify the benefits/effects of preservation treatments including chip seals, slurry surfacing, and cape seals.

CHIP SEALS

Factors Affecting Chip Seal Performance

There are a variety of factors that have been identified as influential in the performance of chip seals, including the following factors identified by AGC Arizona Chapter's Pavement Preservation Committee, Cheng et al., and Cheng:[11]

- Binder types
    - Soft binders are more flexible and perform better in lower-temperature conditions, such as in high mountain areas
    - Harder binders are less flexible and perform better in higher-temperature conditions, such as in desert areas
- Traffic conditions
    - Upper limit for average daily traffic (ADT)
    - Intersections, stop/go locations, and acceleration/deceleration lanes
    - Traffic levels can affect the performance of chip seals: volume of traffic, the movements of vehicles, stopping conditions, as well as design and construction practices

- Climatic and environmental conditions
    - Temperature
    - Rainfall
    - Freeze/thaw cycles
- Geometrics
    - Maximum grade and superelevation
    - Drainage
- Aggregate quality
    - It is important to utilize an aggregate material that is composed of clean and durable crushed rock
    - All binder types will have problems adhering to aggregate that has too high a percentage of fines or aggregate that is coated with fine dust
- Application rates
    - Aggregate application rates
    - Binder application rates
    - Excess/insufficient binder and/or aggregate can cause early project failure such bleeding, rock loss or raveling
- Existing pavement/surface condition
    - Rutted pavement
    - Cracked pavements
- Construction practices and methods
    - Surface preparation (patching, crack sealing, cleaning)
    - Start of chip seal shots
    - Allowable time between binder and aggregate application for emulsions
    - Rolling
    - Aggregate embedment/adhesion
    - Project inspection
    - Ambient temperatures for applying chip seals
    - Start and end dates for chip seals
    - Fog seal / flush coat

  - Chip seal warranties
  - Condition of contractor’s equipment
- Quality assessment practices
  - Quality of equipment
  - Quality control testing
  - Inspections
    - Material sampling
    - Spread rate testing
- Contract administration (usually carried out by the resident engineer)
  - Adherence to plans and specifications
  - Quantities/contract payments
  - Set application rates of materials
  - Supervision of inspectors
  - Contract change orders
  - Rejection of out-of-specification materials
- Knowledge and training of inspection personnel
  - Responsible for sampling and testing the materials
  - Confirmation and calibration of equipment
  - Construction method monitoring
  - Alerting the resident engineer of the need to adjust material application rates

Performance of Chip Seals

Knowledge of the existing performance of the chip seal treatments—in addition to the factors that affect the performance—is vital for the determination of performance models. Chip seal performance studies reviewed[12] show that the factors affecting performance include:

- Moisture: chip seals in state of Washington work in both wet and dry conditions but perform better in drier conditions.

- Traffic: some agencies do not use chip seals due to high traffic volumes present on their roadways.

- The existing pavement condition for which most districts in California use chip seals is good to fair.

- Asphalt rubber (AR), polymer-modified (PM), and terminal blend (TB) chip seals are most commonly used in California.
- In California, chip seal preference varies by the district and its needs.
- Some agencies use warrantees of one to three years for chip seals.
- Life expectancy for counties ranged from 3 to 20 years: many responses indicated failure between 6 and 10 years, with a projected average (from 12 districts) being 9 years.
- The expected treatment life under good conditions for chip seals ranges from 4 to 10 years with an average of 7 years.

According to an FHWA study, chip seals are affected the most by construction and workmanship, followed by the condition of the pavement prior to treatment.

Figure 7 displays the effect that construction and workmanship have on the overall performance of the pavement with the chip seal treatment. Figure 8 shows the average chip seal life reduction due to the existing condition before treatment. The percent reductions for chip seals caused by poor and marginal construction procedure and workmanship are 68% and 46%, respectively.[13] These grades of workmanship also result in the reduction of life by 2.2 years and 3.8 years, respectively.[14]

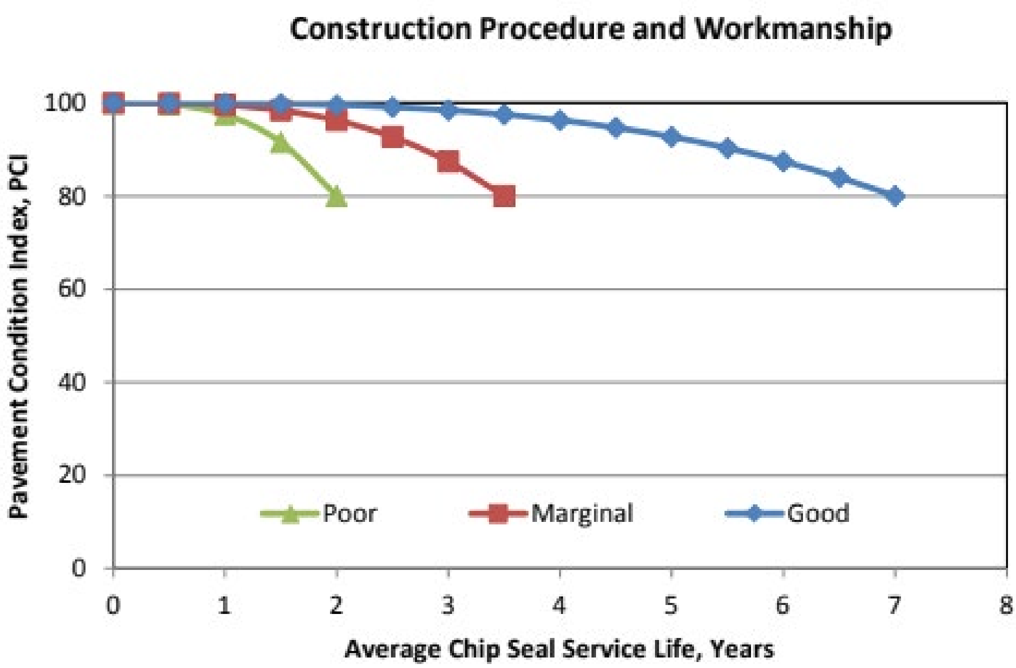

Figure 7. Chip Seal Treatment Life Reduction Due to Different Quality Construction Procedures and Workmanship

Source: Hicks G. R., Visintine B., Cheng D., Elkins G., Groeger J. *Factors Affecting the Performance of Pavement Preservation Treatments: Sensitivity Analysis Report*, Beltsville, MD: AMEC Environment & Infrastructure, Inc., 2013. 1–33.

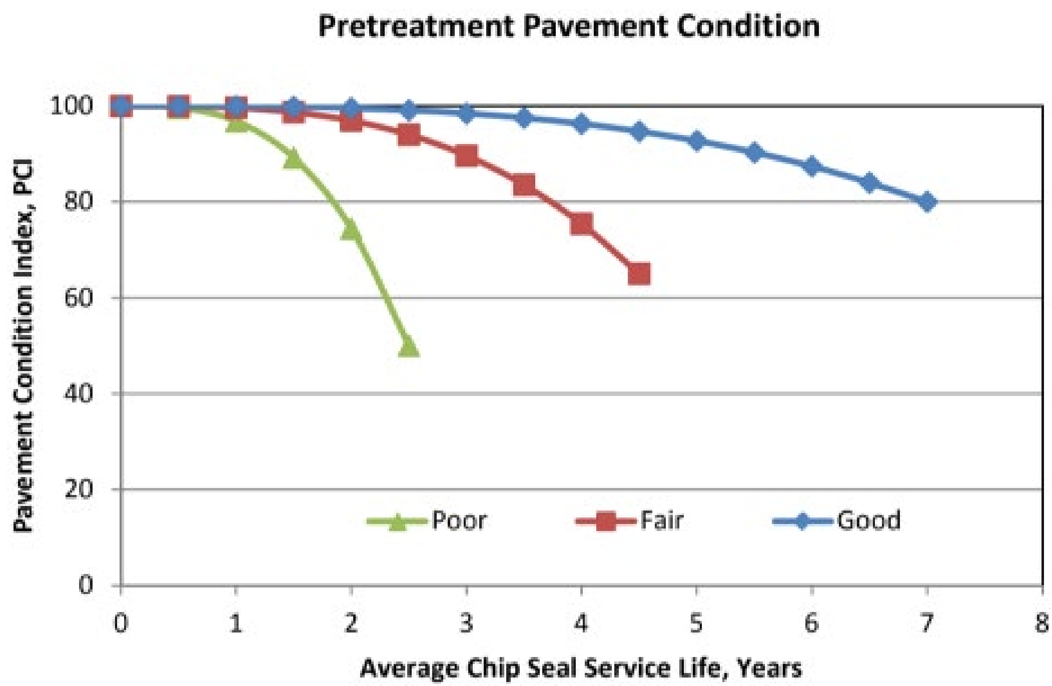

Figure 8. Chip Seal Treatment Life Reduction Due to Different Pretreatment Pavement Conditions

Source: Hicks G. R., Visintine B., Cheng D., Elkins G., Groeger J. *Factors Affecting the Performance of Pavement Preservation Treatments: Sensitivity Analysis Report*, Beltsville, MD: AMEC Environment & Infrastructure, Inc., 2013. 1–33.

The life expectancy of chip seal binder types varies over time. The expected performance of the different binder types for local agencies in California assessed using the PCI approach in StreetSaver is shown in Figure 9. In addition, Figure 10 displays the expected performance curve of the different binder types using the International Roughness Index (IRI) as the performance measure which is favored by Caltrans.[15]

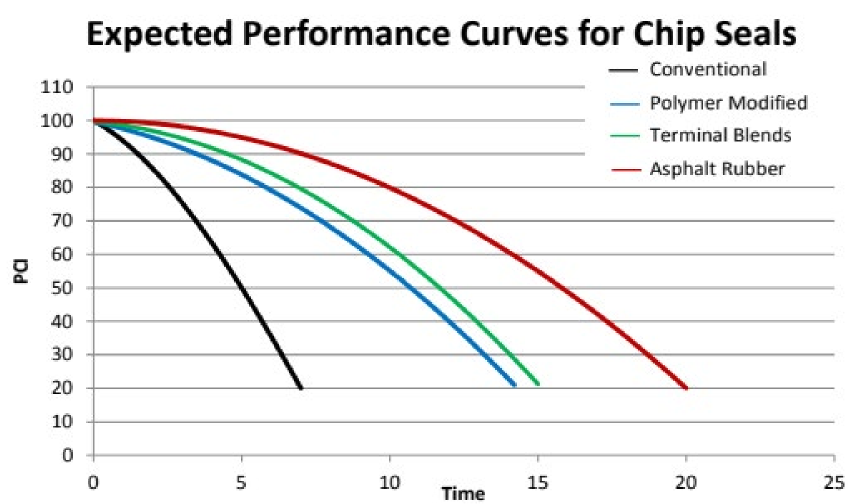

Figure 9. PCI for Different Binder Types for Local Agencies

Source: Cheng D., Hicks G. R., Wingo C., Krumdieck J., Worcester K. *Literature Review on Chip Seals Including Performance Models*, Sacramento, CA: California Department of Resources Recycling and Recovery, 2016. 1–70.

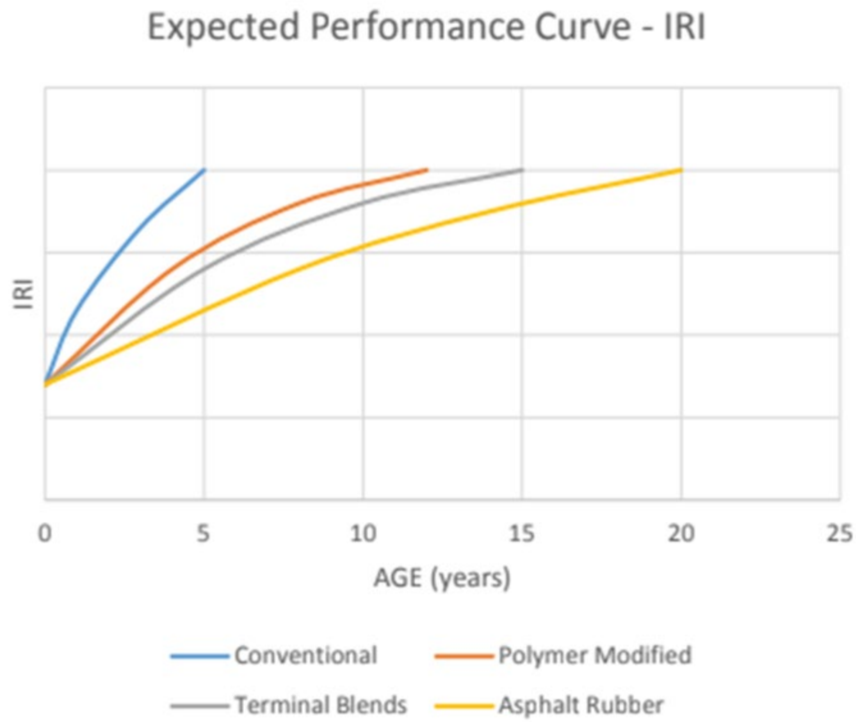

Figure 10. Expected Performance Curves for Chip Seals

Source: Cheng D., Hicks G. R., Wingo C., Krumdieck J., Worcester K. *Literature Review on Chip Seals Including Performance Models*, Sacramento, CA: California Department of Resources Recycling and Recovery, 2016. 1–70.

The expected performance of chip seals over an existing asphalt pavement is shown in Figure 11, which shows the resulting performance of chip seals within each state. In California, the expected performance is good according to this study.

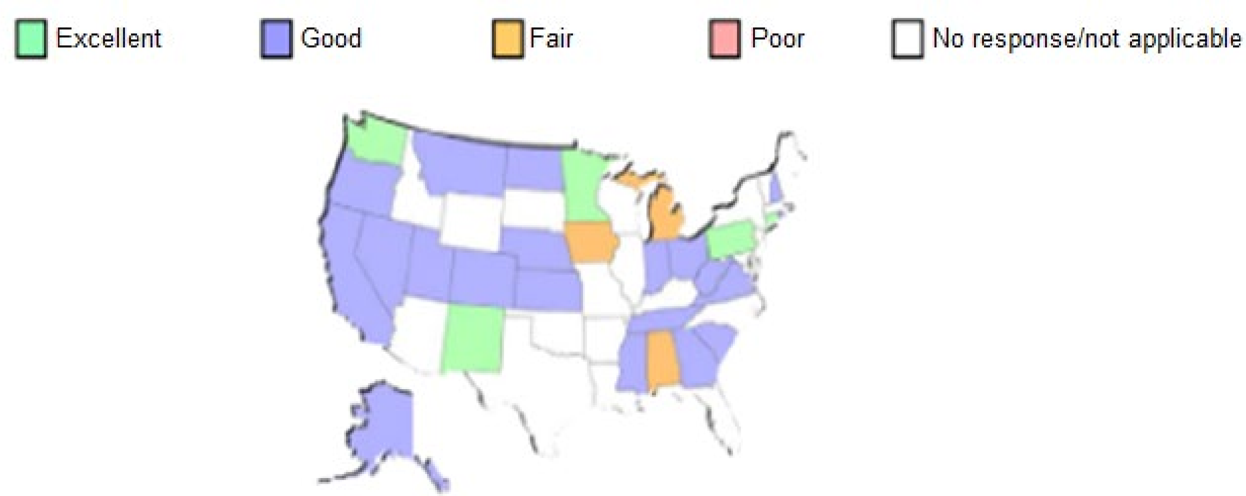

Figure 11. Performance of Chip Seal Over Existing Asphalt Pavement

Source: Pierce L. M., Kebede N. *Chip Seal Performance Measures–Best Practices*, Urbana, IL.: Applied Pavement Technology, Inc., 2015. 1–57.

The primary factors included in a CalRecycle report showed that binder type, functional class, and climate all affected the performance curves.[16] The performance curves showing the expected performance of chip seals with respect to road functional class are shown in

Appendix B.2; this appendix also contains the performance curves based on the effects of functional class and climate on the pavement condition index (PCI) with polymer-modified emulsion (PME) binders. Some curves are specific to regions and areas in California that have different environmental conditions from most California counties.[17]

In a national study performed by the Washington State Department of Transportation (WSDOT), a survey was distributed to each state, and 33 agencies responded reporting an average chip seal life of 5.8 years. The study found that out of the factors previously discussed, the quality of the aggregate had the least impact.[18]

A study performed by Washington's DOT evaluated the effectiveness of chip seals on alligator cracking and longitudinal cracking. The overall performance of the chip seal treatment was not as effective as planned; however, the chip seal still served the purpose of extending the overall pavement life. The treatment did not allow potholes to form and did not show the presence of longitudinal reflection cracking and raveling. It was determined that chip seals "are capable of extending pavement life for five years or more."[19]

- Full lane chip sealing could be used more frequently than it currently is, because it can mitigate several pavement distress conditions. Full lane chip sealing on SR101 in the Olympic region in Washington provides visual evidence of the effectiveness of chip sealing as a preventive measure. The pavement quality of the chip seal test sites was not the best; however, the chip seal performs the essential function of extending pavement life.

- Most of the chip seals constructed under region-wide contracts over many years have had excellent performance, indicating that the problems at test sites may be due to materials or workmanship issues. It may also be that the chip seal was placed on a surface with distresses not compatible with a chip seal, such as delamination.

- Two in-wheel-path chip seals were applied to address alligator cracking and longitudinal cracking. The performance of these chip seals was disappointing; however, each chip seal applied did hold the pavement together, not allowing potholes to form, and did perform its function of extending pavement life. After four years, due to the presence of longitudinal reflection cracking and raveling, the condition of the project went from good to fair.

- The eastern region of Washington is using in-wheel-path chip seals to fill ruts and is following with a full-lane chip seal in one to two years. This technique of preventive maintenance displays excellent performance.

- Crack sealing is often used before chip sealing: for example, if the cracks were wide block cracks and wide, deep transverse thermal cracks, they were sealed using a special sealant called Nuvo Gap. After the crack sealing, the road sections were left alone for about a year before applying the chip seal. The performance of the chip seal placed over the crack sealed pavement was excellent. The appearance of the chip seal changed over time to show some shadowing of the underlying crack sealing, but this result has not been detrimental to the performance of the chip seal in extending pavement life.

- Dig-out repairs (patches) prior to chip sealing showed variations of overall performance on pavement sections.

Advantages and Disadvantages of Chip Seals

Advantages

Based on the literature, the following items are the major advantages of using chip seals:[20]

- Enhances and extends the life of a road by 5 to 10 years
- Cures quickly
- Restores skid resistance to a road surface
- Corrects raveling
- Halts pavement oxidation
- Resists reflection cracking
- Costs less than a reconstruction while still addressing minor road damage
- Can “mitigate a number of pavement distress conditions” if applied correctly
- Works best on roads with sound structural integrity and low distress level
- Can be used on high-volume roads, if applied prior to the appearance of distress
- Life expectancy for roads in various counties ranged from 3 to 20 years, with many chip seal projects failing between 6 and 10 years and a projected average life (from 12 districts) of 9 years
- Protects roadway from deteriorating effects of sun, water, and cracking

Disadvantages

Although there are many benefits to using chip seals, there are several disadvantages and limitations to consider, including the following:[21]

- Cure time for emulsion chip seals takes hours, depending on the climate conditions of the project, before the road can be opened to traffic
- Flying chips can damage windshields if not swept and fog sealed/flush coated before being opened to traffic

- Noise pollution when driven on
- Weather conditions, such as rain, can limit the time of application of chip seals during construction
- Chip seals create a rougher surface and do not improve ride quality
- Polymer-modified emulsion (PME) chip seals are not normally suitable for intersections nor high-stress areas
- Hot applied binder using Performance Graded (PG) asphalt and asphalt rubber (AR) chip seals cure quickly; therefore, it is imperative that the aggregate be applied quickly behind the binder application and immediately rolled

SLURRY SEAL AND MICROSURFACING

Factors Affecting Slurry Seal and Microsurfacing Performance

The primary factors that affect the performance of slurry seal and microsurfacing are as follows:[22]

- Existing pavement/surface conditions
- Surface preparation prior to chip seal treatment
- Materials
  - Aggregate type and quality
    - Shape
    - Gradation
    - Cleanness
  - Emulsions (speed of set and characteristics of the finished product)
  - Additives
  - Fillers
  - Mix design
- Equipment
  - Calibration
  - Condition
  - Operators
- Placement/application practices

- Existing roadway conditions (deterioration and porosity of the roadway)
- Maintenance efforts and timing of those efforts, such as crack sealing and pothole repair prior to application

- Traffic conditions (present and future volume; percentage of truck traffic)
    - Average Daily Traffic (ADT)
    - Truck percentage
- Weather and environmental conditions during construction
    - Temperature
    - Humidity
    - Rainfall
    - Other
- Construction procedures
    - Surface preparation
    - Equipment requirements, including calibration
    - Stockpile/project staging area requirements
    - Safety and traffic control
    - Application conditions: the emulsion must break and form a continuous film for the slurry seal to be cohesive
    - Rolling
    - Types of applications include parking lots, highways, city streets
    - Workmanship and quality issues including longitudinal joints, transverse joints, edges and shoulders, uneven mixes and segregation, smoothness problems, and damage from opening to traffic too soon
    - Post application activities include rolling, sweeping, and sanding
    - Post-treatment requires additional sweeping to remove loose aggregate

Performance of Slurry Seals and Microsurfacing

Slurry Seals

An Asphalt Institute report referenced a California project estimating the slurry seal life expectancy to be 3 to 5 years with a maximum of 15 years when the treatment is applied as a preventive maintenance measure.[23]

In a Texas study, it was found that the slurry seal coats are more cost effective compared to conventional asphalt seal coats.[24] Even though slurry seals are generally used on roads that are in poorer condition, the results showed that, on average, the cured surface had higher skid resistance and a marginally better ride quality at a lower total cost than conventional asphalt seal coats.[25]

In a study done by UNR, the application of the slurry seal at years 0 and 1 did not show a significant change in the shape of the performance curve or in the initial PCI value.[26] Additionally, the pavement service life was not extended by application of the slurry seal except in a few cases.[27] The application of the slurry seal at years 3 and 5 showed significant jumps in the PCI value at the time of application and in the shape of the performance curve for future years. On average, the initial PCI value increased by 12 points when slurry seal was applied 3 years after construction. On the other hand, an increase in the initial PCI value between 11 and 24 points was observed for the newly constructed pavements when slurry seal was applied 5 years after construction. The increase in PCI value was more significant for the residential roads, followed by the collector and arterial roads. In the case of asphalt pavements, the increase in initial PCI value when slurry seal was applied 5 years after construction ranged between 22 and 31 points with the highest increase being observed on arterial roads. Typically, the slurry seal performance life ranged from 2 to 4 years, except when applied in years 0 and 1.[28]

Slurry seals are also affected by construction and workmanship. An FHWA-funded report emphasizes how certain factors, especially workmanship and construction practices, affect the result of treatment applications and their performance.[29]

Figure 12 displays the general trend of how construction and workmanship influence the performance of slurry seals, while Figure 13 displays the pre-treatment pavement condition and its effect on slurry seal life reduction. The pavement condition prior to treatment is the second most significant factor affecting slurry seal performance.[30]

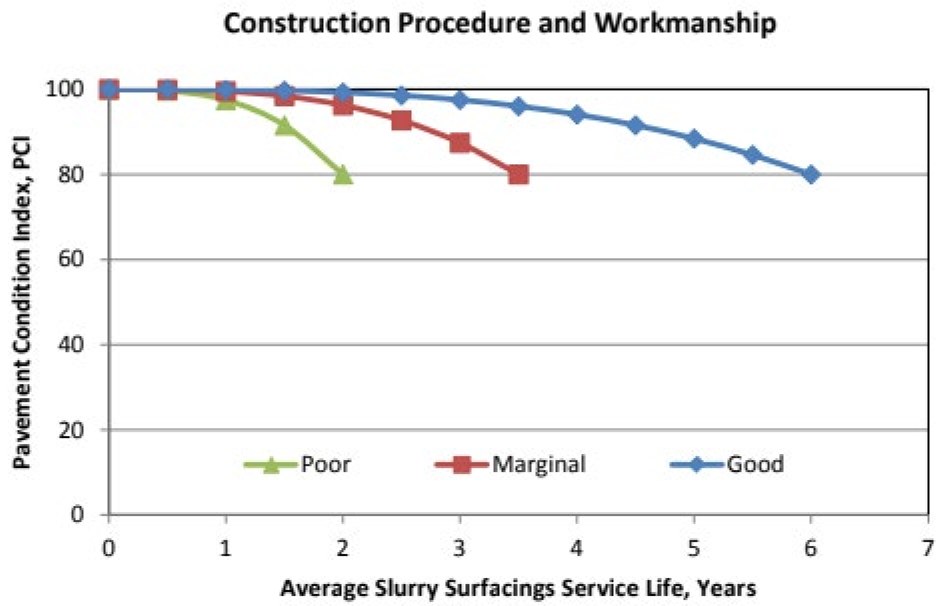

Figure 12. Slurry Surfacing Treatment Life Reduction Due to Construction Procedures and Workmanship Varying in Quality

Source: Hicks G. R., Visintine B., Cheng D., Elkins G., Groeger J. *Factors Affecting the Performance of Pavement Preservation Treatments: Sensitivity Analysis Report*, Beltsville, MD: AMEC Environment & Infrastructure, Inc., 2013. 1–33.

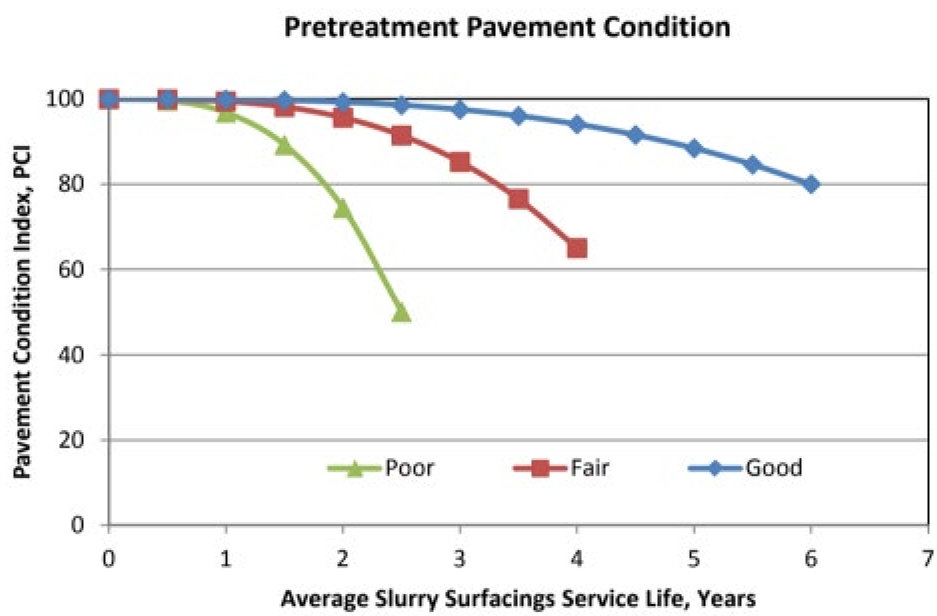

Figure 13. Slurry Surfacing Treatment Life Reduction Due to Different Pretreatment Pavement Conditions

Source: Hicks G. R., Visintine B., Cheng D., Elkins G., Groeger J. *Factors Affecting the Performance of Pavement Preservation Treatments: Sensitivity Analysis Report*, Beltsville, MD: AMEC Environment & Infrastructure, Inc., 2013. 1–33.

Microsurfacing

A survey was performed to determine the service life of microsurfacing seals. The study considered which states and provinces in the U.S. and Canada utilized microsurfacing and which did not. Overall, the highest number of results in the U.S. indicated service lives ranging primarily from 5 to 7 years. A summary of the expected life data gained from the survey can be found in Figure 14.[31]

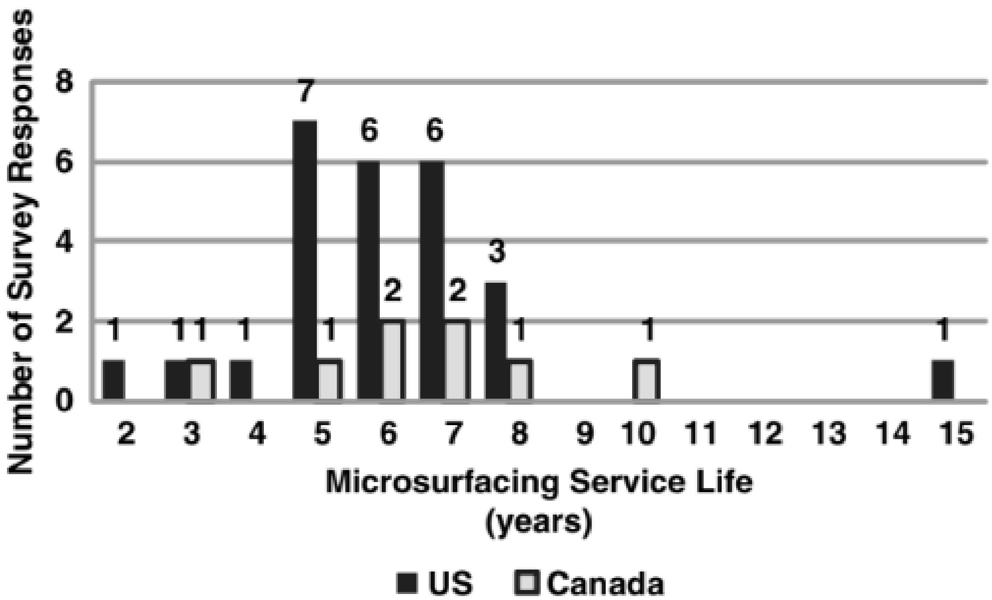

Figure 14. Summary of Survey Results for Microsurfacing Service Life Responses

Source: Gransberg D., James D. M. B. *NCHRP Synthesis 342 Chip Seal Best Practices*, Washington, D.C.: Transportation Research Board, 2005. 1–111.

In the Canadian province of Quebec, several microsurfacing projects include but are not limited to Autoroute 30 at Verenne, Autoroute 10 at Lac Brome, and Autoroute 70 at Chicoutimi. These projects were done between 2007 and 2009 and are similar to each other in that these routes have very high and heavy traffic flow. While some projects were reported to be performing excellently, others were not. The worst-performing project was Autoroute 70 in Chicoutimi. The first section, placed in 2008, was severely damaged by snow plows and the heavy truck traffic. Repairs were performed in 2009 with improved results but road condition far from what was desired. The main causes for the unsatisfactory performance include un-tested aggregate, rutting, and severe climate and traffic conditions (e.g. aggressive plowing up to 6 months per year, heavy traffic using studded tires).[32]

Advantages and Disadvantages of Slurry Seals and Microsurfacing

Advantages

Slurry seal advantages include:[33]

- Lower cost in comparison to microsurfacing

- Provides waterproofing and protection of the underlying surface
- Provides 'new pavement' look
- Allows for re-alignment of striping
- Good for low-volume roads
- Can treat raveling, protect oxidized pavements with hairline cracks, and improve skid resistance
- Covered aggregate is not loose
- Improves quality of surface texture
- Corrects minor texture deficiencies
- Curb height loss is minimal
- Manhole and utility box adjustments are not needed during application.
- New pavement surface for better lane delineation
- Minimal aggregate loss when open to traffic.

Microsurfacing advantages include:[34]

- Overall higher durability for heavier traffic volumes than slurry seals
- It can be placed at night and/or in cooler temperatures
- It can correct minor surface irregularities, including rutting
- Able to be open to traffic in approximately 1 hour with favorable weather, minimizing user work zone delays and improving traffic safety
- Can treat raveling, oxidized pavements with hairline cracks, rutted pavements, and rough, washboard pavements
- Improves skid resistance and aesthetics with new surfacing
- Smaller environmental footprint than HMA overlays
- Can be applied on roads with snow if the snow is regularly removed and the pavement is structurally sound

Slurry seals and microsurfacing are similar, as they reduce pavement permeability and share the ability to easily adjust application rates to address surface distresses. However, there are differences between the two, such as ambient temperature for application, what it treats, and the lifespan. Furthermore, microsurfacing generally uses better-quality aggregates and has a fast-setting emulsion of higher viscosity, allowing for thicker layers to be applied. Neither treatment can be used to treat or improve the structural integrity of the existing pavement.[35]

Disadvantages

The disadvantages of slurry seals include distress modes that cannot be addressed by this treatment, such as:[36]

- Rutting
- Cracking
- Base failures
- HMA layers that exhibit plastic shear deformation
- Slurry seals require several hours to cure, where microsurfacing may require much less time to cure
- Slurry seals require warmer temperatures during construction than microsurfacing

CAPE SEALS

Factors Affecting Cape Seal Performance

The factors that affect cape seal performance are similar to those of chip seals and microsurfacings and include:[37]

- Existing pavement condition
- Surface preparation
- Material properties
- Material mix design
- Construction practices
- Traffic level
- Pavement structure
- Environment

Performance of Cape Seals

Nevada DOT (NDOT), partnered with the Department of Civil and Environmental Engineering at the University of Nevada, Reno, performed an analysis of Washoe County's pavement management system. The analysis was intended to evaluate the long-term performance of cape seals constructed with either microsurfacing or slurry seal. The study evaluated factors including construction practices, material properties, mix design, traffic level, pavement structure, environment, and pavement condition index (PCI) before application. The study focused on evaluating 33 microsurfacing seals and 22 slurry sealed roads. Agency experience formulated the assessment of what worked and what did not with respect to the type of pavements.[38]

Washoe County of northern Nevada has been using cape seals repeatedly to preserve its road network (total of 710 lane miles). The cape seal using slurry seal (type 3) has been regularly used in the Truckee Meadows and desert stretches of Washoe County. However, for the highly trafficked mountain roads at higher elevations such as the Incline Village area at Lake Tahoe, the cape seal treatment using microsurfacing has mostly been the standard practice.[39]

Microsurfacing, when used as the top layer of the cape seal, exhibit very consistent long-term performance regardless of the conditions of the existing pavement, as expressed by the pre-PCI level. The effective performance life of microsurfacing cape seals is 7 years in the Truckee Meadows and 5 years in Incline Village. The effective performance life of slurry seal cape seals is 3.5 years in the Truckee Meadows and 3 years in Incline Village.[40]

From the NDOT study, the performance of the East Lake Boulevard is displayed in Figure 15 as an example of the performance curve developed for a slurry seal cape seal.[41] The lifespan of cape seal sections studied lasted from 3 years to 9 years in Nevada across the different sites. The study used cape seals with both slurry seals and microsurfacing.[42]

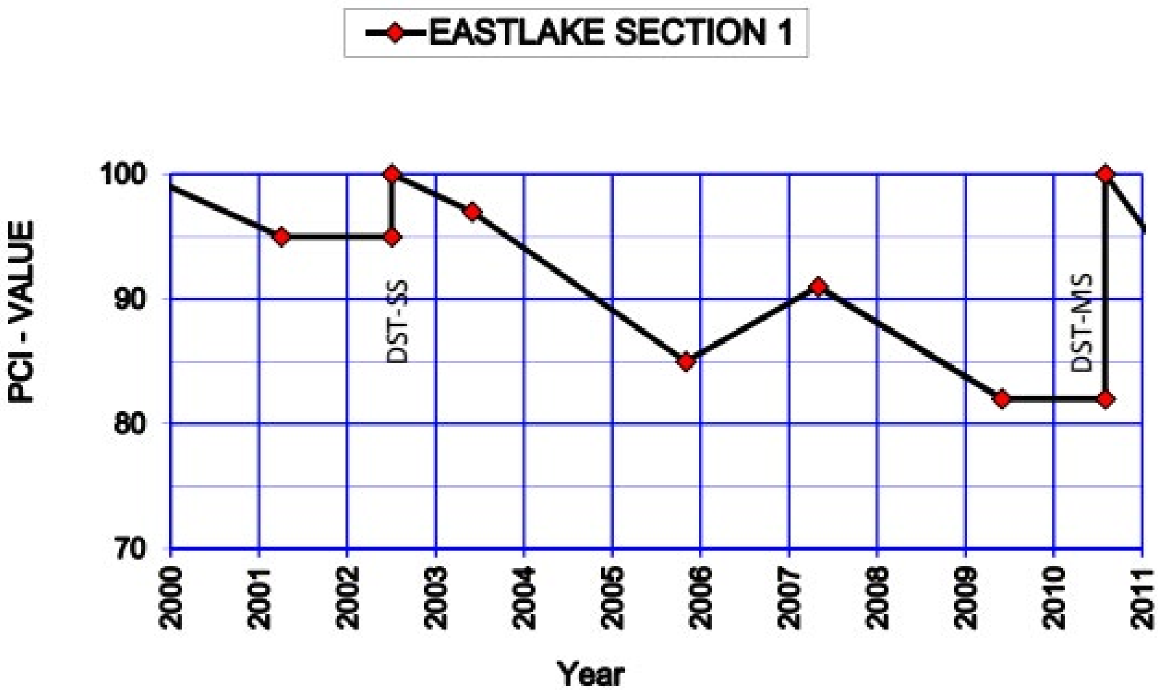

Figure 15. Performance of Slurry Seal Cape Seal on East Lake

Source: Sebaaly, P.E., Hajj, E.Y., Weitzel, D., Belancio, G. *Effectiveness of Cape Seal Pavement Preservation Technique in Northern Nevada*, Reno, NA: SOLARIS University Transportation Center, 2016.

Cape seal performance in South Africa has shown significant quality performance over the years even with the varying environments and terrain. Cape seals seem to have the lowest risk as an initial seal on low-volume roads. This treatment type can sustain cold temperatures without raveling and can handle traffic turning movements, making it a favorable treatment in South Africa. The expected life of Cape seals before any significant cracking occurs as experienced in South Africa is 10 years.[43]

In South Africa, the significant distress types seen with cape seals include early cracking, bleeding, and raveling. Early cracking could be a product of colder weather and a non-flexible binder. Properties of the binder as well as the temperature, traffic, and moisture content of the aggregate and surface of the roadway can contribute to the early cracking. Bleeding could be the result of large aggregate embedment, binder rise due to evaporation from the base and solvent volatiles, loading, and application of treatment before the emulsion tack coat has completely cured. Excess moisture can result in poor adhesion.[44]

Advantages and Disadvantages of Cape Seal

Advantages

A Cape seal is a favored treatment for local agencies because it does the following:[45]

- Provides the benefits of both a chip seal and a slurry surfacing
- Seals existing pavements to keep air and moisture out of the cracks

- Prevents raveling
- Provides a skid-resistant driving surface with the appropriate aggregate
- Provides a smooth, durable surface treatment
- Prevents loss of chips when bonded to slurry
- Prevents abrasion and erosion
- Is appropriate for city use because of the noise reduction and ride quality improvement
- Has higher benefit–cost ratio for microsurfacing cape seals in comparison to slurry seal cape seals
- Resists raveling in colder weather and can handle traffic turning movements without distress

Disadvantages

Although Cape seals have some great advantages that make them a favored treatment for specific projects, they also have some disadvantages:[46]

- Slurry seal Cape seals cannot be applied in cold weather
- Lower benefit–cost ratio for slurry seal Cape seals in comparison to microsurfacing cape seals
- More construction time because it requires a PME chip seal to cure before a slurry seal or microsurfacing treatment can be applied as a wearing surface
- Higher cost than the individual treatments

SUMMARY

This chapter discussed the common pavement preservation treatment systems used in California and neighboring areas. In addition, this chapter detailed the factors that affect treatment types, the performance of each treatment type, and the advantages and disadvantages for chip seals, slurry seals, and Cape seals.

The benefits of pavement preservation treatments were explored, detailing the influence pavement preservation has on the overall condition and performance of roadways. The use of a PMS can improve the efficacy of preventative maintenance treatments by determining the most cost-effective strategy and can improve the overall quality of the roadway network by informing proper timing of preventative maintenance treatments. By identifying the factors that affect the roadway in a district, predictions and conclusions can be formulated to determine the expected performance of the road over time.

The performance curves from the literature review detail the influence of specific quality factors that can lead to deterioration of the pavement at a much faster rate. Two major factors were the quality of workmanship and construction and the pre-existing pavement condition.

The review also included extensive surveys conducted by different agencies to rank the most important factors that are to be considered when selecting treatments:[47]

- Pre-existing pavement conditions
- Quality of construction
- Quality of materials
- Proper selection of treatment
- Traffic volume
- Material compatibility with mix design
- Construction capabilities and knowledge
- Traffic type
- Environmental factors
- Construction equipment
- Freeze/thaw cycles
- Ultraviolet (UV) exposure
- Urban vs. rural treatment situations

III. BEST PRACTICES FOR PAVEMENT PRESERVATION TREATMENTS

This chapter presents the best practices for project selection, design, construction, and quality assurance.

CHIP SEALS

When to Use and When Not to Use Chip Seals

In addition to use on roads in good condition as a preventive maintenance measure to increase service life, slurry seals may also be used to treat certain minor distresses.

Chip seals have specific limitations and parameters that must be followed to produce an effective treatment. For example, chip seals should adhere to the following guidelines:[48]

- As a surface for light to medium traffic, at an average daily traffic (ADT) value of less than 30,000
- For a conventional chip seal application, it should be used to treat structurally sound pavements with minimal cracking
- PME chip seals are used for raveling and pavement oxidation; however, many local agencies use PME chip seals as a treatment for all road distresses
- Rubberized chip seals cure quickly, restore skid resistance, and resist reflection cracking
- Full lane chip sealing is best for treating longitudinal and transverse cracking at a width less than ¼-inch, and alligator cracking
- Chip seals should be placed when the ambient temperature is a minimum of 50°F (10°C) when using emulsions, and the surface temperature should be 70°F (21°C) when using asphalt cement
- The surface temperature should be a minimum of 70°F (21°C) with a maximum of 140°F (54°C) when using emulsions
- For hot chip seals, the minimum surface temperature should be 70°F and rising
- Wheel path chip sealing is best for treating alligator cracking and rutting in the wheel paths

According to WSDOT, U.S. agencies generally place chip seals when there is some evidence of distress on the roadway.[49] The best design approaches include steps for evaluating and determining the following:[50]

- Surface texture and surface condition
- Traffic conditions: volume, speed, percentage of trucks, etc.
- Climate and weather conditions
    - Humidity and wind
    - Air temperature
    - Surface temperature
- Type of chip seal suited to treat the distress type
- Aggregate selection
    - Type and condition of aggregate
- Binder application rate
- Time available for construction operations
- Gradation and fractured faces

Selection of the correct asphalt type and grade is critical for the overall performance of chip seals. To know whether the correct selection was made, the binder needs to:[51]

- Be fluid enough to spray uniformly and not puddle, which is directly related to equipment problems
- Retain consistency to bond with aggregate after application
- Cure and adhere quickly
- Prevent major loss of aggregate after traffic is released back onto the roadway
- Not bleed or strip based on the weather conditions

Chip seals should not be used for the following reasons:[52]

- Structurally deficient pavements
- Cracks greater than 1/4 -inch width unless it is sealed
- Large number of potholes
- Ride quality needs significant improvement
- If using conventional or hot applied chip seals, distresses such as cracking, severe

flushing, and base failures cannot be treated and need to be repaired prior to seal coat treatment.

- Deformation, rutting, and shoving cannot be treated with any type of chip seal
- Chip seal asphalt emulsions should not be applied when the ambient air temperature is predicted to be less than 39°F within a day following application
- Rain will be expected within 24 hours to protect waterways, and to ensure quality of applied product
- High wind may cause safety issues

Construction Process

This subsection lists the most common equipment to use for chip seal applications along with various requirements for each equipment item for a successful application and performance of the treatment:[53]

- Emulsion distributor truck that heats up the emulsion evenly to 85°C (185°F), pumps emulsion with even application and uniform coverage, and a rear-mounted spraybar that can be adjusted to the application rate ordered or specified
- Aggregate spreader needs to be a mechanical self-propelled type to obtain a uniform aggregate application rate as ordered or specified
- Roller, preferably pneumatic-tired, especially when the surface is uneven
- Rotary power broom needs to be vacuum-assisted to clean the surface and sweep away excess chips before application of the binder
- The surface temperature prior to chip seal application must be at least 10°C (50°F) and there should be no expectation of rain within a 24-hour period
- Rolling must follow immediately after the application of aggregate with pneumatic tired rollers
    - A minimum of three roller passes after the initial rolling, with an optional steel-wheeled roller weighing from 5 to 8 tons as the final roll
    - Only one complete coverage should be made with a steel-wheeled roller to avoid excess crushing of chips
    - Most chip seal projects do not include a steel-wheeled roller
- Cleaning equipment (for spray bar on distributor truck, and scrapers on rollers) is needed to ensure a quality application

The basic construction process for chip seal application recommended by the Asphalt

Institute is as follows:[54]

1. Patch potholes and repair existing areas with damage and then allow it to cure.
2. Use vacuum sweeper or broom to clean the surface.
3. Spray liquid asphalt or emulsion at a uniform rate as specified or ordered.
4. Spread aggregate at a uniform rate as specified or ordered.
5. Immediately roll aggregate to embed in binder (emulsion or hot applied asphalt).
6. Sweep loose aggregate off the pavement surface.

To prevent longitudinal streaking (corn-rowing), avoid the following errors:[55]

- Improper spray bar height
- Height changing as it distributes the application
- Incorrect nozzle settings
- Inconsistent pump speed and/or pressure to the nozzles.
- Emulsion breaking too soon
- Emulsion too high in viscosity (may be too cold)

To prevent bleeding, one needs to check the following:[56]

- Improper emulsion application rate (too heavy)
- Improper aggregate application rate (too light)
- Moisture within the underlying pavement
- Pre-existing bleeding of underlying pavement

To avoid loss of aggregate, avoid making the following mistakes:[57]

- Applying aggregate after the emulsion has broken
- Using dirty aggregate (should meet specified cleanness value)
- Using too much aggregate
- Not correctly following the rolling procedures

- Using too low of binder spread rate
- Embedding the aggregate improperly
- Applying the mix in cold weather, high humidity, rain, and/or on a dusty or wet surface
- Inadequate traffic control (not keeping traffic out of the work zones)
- Sweeping before the asphalt has a chance to cure

Best Practices for Design of Chip Seals

To determine the best practices for design of chip seals, the equipment, experience level, materials, and various other factors were reviewed to determine the best practices for both chip seal design and field work.

The use of chip seals is not typically encouraged on high-volume roads or on residential streets. The practices and the reasons behind them are displayed in Table 1. The practices focus on reduction in aggregate properties, the different uses associated with chip seal types, preparation methods and materials used, as well as traffic control.[58]

Table 1. Best Practices for Constructing High-Volume Chip Seals

Best Practices for Construction of High-Volume Chip Seals	
Practice	Reason
Reduce excess aggregate	Sweeping proficiency increased
Reduce aggregate size	Larger aggregate causes more damage
Use of double chip seals	Smaller aggregate in contact with tires
Use of lightweight aggregate	Lower specific gravity causes less damage
Use of choke stone	Locks in larger aggregate
Fog coat	Improved embedment, reduced rock loss
Precoat aggregate	Improved adhesion
Use of polymer modifiers	Improved adhesion
Allow traffic on chip seal	Vehicles provide additional embedment
Control traffic speed on chip seal	Reduced whip-off

Source: Gransberg, D. D. *NCHRP Synthesis 411 Microsurfacing A Synthesis of Highway Practice*, Washington D.C., MD: National Academy of Sciences, 2010.

According to WSDOT, the McLeod Design Method is a good approach to determine the application rates for chip seals. Factors and steps to consider in this approach include:[59]

1. Determine aggregate gradation, bulk specific gravity, and percent absorption.
2. Determine median particle size.

3. Determine the flakiness index (FI) using the equation.

$$FI = \frac{\text{Weight of Flat Chips}}{\text{Weight of Sample}}$$

4. Determine the average least dimension (H) using results from step 2 and step 3; to calculate the upper and lower H use the maximum and minimum FI-value, respectively.

$$H = \frac{M}{1.139285 + (0.011506)FI}$$

5. Determine the loose weight of the aggregate (W).

$$W = \frac{\text{Weight of Aggregate}}{\text{Volume of Cylinder}}$$

6. Determine the voids in the loose aggregate (V). To determine upper and lower void values, use the maximum and minimum W-value, respectively.

$$V = 1 - \frac{W}{62.4G}$$

7. Determine the aggregate application rate. To determine the upper and lower aggregate application rate, use the maximum and minimum V-value as well as the maximum and minimum H-value, respectively.

$$C = 46.8 \times (1 - (0.4)(V)) \times (H)(G)(E))$$

Where

E = Wastage = 1.05

G = Specific Gravity = 2.67.

8. Determine the binder application rate.

$$B = \frac{(2.244)(H)(T)(V) + S + A}{R}$$

Where

T = Traffic Factor found in Table 2.

S = Surface Condition found in Table 3.

Table 2. Traffic Factor (T)

Traffic Factor				
Traffic Vehicles per Day				
Under 100	100 to 500	500 to 1000	1000 to 2000	Over 2000
0.85	0.75	0.7	0.65	0.6

Table 3. SSurface Condition Factor (S)

Existing Pavement Texture	Correction, S
Black, flushed asphalt surface	-0.01 to -0.06
Smooth, nonporous surface	0
Slightly porous, oxidized surface	0.03
Slightly pocked, porous, oxidized surface	0.06
Badly pocked, porous, oxidized surface	0.09

Source: Mahoney J. P., Slater M., Keifenheim C., Uhlmeyer J., Willoughby K., Moomaw T. *WSDOT Chip Seals–Optimal Timing, Design, and Construction Considerations*, Olympia, WA: Washington State Transportation Center, 2014. 1–88.

In addition to the McLeod Design Method, other methods are used throughout the United States as sourced from the American Association of State Highway and Transportation Officials[60] and the Asphalt Institute.[61] Application rates for emulsion and aggregate utilized by many agencies simply come from experience. When applying the treatment, 70% of the aggregate particles must be embedded within the asphalt emulsion. If asphalt emulsion is used, the aggregate particles must be 55–60% embedded within the residual asphalt.[62] The ideal aggregate particle shape for chip seals is cubical.[63]

Best Construction Practices for Chip Seals

The best practices for chip seal application include parameters for administration, construction procedures, climate conditions, and testing, such as the following:[64]

Surface and Application Preparation

- Material testing and compatibility should be performed before the application using materials representative of the project

- The minimum ambient air temperature for application should be at 50°F (10°C) for emulsions and 70°F (21°C) for asphalt cements; the temperature cannot exceed 105°F (41°C)

- The minimum surface temperature for emulsion applications is 70°F (21°C) and it should not exceed 140°F (54°C)

- Evaluate the compatibility between aggregates and binders to ensure successful performance in the region

    - Test prior to application to ensure specifications are met

- Computerized distributor trucks are best for chip seal application
- Patch repairs should be done 6 months prior to chip seal application, whereas crack seals should be done 3 months prior; with specialized HMA mixes, and non-expansive crack seal material, this work can be performed just prior to the chip seal
- Rutting and local depressions should be pre-leveled
- Field tests should be performed for binders at the distributor and the stockpiles of aggregate to make sure that the material is not worn down during transportation
- Chip seals perform best when they are applied in warm, dry weather
- Reduce aggregate spread rates in areas of “extensive stopping and turning movements take place” can result in a reduction of rolling and scuffing
- Polymer-modified binders can be used to improve chip seal performance
- Traffic control is important to ensure maximum curing time for the seal coat
- Aggregate must be free of dust and slightly dampened
- Existing pavement must be strong enough to support the traffic load expected
- Dust palliatives can be used as a dust control agent on an unpaved surface when applying a diluted asphalt emulsion

Application of Binder using a Distributor Truck

- Within 30 minutes of application, the first pass should be followed by the chip spreader with a total of three passes
- Distributor truck spread rate, and aggregate spread rate, determine rolling time and the required number of times that the roller passes
- Calibration of the distributor truck and the chip spreader should be performed regularly
    - Generally, the equipment is calibrated yearly and has a sticker from Caltrans Independent Assurance
    - Calibration on the job site should be checked by doing a test strip prior to proceeding with construction
- The equipment spread rates should be checked with a test strip prior to beginning production

- Variable nozzles can be adjusted to reduce the binder amount that is distributed in the wheel paths

Application of Aggregate using an Spreader

- Use of aggregate spreaders to uniformly apply the aggregate
- Aggregate application should occur immediately after application for hot asphalt and emulsion binders
- The equipment spread rates should be checked with a test strip prior to beginning production
- Rollers should follow closely behind the aggregate/chip application

Sweeping

- Sweep at the appropriate time based on the surface temperature and ambient temperature and whether the emulsion has sufficiently cured (generally, sweeping will have to be done more than once)
- The sweeper speed is set for a maximum speed of 15 mph over a recently applied chip seal until the loose aggregate is removed
- Drag brooms help to correct minor deficiencies arising from spreading: these deficiencies could include missed areas, uneven spreading, and corrugation
- Plastic bristles on rotary brooms are best for sweeping to avoid removing bonded aggregate from the seal coat

Fog/Flush Seal

- If a seal coat is followed by a fog seal/flush coat, the surface must be dry and should not have any excess materials or aggregate
- The fog seal is applied to help secure the chip seal aggregate in place

Inspection of Processes

- An experienced inspector should be the one to recommend field rate adjustments; the resident engineer approves all changes in spread rates
- State-of-the-art equipment should be used by contractors, who control the operation to ensure a successful application
    - Equipment should be calibrated and work properly, whether it is state-of-the-art or not

- Workers with chip seal experience should be assigned to quality control and quality assurance
- Adopting a quality control test program and utilizing close inspections helps to ensure chip seal success
- Warranties for chip seals should only be used when the contractor is given the ability to choose the final materials and methods to meet the specifications for the project

SLURRY SEAL AND MICROSURFACING

When to Use and When Not to Use Slurry Seals and Microsurfacing

Slurry Seals

Emulsified asphalt slurry seals are primarily used to provide preservation treatments on roads with minor to moderate distresses. Slurry seals should be used to:[65]

- Protect pavement from further damage (for sound and oxidize pavements)
- Restore surface texture by providing a new skid-resistant wearing surface
- Improve waterproofing characteristics
- Correct raveling
- Provide a new surface where weight restrictions preclude the use of heavier overlays such as bridge decks
- Provide a new surface where height restrictions are a problem, such as undercrossings, and locations where there are utility boxes, manholes, curbs and gutters
- Treating surface defects and voids
    - With Type I Slurry, used to treat surface voids and cracks, minor surface defects
    - With Type II Slurry, used to treat moderate surface defects such as surface voids
    - With Type III Slurry, used to improve friction and skid resistance
    - Significant deficiencies in the pavement surface should be repaired prior to slurry seal
    - Pavement edge deterioration should also be repaired prior to slurry seal

- Traffic loading relationship
    - Type I slurries are used for lightly trafficked roads or parking lots
    - Type II slurries are typically used on roadways with moderate to heavy traffic
    - Type III slurries are used on arterial streets and highways which typically have a higher traffic level

Slurry seals should not be used to (18, 13, 20):[66]

- Correct surface profile
- Fill potholes
- Alleviate cracking
- Correct rutting
- Improve the structural integrity of the existing pavement

Microsurfacing

Microsurfacing performs the same functions as slurry seals but has additives and properties that are not found with slurry seals. They also use a higher-quality aggregate and are quicker to cure. Microsurfacing is best used to treat the following road conditions:[67]

- Correct surface irregularities that are minor
- Correct rutting
- Microsurfacing works best for the following projects:
    - Type I microsurfacing is used for airport runways, and urban and residential streets
    - Type II microsurfacing is best to treat the surface irregularities, raveling, and oxidation, and to improve surface friction
    - Type III microsurfacing is used on arterial streets and highways which typically have a higher traffic level

Microsurfacing does not improve the structural integrity of a pavement: it is meant to improve the surface of the pavement. It should not be used to treat and/or prevent cracks from forming.[68]

Construction Process

Slurry Seal

In addition to use on roads in good condition as a preventive maintenance to increase service life, slurry seals may also be used to treat certain minor distresses. The distress modes that warrant the use of slurry seal treatment include raveling, oxidized pavement with hairline cracks, and friction loss. Distress modes that should not be addressed using this treatment type include rutting, cracking, base failures, and HMA layers.[69]

According to the *Maintenance Technical Advisory Guide Volume I–Flexible Pavement Preservation*, aggregate characteristics that are best suited for incorporation into slurry surfacing mix are defined by geology, shape, texture, age and reactivity, cleanliness, and soundness and abrasion resistance.[70] A tack coat preceding a slurry system treatment may improve the uniformity of the absorptive nature of a road surface, thus improving application success. The more the slurry mix is worked, the more segregation takes place. As the squeegee moves the matrix back and forth, the larger aggregate is then inadequately embedded and may ravel.

As for the design of slurry seals, the best practices are now included in the AASHTO design practice for slurry seals.[71] The proper piece of equipment for slurry seal application would be a slurry seal machine that delivers the materials (aggregate, emulsion, water, and additives) to a mixing chamber with the appropriate amount of aggregate, mineral filler, and other additives and emulsion.[72]

To ensure quality slurry seal application, the appropriate sequence for construction is as follows:[73]

1. Clean the existing pavement surface
2. Place the mixture uniformly
3. Roll the mixture (optional)
4. Maintain traffic control until slurry surfacing is cured

Microsurfacing

The project criteria for microsurfacing application are:[74]

- The existing surface should be cleaned and well drained
- There must be no distresses such as potholes and cracking; if there are, they must be repaired prior to slurry application by several weeks
- Emulsion crack filling needs to be done months before slurry application

- Current approved mix design should be utilized for the project

Weather and climate conditions that are best for this product include:

- Temperature should be a minimum of 50°F (10°C) and above
- Ambient temperature of 45°F and rising
- Slurry seals should not be placed during periods of abnormally high humidity: humidity should be 60% or below
- If rain or freezing temperatures are anticipated within 24 hours of construction, application should not be performed

During the construction of a microsurfacing application, the following should be considered in producing an overall effective application.[75]

- For each inch of applied micro-surface for rut filling, add ⅛-inch to ¼-inch crown (overfill rutted area) to compensate for return traffic compaction
- Rut-filling should only be used on stable ruts that have resulted from long-term traffic compaction rather than failures in the base or sub-base; if rutting is ongoing, the micro-surfacing will not prevent its continued development
- A cross-section rut of less than 1/2-inch deep should be addressed with a full-width scratch coat of microsurfacing to level the surface before the final surface lift is placed
- If greater than 1/2-inch it should be filled with microsurfacing and a rut box, or 1/4-inch HMA
- All rut-filling and leveling material should be subjected to traffic for at least 24 hours before additional material is placed

The best equipment for microsurfacing application includes the following:[76]

- A continuous flow mixing unit is needed to deliver the mixture to discharge at a continuous flow rate
    - A self-loading component may be needed to minimize construction joints
- Spreader box should be equipped with a front seal to reduce mixture loss at contact point with road, and a rear seal to serve as the final “strike-off”

Best Practices

Best practices for slurry surfacing include the following:[77]

- Preparation of the roadway prior to application is necessary to ensure the effectiveness of the treatment applied

- The surface temperature of the roadway should be 50°F or higher with an ambient temperature of 45°F and rising
- Prior testing of materials is needed for a mix design
- Onsite sampling at multiple points of the project should be implemented to meet a quality control/quality assurance plan
- It is important to maintain the material in the spreader box in liquid state: this will influence the smoothness of application
- General rule of thumb for a slurry seal treatment is that it can be reopened to traffic when it turns black and does not track

Slurry Seal

For a quality slurry seal application, the following are needed:[78]

- Consistant aggregate flow rate and level of mix calibration
- Trial runs or test sections
- Damp surface with no free water
- Homogenous mix for uniform spreading of slurry seal
- If there is lumping, aggregate separation, balling or an unmixed product, suspend application until the problem is resolved
    - Careful attention to longitudinal and transverse joints due to the possibility of excessive buildup of seal
    - Joints should be made after the previous pass has set
- Utilize a canvas or burlap drag to improve joint quality and the aesthetic of the roadway
- Hand squeegees or drags can be used to improve the sections of the roadway that cannot be reached by the application machine
- Taxiways, runways, parking lots, and truck yards are best for slurry seal application due to their short-term durability

Microsurfacing

The best practices for microsurfacing include:[79]

- When the surface texture of the existing pavement is non-uniform, the surface of the microsurfacing will also be non-uniform
    - A "scratch coat" may be needed prior to application of the final surface to create a uniform surface
    - Scratch coats are primarily used with microsurfacing to create a uniform surface and correct minor surface irregularities
- Rolling is not necessary for microsurfacing on roadways.
    - Airports and parking areas should be rolled by a self-propelled, 10-ton pneumatic tire roller equipped with a water spray system
    - Rolling shall not start until the microsurfacing has cured sufficiently to avoid damage by the roller
    - Rolling too hard may affect the overall quality of the application
- General rule of thumb for microsurfacing is that it can carry traffic when it is expelling clear water
- Service entrances must be protected using an appropriate method, such as covering with Kraft paper or tar paper
- Cracks greater than 1/4-inch must be corrected at a time prior to the application of microsurfacing.
- Pre-wetting is best when warm weather is expected or the pavement surface is rough
- Evaluate test strip in the expected project conditions prior to proceeding with production

CAPE SEALS

Cape seals consist of a chip seal followed by a slurry seal or microsurfacing. As such, the places where one would use cape seals would be similar to those for chip seals and microsurfacing. The construction and best practices are the same. Cape seal performance essentially depends on the same factors and methods that affect chip seals, slurry seals, and microsurfacing. Some of the best practices include:[80]

- Before applying the slurry surfacing, the surface must be cleaned and, if necessary, washed with a water truck to remove excess debris
- Road agencies should implement an effective crack sealing program prior to the application of the cape seal treatment
- Pre-PCI shows the most impact on the performance of cape seals, but this could also have been a product of the decision-making process pertaining to the application of the cape seal

- Before using a chip seal cape seal, the seal coat design should be submitted; testing for compatibility and performance should be conducted for the chip seal and emulsion type
    - In addition, the emulsion application rate should be determined using design procedures suggested
    - Procedures including AEMA, ASTM, and ISSA standards and procedures
- For chip seals or tack coats, the surface temperature prior to application should be no less than 10°C (50°F) and there should be no rain expected within 24 hours.
- For slurry seal, the surface temperature should not be less than 12°C (54°F) but treatment can be applied if temperature is above 7°C (45°F) and rising, and there should be no rain or freezing conditions expected within 24 hours
- Cape seals should be sufficiently cured before being opened to traffic
- Prepare the existing surface by lightly watering the surface to allow for better asphalt emulsion penetration
- The application of the aggregate should be uniform
- Some expert sources advocate for the slurry layer to be applied by hand with "crisscross movement of soft blade squeegees" but only for small areas.[81]
    - The cure time should be a minimum of 3 days between emulsion chip seal application and a subsequent application of slurry seal.
    - One day may be enough time between hot applied chip seals and a slurry surfacing

SUMMARY OF BEST PRACTICES FOR PAVEMENT PRESERVATION TREATMENTS

Best practices are vital in ensuring that the treatment will perform its necessary functions and perform well. An inspector should monitor the project daily to track the amount of materials being placed. This may be accomplished by keeping a spreadsheet of the quantities delivered in each truck as it is placed or tracking deliveries of material to the project. Considering all potential factors that affect the overall performance of chip seals, slurry surfacing seals, and cape seals, the best practices for each treatment type are outlined below. Implementing these best practices and strategies will help in the long run by providing necessary knowledge for treatment applications and inspections.[82]

This chapter discussed when and when not to use a specific treatment, the construction processes best for each treatment, and the overall best practices for each treatment type. The sections also covered topics such as when and when not to use a specific treatment based on different factors, what distress type the treatment is being used to treat. Items for consideration of treatment type also included design parameters, material limitations, and traffic conditions.

Construction procedures are a major factor affecting the overall performance of treatments. The process that needs to be used to successfully select the proper strategy for the specific treatment type includes:[83]

- Select the Right Treatment
  - Collect project-related information
  - Select feasible pavement that meets treatment recommended distress conditions
  - Detailed comparison among treatments including a life cycle cost analysis (LCCA)
- Apply Treatment with Right Method
  - Ensure quality pavement condition
  - Ensure good quality of construction and workmanship
  - Provide quality materials that meet specifications
  - Follow proper design of treatment mixtures
  - Meet traffic volume (light, medium, heavy) mix recommendations
  - Make sure the weather or climate is suitable for application
- Conduct an Economic Performance Evaluation and Feedback
  - Evaluate cost-effectiveness of treatment under good conditions
  - Evaluate the economic impact of treatment placed under non-ideal conditions
  - Compare the economic impact
  - Provide evaluation results and feedback for best treatment strategy selection.

The best practices that can be concluded from the literature review include:[84]

- Optimal Application Timing
  - When distress begins to show, that is the suggested time to begin applying preventive maintenance treatments.
- Design and Materials
  - Follow recommended rutting depth limits to ensure optimum chip seal performance and a decrease in maintenance afterward

- Construction
    - Use diluted or undiluted emulsion when applying flush coats/fog seals and make sure that the residual oil content meets the specification

IV. TRAINING NEEDS

As a part of this effort, two surveys were identified to indicate the types of treatments that are commonly used by local agencies and the training needs that local agencies need to help them do their jobs better.

CALRECYCLE SURVEY

The first survey was done as a part of a CalRecycle project.[85] It consisted of questions used to identify the most widely used pavement preservation treatments by Caltrans and local agencies. The survey was sent to all Caltrans districts and all 58 counties. Calls were placed to several cities and their responses were summarized. The results indicated the following:

- Caltrans uses chip seals (emulsion and hot applied) and thin hot mix overlays as their major preservation treatments.
- Counties use chip seals as their primary preservation treatment. These include both emulsions and hot applied chip seals.
- Cities use slurry seals and cape seals as their primary treatments. The chip seals used by the cities can be either emulsion or hot applied.
- From this survey, it was determined that the preservation treatments most used by local agencies include chip seals, slurry seals, and cape seals.

CCPIC SURVEY

The second survey was conducted by the UC Davis Pavement Research Center in 2018 as a part of the City and County Pavement Improvement Center (CCPIC).[86] The survey was sent to all 58 counties and 482 cities. A total of 180 responses were received including 25 counties and 155 city responses.[87]

The responses dealing with training needs, technical support, specifications and research and development regarding pavement preservation, maintenance and rehabilitation are summarized in Table 4 and Table 5.[88]

For cities, the highest need was technical guidance and training on the operation of their PMS, including prioritization on project and treatment selection. The second most important need was guidance and training on all aspects of preservation, maintenance and rehabilitation practices. This item included guidance and training in both the design and construction phases of the treatments as well as specification help. The other areas of interest ranked lower than those described above.

For counties, help with specifications was of the highest priority while the next-highest item dealt with information to improve preservation, maintenance and rehabilitation practices. This interest was stated in several ways in the project delivery process from project selection through design and construction.

Table 4. Responses to CCPIC Questions About Needs from Cities

Need Category	1st priority	Top four priority	Overall ranking[a]
PMS operation, prioritization, treatment selection	24	36	204
Maintenance and rehabilitation practice	12	24	120
Implementation support	4	18	70
General pavement training and design	6	15	69
Specification help	4	13	55
Construction Management	3	10	42
PMS data collection, pavement assessment	4	6	34
Sustainable pavement practices	1	8	28
Complete streets	1	4	16

Calculated as 4#1 priority + 3*(#1–4 priority)*

Source: Harvey J., Li H. Analysis of Voluntary Additional Survey to Help Advance Understanding of Local Streets and Roads Needs and Issues, City and County Pavement Improvement Center (CCPIC), UC Davis, Davis, CA: 2018.

Table 5. Responses to CCPIC Question About Needs from Counties

Need Category	1st priority	Top four priority	Overall ranking[a]
Maintenance and rehabilitation practice	4	6	34
Specification help	3	5	27
Construction management	1	5	19
PMS operation, prioritization, treatment selection	1	2	10
PMS data, pavement assessment		2	6
Sustainable pavement practices		2	6
Implementation support		1	3
General pavement training and design		1	3
Complete streets		0	0

Calculated as 4#1 priority + 3*(#1–4 priority)*

Source: Harvey J., Li H. Analysis of Voluntary Additional Survey to Help Advance Understanding of Local Streets and Roads Needs and Issues, City and County Pavement Improvement Center (CCPIC), UC Davis, Davis, CA: 2018.

The responses to these two surveys provided important feedback on the needs of local agencies, and as such, they provide support for our recommendations for training needs. As such, the authors propose that training be developed to include the following:

- **Project selection:** This topic is a chapter in the Caltrans MTAG document and includes a computer program to help agencies select the most appropriate treatment for a given job. The MTAG information will be updated to help local agencies select the best treatment for a given job.

- **Chip seals:** This topic is a chapter in the Caltrans MTAG document which could be updated to reflect current practices. It includes information on the design, materials, construction and quality assurance for one of the most widely used and misused treatments in the state.

- **Slurry surfacing:** This topic includes both slurry seals and microsurfacing, which are widely used by local agencies, either alone or after the placement of a chip seal, which is also known as a cape seal. Slurry seals and microsurfacing are also chapters in the Caltrans MTAG document and will be updated as needed.

- **Cape seal:** This item is not a chapter in the Caltrans MTAG but since it is a combination of both a chip seal and a slurry surfacing, it is covered in MTAG for chip seals and slurry surfacing.

V. SUMMARY AND RECOMMENDATIONS

SUMMARY

This report was developed to document the performance of pavement preservation treatments including chip seals, slurry seals, microsurfacing, and Cape seals. In addition, this report provides an informative analysis on the use of pavement management systems, the importance of pavement preservation, and how they positively affect the overall conditions of roadways when effectively utilized.

Pavement management systems are vital tools that can assist in cost-effective decision-making in pavement preservation for various state and local agencies. The system must be able to record and store road network data that can be easily accessed and analyzed when needed. In California, two popular pavement management systems meeting these criteria are MTC's StreetSaver and Caltrans' PaveM. Both systems store an array of data that can be used in economic decision-making or observing the effectiveness of preservation treatments.

As a part of this report, a procedure was introduced to identify how the benefits of preservation treatments can be determined. The report also provided information on the best practices to use to design and construct these treatments, including:

- Design
- Surface preparation
- Construction
- Inspection/quality assurance

Information related to the performance of chip seal, slurry seal, microsurfacing, and cape seal treatments include:

- Common factors affecting each preservation treatment type:
  - Existing condition of the pavement
  - Quality of construction and construction practice
    - Equipment
    - Specifications
    - Quality of work done by employees
  - Quality of materials used for application including binder, aggregate, emulsion
  - Weather and climate conditions
  - Traffic volumes ranging from low, medium, and high

- Overall performance of preservation treatments including chip seals, slurry seals, microsurfacing, and cape seal with respect to specific factors and project conditions
  - Application rates of binder or emulsion affect the performance of chip seals
  - Application rates of aggregates affect the performance of chip seals
  - Mix designs are needed for slurry seals and microsurfacing
  - Binder properties, temperature, traffic, and moisture content of the aggregate influence the overall performance of cape seals.
  - The overall success of the applications over time are influenced by the region (weather, traffic volumes, population, climate, elevation, etc.).
- Advantages and disadvantages of chip seals, slurry seals, microsurfacing, and cape seals
  - The advantages of these treatments include cost-effectiveness in comparison to rehabilitation or reconstruction and an overall improvement to the condition of a roadway and extension of pavement life. These treatments also correct and prevent raveling and improve the skid resistance, aesthetics and overall quality of the roadway by treating specific distress types. The following are the advantages of chip seals, slurry seals, microsurfacing, and cape seals:
    - Chip seals can extend the life of a roadway by 5 to 10 years (with some exceptions from 3 to 20 years). This is, in part, due to the protection against the deteriorating effects of sun, water, and cracking. They cure quickly, halt pavement oxidation and resist reflection cracking. They can also be used on high-volume roads with sound structural integrity and reduce the severity of various distresses (better if severity is low).
    - Slurry seals can correct and treat oxidized pavements with hairline cracks and minor texture deficiencies. Slurry seals provide necessary waterproofing and protection for the underlying surface. Additionally, slurry seals are good for low traffic volumes and offer minimal curb height loss. The new surface is favorable for lane delineation.
    - In comparison to slurry seals, microsurfacing requires less time to cure and can be placed at night or in cooler temperatures. If weather is favorable, the road can be opened to traffic in approximately 1 hour following application of treatment. Microsurfacing corrects minor surface irregularities such as oxidized pavements with hairline cracks, washboard pavements, and rutted pavements. Microsurfacing is more environmentally friendly than HMA overlays, creating a smaller environmental footprint, and has a higher durability for high traffic volumes. Microsurfacing can be applied on roads where snow is common if the snow is regularly removed and the pavement is structurally sound.
    - Cape seals possess similar benefits of chip seals and slurry surfacing treatments. The use of cape seals results in noise reduction and

improvement in the ride quality. Cape seals prevent raveling (especially in cold weather), loss of chips when bonded to slurry, air and moisture exposure, abrasion and erosion. Microsurfacing cape seals have a higher benefit–cost ratio than slurry seal cape seals.

- The disadvantages of these treatments are that they cannot improve the structural integrity of the roadway nor can they treat *all* distress types. Temperature and environmental conditions can also hinder the progress and quality of the application. The following are the disadvantages of chip seals, slurry surfacing, and cape seals:
  - The disadvantages of chip seals are that climate conditions can potentially extend the cure time for chip seals and weather conditions can limit application time. Chip seals do not improve ride quality and can create a rough surface, resulting in noise pollution when driven on and damage when not swept and flushed properly. PME chip seals are not favored in intersections and high stress areas. PG asphalt and AR chip seals cure quickly with hot applied binder.
  - The disadvantages of slurry seals include the inability to address rutting, cracking, base failures, and plastic shear deformation of HMA layers. They require several hours to cure and warmer temperatures during construction.
  - Disadvantages of cape seals include those of both chip seals and slurry surfacing treatments. Slurry seal cape seals cannot be applied in cold weather and have a lower benefit–cost ratio in comparison to microsurfacing cape seals. Cape seals have an overall higher cost than individual treatments and require more construction time.

Best practices for construction, surface preparation, design, material specification, and inspection were outlined and discussed to provide general guidelines to be used by various agencies throughout the United States and other regions of the world.

Finally, training needs were identified through two surveys which resulted in specific training recommendations for the remainder of the project.

RECOMMENDATIONS

The recommendations resulting from this literature review include the following:

- Pavement management systems should be used by local and state agencies to ensure a cost-effective, quality application to improve roadway conditions.

- Performance models, which present the life and capabilities of pavement preservation treatments, should be developed as part of implementing a pavement management system for local and state agencies.

- Training modules should be developed to illustrate the proper way to design and construct chip seals, slurry surfacing, and Cape seals.

- To ensure a quality application of any preservation treatment, follow the specifications and construction procedures closely.

APPENDIX A: PAVEMENT PRESERVATION MODELS

This appendix discusses the performance models most commonly used in California, including the Street Saver model promoted by the MTC and the PaveM model promoted by Caltrans.

A1. METROPOLITAN TRANSPORTATION COMMISSION (MTC)

The performance model used to predict the change in Pavement Condition Index (PCI) is shown below:[89]

$$PCI_{PRO} = 100 - \frac{\chi\rho}{\left(\ln\left(\frac{\alpha}{Age - Shift}\right)\right)^{\frac{1}{\beta}}}$$

Where

PCI_{PRO}	= Projected Pavement Condition Index Value
Age	= Years since the last major rehabilitation/reconstruction activity
Shift	= A projection modifier initially set to 0
α	= Regression constant that controls the age at which the curve is asymptomatic
β	= Regression constant that controls how sharply the PCI family curve bends
ρ	= Regression constant that controls the age at which the inflection point in the PCI family curve
χ	= A projection modifier initially set to 1.

A2. CALTRANS PAVEM PAVEMENT MANAGEMENT SYSTEM

The PaveM program developed by Caltrans uses individual distress as performance measures and predicts the change in individual distress over time (see Table 6). This table discusses the performance variables utilized by the PaveM pavement management system. The table details the performance variable or index, the intended purpose of the variable or index, the pavement condition data needed to determine the performance, and the performance equation used within the PaveM program.

Table A1. PaveM Performance Variables for Flexible Pavements

Performance Variable or Index	Intended Purpose	Pavement Condition Data to be Included in Performance Variable	Performance Equation Form
IRI	Indicator of pavement smoothness	IRI (International Roughness Index)	$y = a + bx^c$
Flexible Wheelpath Cracking	Indicator of need for structural improvement based on pavement cracking caused mainly by truck traffic	Percent of wheelpaths (right and left) in data segments with crack length ratio greater than 1.25 (assumed to be the threshold above which Caltrans “Alligator B” cracking is present; average patch area)	$y = 100 \times \left(1 - e^{-\left(\frac{x}{a}\right)^b}\right)$
Total Cracking Index	Indicator of need to seal surface based on total crack length on the pavement regardless of type or cause	Average crack length ratios of wheelpath cracking in both wheelpaths; average crack length ratio of XF cracking (cracks outside of wheelpaths); number of narrow transverse cracks, wide transverse cracks, narrow longitudinal cracks and wide longitudinal cracks	$y = 100 \times 2^{\left(\frac{100}{7.5}\left(1-e^{-\left(\frac{x}{a}\right)^b}\right)\right)}$
Raveling	Indicator of need to correct loss of aggregate from surface causing potential roughness and noise problems	Average Mean Profile Depth (MPD)	$y = a + bx^c$

Source: Tseng, E. The Construction of Pavement Performance Models for Flexible Pavement Wheelpath Cracking and IRI for the California Department of Transportation New Pavement Management System. Thesis. University of California Davis, 2012.

PaveM utilizes two conditions to determine the performance model of treatment types: total cracking value (TCV) and wheel path cracking value (WPCV). Wheel path cracking value can be expressed as a real number or a percentage:[90]

$$WPCV = \frac{(100 * wpc_{high} + 0.6 * PAT_{area} * L)}{L}$$

Where

WPCV = Wheel Path Cracking Value
wpc_{high} = Length of wheel paths in the segment with crack-to length ratio greater than 1.25 m/m
PAT_{area} = Percent of patched area averaged across all data segments
L = Length

PaveM also views wheel path cracking value (WPCV) as the percentage above a failure threshold, which leads to the need for a Weibull distribution curve. This curve allows PaveM to model the failures in a population and for total cracking value (TCV) shown in the following equation:[91]

$$\boldsymbol{WPCV\ or\ TCV = 100 * \left(1 - \exp\left(-\left(\frac{t}{a}\right)^{b}\right)\right)}$$

Where

WPCV = Wheel Path Cracking Value
TCV = Total Cracking Value
t = Age, years
a, b = Fitted model coefficients

Fitted model coefficients of WPCV for seal coats based on Equivalent Single-Axel Load (ESAL) Counts:

Traffic level A: a = 30.7, b = 1.791, < 100,000 ESALs
Traffic level B: a = 25.5, b = 1.819, 100,000 to 500,000 ESALs
Traffic level C: a = 24.3, b = 1.854 > 500,000 ESALs

Fitted model coefficients of TCV for seal coats based on Equivalent Single-Axel Load (ESAL) Counts:

a = 9.6 for mild climate, 8.5 for severe climate
b = 5.500.

APPENDIX B: LITERATURE REVIEW RESULTS

B1. MTAG VOLUME I—FLEXIBLE PAVEMENT PRESERVATION, 2ND EDITION (2008)

Table 7 displays the various chip seal binder combinations recommended for specific distress types, including raveling, aged pavement, bleeding/flushing, load-and climate-associated cracks, waterproofing, heavy traffic volumes, stone retention, and skid resistance improvement. The varying combinations include polymer modified emulsions (PME), performance graded (PG) asphalt, asphalt rubber (AR), and rejuvenating emulsion with single, double, and/or sand chip seal application.

Table B1. Binder/Chip Seal Combinations for Addressing Specific Distress Mechanisms

Binder/Chip Seal Combination	Raveling	Aged Pavements	Load-Associated Cracks	Bleeding/Flushing	Water Proofing	Climate-Associated Cracks	Heavy Traffic Volumes	Stone Retention	Improve Skid Resistance
PME/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Double	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PME/Sand	Yes	Yes	No	No	Yes	No	No (light)	Yes	Yes
PG/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
PG/Double	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
PG/Sand	Yes	Yes	No	No	Yes	No	No	Yes	No
AR/SAM	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes
Rejuvenating Emulsion/Single	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes

Source: Asphalt Institute, Asphalt Emulsion Manufacturers Association. ***Asphalt in Pavement Preservation and Maintenance***. 4th Ed. of MS-16. Lexington, Kentucky: 2009. 1–144.

B2. FINAL SUMMARY REPORT ON PERFORMANCE MODELS FOR CHIP SEALS IN CALIFORNIA

The primary factors included in a CalRecycle report showed that binder type, functional class, and climate all affected the performance curves.[92] Some curves are specific to regions and areas in California that have different environmental conditions from other counties.[93] Figure 24 displays the expected performance of chip seals based on the effect of functional class. From these graphs, it can be seen the residential roads are in the best condition at the end of 20 years, while arterial roads are in the worst condition at the end of 20 years.

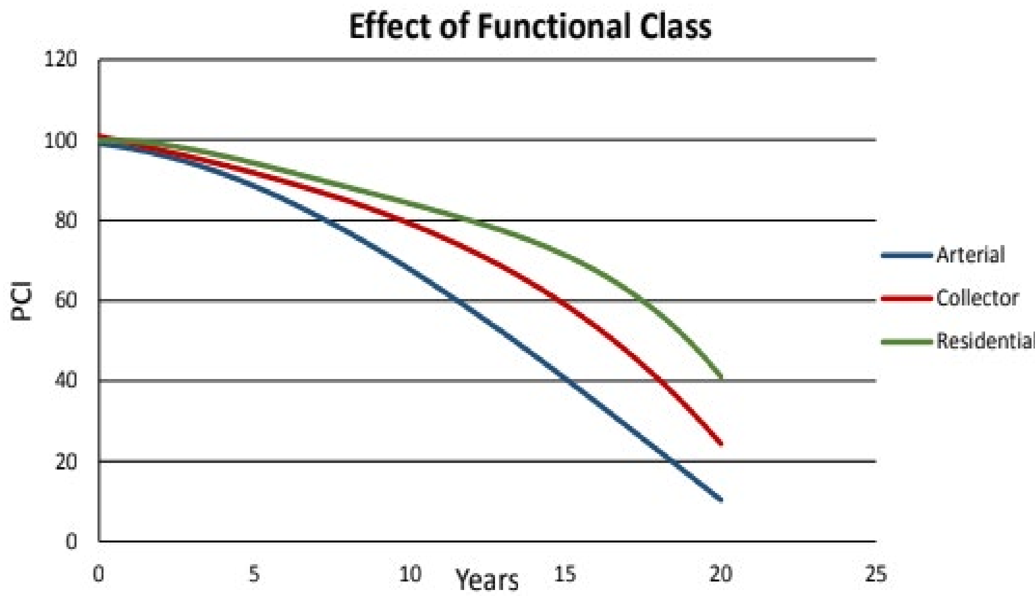

Figure B1. Expected Performance Curve for Functional Class for Chip Seals

Source: Cheng D., Hicks G. R., Wingo C., Krumdieck J., Worcester K. *Literature Review on Chip Seals Including Performance Models*, Sacramento, CA: California Department of Resources Recycling and Recovery, 2016. 1–70.

Figure B2 displays the expected performance of chip seals based on the effect of climate.

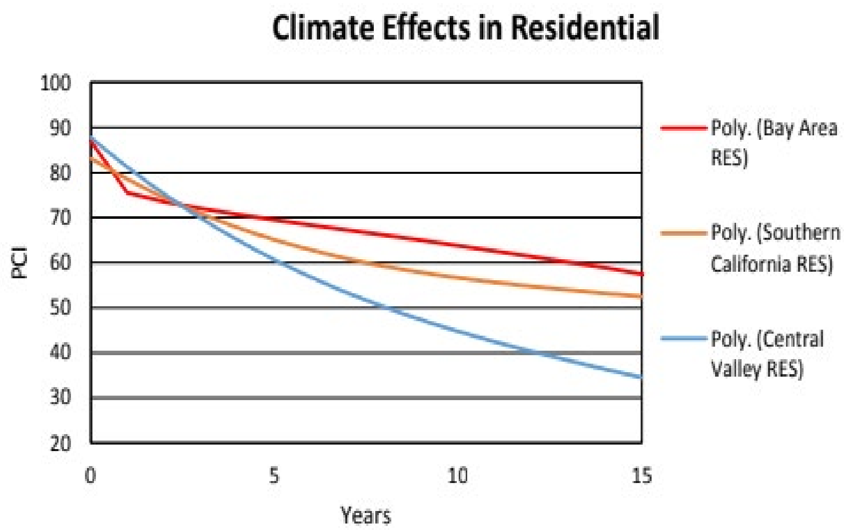

Figure B2. Effect of Climate on Chip Seals

Source: Cheng D., Hicks G. R., Wingo C., Krumdieck J., Worcester K. *Literature Review on Chip Seals Including Performance Models*, Sacramento, CA: California Department of Resources Recycling and Recovery, 2016. 1–70.

Figure B2 displays the expected performance of PME chip seals based on the effect of functional class.

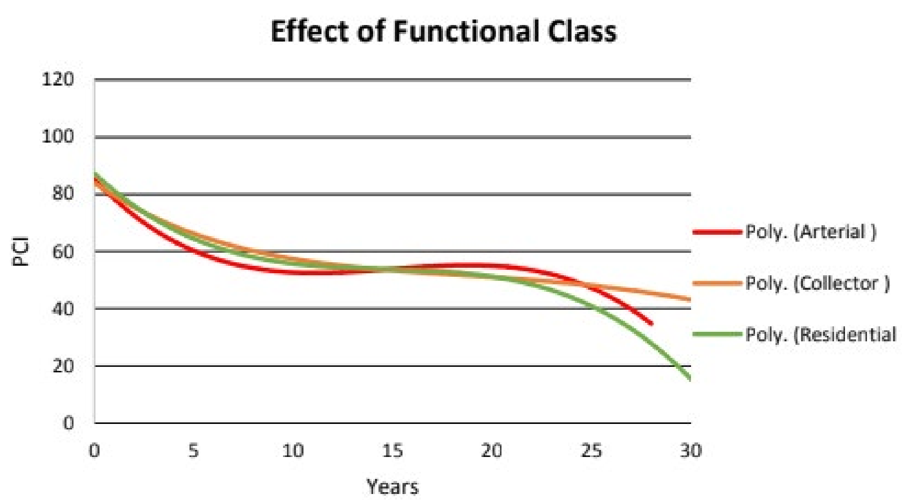

Figure B3. Effect of Functional Class on PCI for PME Chip Seals

Source: Cheng D., Hicks G. R., Wingo C., Krumdieck J., Worcester K. *Literature Review on Chip Seals Including Performance Models*, Sacramento, CA: California Department of Resources Recycling and Recovery, 2016. 1–70.

APPENDIX C: QUESTIONS ASKED FOR TRAINING NEEDS

Analysis of Voluntary Additional Survey to Help Advance Understanding of Local Streets and Roads Needs and Issues by John Harvey and Hui Li (2018)

Question 1: Needs and priorities

Who should answer: technical staff in charge of pavements, may require asking across different departments involved with pavement.

Q1: Please fill in what are the top four areas for which your agency could use training, technical support, pilot implementation support, technical guidance, example specifications or research and development regarding maintaining your road network? For each issue indicate what type of support you are looking for.

- 1.
- 2.
- 3.
- 4.

Questions 2 through 9: Pavement management practices

Who should answer: technical staff in charge of pavement management?

Q2: Does your agency apply maintenance (preservation) treatments prior to the appearance of extensive distress on the pavement surface as a standard practice?

- Yes
- No
- Additional comment (fill in)?

Q3: Does your agency select treatments primarily based on Pavement Condition Index (PCI)?

- Yes
- No
- Any other criteria for selecting treatments (fill in)?

Q4: For your asphalt surfaced pavements that handle heavy traffic (buses, trucks) other than garbage trucks what is the typical preservation or maintenance treatment that you would use for each of these cases?

- If heavily cracked (fill in)?
- If moderately cracked (fill in)?
- If no cracking but showing signs of aging (fill in)?

Q5: For your asphalt surfaced pavements that handle heavy vehicle traffic (buses, trucks) other than garbage trucks how many preservation or maintenance treatments do you typically do before you do a rehabilitation?

- (fill in number)?

Q6: For your asphalt surfaced pavements that do not handle heavy vehicle traffic other than garbage trucks what is the typical preservation or maintenance treatment that you would use for each of these cases?

- If heavily cracked (fill in)?
- If moderately cracked (fill in)?
- If no cracking but showing signs of aging (fill in)?

Q7: For your asphalt surfaced pavements that do not handle heavy vehicle traffic (buses, trucks) other than garbage trucks how many preservation or maintenance treatments do you typically do before you do a rehabilitation

- (fill in number)?

Q8: Does your agency routinely consider use of recycling treatments for your asphalt pavements such as cold in-place recycling (CIR), Cold Central Plant Recycling (CCPR), subgrade stabilization or full-depth reclamation (FDR) in your treatment selection process for pavements with extensive cracking?

- Yes
- No
- Additional comment (fill in)?

Q9: Has your agency done life cycle cost analysis (LCCA) to evaluate the timing and selection of your preservation, maintenance and rehabilitation treatments included in your PMS decision trees?

- Yes
- No
- Additional comment (fill in)?

Questions 10 through 17: Pavement materials and construction specifications

Who should answer: technical staff in charge of pavement materials and construction quality management.

Q10: Does your agency allow supplementary cementitious materials to replace cement in your concrete for pavement, gutters and sidewalks?

- Yes
- No
- Don’t know

- Additional comment (fill in)?

Q11: Does your typical specification language include a required minimum cement content in your concrete for pavement, gutters and sidewalks?

- Yes
- No
- Don’t know
- Additional comment (fill in)?

Q12 Does your typical specification language require measurement of density on compacted asphalt in the field using cores or calibrated nuclear gauges?

- Yes
- No
- Don’t know
- Additional comment (fill in)?

Q13 Who does your agency use to monitor asphalt compaction in the field?

- City staff person
- Contracted private firm
- Construction contractor self-reports
- A combination of the above (please fill in which)
- Compaction is generally not measured in the field

Q14 Does your agency assess penalties on the contractor for poor asphalt compaction based on measured in place densities?

- Yes
- No
- Don’t know
- Additional comment (fill in)?

Q15 Does your agency offer any incentives for contractors to meet or exceed the asphalt compaction standard?

- Yes
- No
- Don’t know
- Additional comment (fill in)?

Q16 How would you rate your agencies satisfaction that adequate asphalt compaction is being achieved?

- Outstanding
- Sufficient

- Insufficient
- Very Insufficient
- Not sure

Q17 Do you allow the use of recycled asphalt pavement (RAP) in your asphalt mixes?

- Yes
- If Yes, maximum percentage (fill in)?
- No
- Don’t know
- Additional comment (fill in)?

TERMINOLOGY AND ACRONYMS

TERMINOLOGY

- **Cape Seal:** This treatment type consists of the placement of a chip seal followed by a slurry seal or a microsurfacing. . Cape seals typically increase durability and produce a smooth surface. The binder for the chip seal can be either an emulsion or asphalt rubber.

- **Chip Seal:** A bituminous binder is applied followed by aggregate application and rolling to embed the aggregate into the binder. The binder can be an asphalt emulsion or asphalt rubber.

- **Corrective Maintenance:** This maintenance type is conducted in response to defects that affect facility operations and integrity of pavement sections. This form of maintenance is also known as reactionary maintenance and can be conducted throughout the lifespan of a pavement. It is typically used to fix localized defects and return a pavement to an acceptable service quality. Maintenance activities include patching of potholes and replacement of concrete slabs.

- **Coverage:** The application of the emulsion to a surface.

- **Distresses:** Deterioration resulting from factors including the environment, construction and design practices, material selection, or load on pavement. There are two distinct categories of distresses: functional and structural.

  - *Functional distress:* Deterioration affecting the pavement's ability to serve its function of being a safe, smooth, and quiet surface for comfort while driving. Using preservation treatments, minor functional problems can be addressed, as long as there are no structural problems.

  - *Structural distress:* Deterioration resulting from excess weight and loading, as well as lack of thickness and support for the pavement structure. Considerable deterioration does not allow for the distresses to be addressed using preservation treatments.

- **High-traffic-volume Roadway:** Rural roadways have an ADT greater than 5,000 vehicles per day and urban roadways have an ADT greater than 10,000 vehicles per day.

- **Major Rehabilitation:** To extend the service of a pavement and/or improve load-carrying capabilities through structural enhancement.

- **Microsurfacing:** This treatment type relates to slurry seals; however, the main variation between the two is the quality of the materials. With this treatment, the polymer and asphalt residual content is greater than that of slurry seals, and the aggregate quality is better. In addition, the cost is greater than slurry seals; however, the cure time is more time-efficient than slurry seals.

- **Minor Rehabilitation:** The distresses addressed are non-structural enhancements to improve the lifespan and surface cracking and to restore the pavement to serve its function. The distresses could be a result of environmental factors. Minor rehabilitations are typically referred to as pavement preservation techniques, occurring midway in a pavement's lifespan when the quality of the roadway begins to diminish.

- **Pavement Condition Index (PCI):** This index is most commonly used by the Metropolitan Transportation Commission (MTC) as a value ranging from 1–100 and directly related to the condition of the pavement.

- **Pavement Preservation:** The practice of utilizing a cost-effective system that allows for tracking and recording to extend and enhance the quality and life of a pavement. In addition, preservation would serve as a way to improve safety and provide good ride quality. The system primarily focuses on preventive maintenance as a cost-effective way to treat roadways and improve the quality of the road.

- **Performance Curve:** Diagram that displays the relationship between time and a variable, such as the Pavement Condition Index (PCI), of road sections. The performance curves would detail the life and condition of a roadway before and after treatment application.

- **Preventive Maintenance:** Cost-effective strategy for treatment to roadway system accounting for ways to preserve the roadway and prevent deterioration in addition to improving or maintaining the condition of the roadway. This is typically performed early before significant structural deterioration can appear. Some activities include joint sealing, crack sealing and filling, as well as utilizing chip seals and slurry seals.

- **Reconstruction:** After failure of the pavement structure to perform its function, removal and replacement of an existing pavement structure is needed. This may involve recycled or new materials to replace the old pavement structure.

- **Routine Maintenance:** Maintenance performed routinely to preserve the roadway's condition or to return the roadway to a proper level of service. Maintenance activities include crack filling and/or sealing, as well as maintaining the drainage system, and they are performed throughout a pavement's life.

- **Slurry Seal:** A thin surface treatment in a thickness equivalent to the largest aggregate size. This treatment returns the roadway's surface texture to an acceptable quality as well as improving waterproofing. The cure time needed before allowing traffic to re-enter is 24 hours.

- **Slurry Surfacing:** Includes microsurfacing and slurry seal treatments.

- **Surface Type:** Surface type is the uppermost layer and is dependent on the type of material used, whether it be HMA or Portland cement. The surface type also depends on the functional class (arterial, collector, residential).

- **Treatment Category:** Treatments with their associated application times and objectives. For instance, one group of treatments is meant to hinder and prevent deterioration; however, other treatments would include maintenance, rehabilitation, and construction of roadways.

- **Treatment Type:** A certain treatment used to treat specific distresses on a roadway. These treatments would include chip seals, slurry seals, microsurfacing, HMA overlays, and diamond grinding. For some situations, treatment combinations are required to ensure quality performance of the roadway.

ACRONYMS

AASHTO	American Association of State Highway and Transportation Officials
AAPT	Association of Asphalt Paving Technologists
ADT	Average Daily Traffic
AEMA	Asphalt Emulsion Manufacturers Association
AGC	Associated General Contractors
AI	Asphalt Institute
APWA	American Public Works Association
AR	Asphalt Rubber
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
Caltrans	California Department of Transportation
CalRecycle	California Department of Resources Recycling and Recovery
CCPIC	City and County Pavement Improvement Center
CP2C	California Pavement Preservation Center
DOT	Department of Transportation
FHWA	Federal Highway Administration
HMA	Hot Mixed Asphalt
IRI	International Roughness Index
ISSA	International Slurry Surfacing Association
LCCA	Life Cycle Cost Analysis
LCC	Life Cycle Cost
LTTP	Long-Term Pavement Preservation
MSA	Maintenance Superintendents Association
MTAG	Maintenance Technical Advisory Guide
MTC	Metropolitan Transportation Committee
MTI	Mineta Transportation Institute
NDOT	Nevada Department of Transportation
PaveM	Caltrans Pavement Management System
PCI	Pavement Condition Index
PCR	Pavement Condition Rating
PME	Polymer Modified Emulsion
PMS	Pavement Management System
TCV	Total Cracking Value
TDA	Tire-Derived Aggregate
TRB	Transportation Research Board
UNR	University of Nevada, Reno
WPCV	Wheel Path Cracking Value
WSDOT	Washington State Department of Transportation

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