# Pavement Maintenance
## Preparing for the 21st Century

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The current state of practice with regard to pavement preservation and some of the challenges facing the pavement maintenance industry in the 21st century have been studied. Pavement preservation (including preventive maintenance) needs to be adopted as an essential program element in agencies so that the U.S. highway system can be properly maintained at the levels expected and demanded by users. Some of the issues and challenges for both rigid and flexible pavements have been addressed.

Highway agencies throughout the world face increasing demands and decreasing resources to maintain and preserve their highway networks. The demand to "do more with less" has become an operating slogan for many of these agencies. Historically, the emphasis has been on constructing new facilities; however, most are currently in the maintenance or preservation mode, a trend that can be expected to continue in the foreseeable future.

According to recent figures reported by the FHWA, the condition of the highway pavements on the national highway system is such that the cost to maintain the system at its existing condition level is nearly $50 billion annually (*1*). The United States is currently spending over $25 billion/year and cost estimates to bring the entire system up from its current level to a "good" level exceed $200 billion. Judging from this, it is clear that current efforts cannot continue using the traditional approaches to managing pavement maintenance and that the pavement preservation strategies employed by the various levels of departments of transportation (state, county, city) need to be restructured.

The purpose of this paper is twofold:

- Present the current state of practice on pavement preservation, including some of the barriers facing the industry; and
- Discuss the challenges or needs for the industry to ensure quality pavement preservation practices into the 21st century.

Pavement preservation is at the core of all future highway programs. It represents a compilation of activities that provide highway users with a higher level of quality and improved cost-effective service. It is directed at preserving the investment in our highway system, extending pavement life and meeting the needs of the users. It is the sum of all activities undertaken to provide and maintain serviceable highways through the timely application of carefully selected surface treatments to maintain or extend a pavement's life.

## Current State of Practice

Pavement maintenance practices currently used by agencies in the United States and throughout the world have evolved with little significant research concerning the numerous maintenance techniques or management meth-

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ods. In contrast, strides have been taken in materials research with developments such as polymer-modified binders for both asphalt and portland cement concrete pavements. This is in part because maintenance historically has taken a backseat to the design and construction of new facilities. During the Strategic Highway Research Program (SHRP) some work was done to improve both sealing and patching techniques. Only recently have agencies begun to invest research and development money into new techniques and practices for maintaining and preserving road systems. Some of the recent efforts are presented in Table 1.

In this section the current state of practice in pavement maintenance treatments, treatment selection procedures, performance of the treatments, and other related factors are described.

**TABLE 1 Recent National Research and Development Efforts Dealing with Pavement Preservation**

| Item | Comments |
|---|---|
| Formation of FPP (Formerly FPRMR) | • Founded in 1992 to initiate research and training efforts in pavement preservation<br>• Board of Directors composed of representatives from industry, user agencies, and academia<br>• Sponsored a recent study "Selecting a Preventive Maintenance Treatment for Flexible Pavements" |
| FHWA workshops, training courses on preventive maintenance | • In 1997 established ETG to provide guidelines and technical assistance<br>• Forum for the Future, October 1998<br>• Pavement Preservation: The Concept of Preventive Maintenance (Released December 1999)<br>• Pavement Preservation: Selecting Pavements for Preventive Maintenance (under contract)<br>• Pavement Preservation: Design and Construction of Quality PM Treatments (future project)<br>• Pavement Preservation: Integrating PM into Pavement Management Systems (future project) |
| NCHRP studies | • 14-14, Optimum Timing of Maintenance Treatment<br>• 20-50(02), Relative Performance of Jointed Plain Concrete Pavements with Sealed and Unsealed Joints<br>• 20-50(03), Effectiveness of Maintenance and Rehabilitation Options |
| AASHTO | • Pooled fund study titled "Microsurfacing Mix Design Procedure"<br>• Developed Lead States Team on Pavement Preservation |
| Innovative Pavement Research Foundation (IPRF) | • Founded in 1998 to foster research and innovation focused on preserving, rehabilitating, and enhancing the existing highway system<br>• Comprised of Industry, State and Federal officials, Academia<br>• Sponsored research of "Best Practices for maintenance and rehabilitation of PCC pavements"<br>• Sponsored research "Influence of Sealing Transverse Contraction Joints on the overall performance of PCC pavements"<br>• Sponsoring synthesis "Cost Effective Restoration Procedures and Optimum Timing for PCC pavements"<br>• Sponsoring research "Effective Repairs of Longitudinal Cracks in PCC pavements"<br>• Sponsoring research for the "Development of a Rolling Wheel Deflectometer" |
| FHWA/TRB | • National Conference on System Preservation, San Diego, CA (planning underway)<br>• Pavement Preservation Forum #2 (planning just underway) |

NOTE: PM = preventive maintenance; PCC = portland cement concrete.

## Preservation Treatments

A number of preservation techniques for both flexible and rigid pavements are used worldwide. The most commonly used are indicated in Table 2. Agencies specify the treatment to be used based on their knowledge of the existing pavement distress, anticipated traffic loading, environmental conditions at the project, cost of the treatment, and their experience with the performance history of a particular treatment. Several types of seals for flexible pavements are indicated in Table 2 and the use of some may be restricted to low-traffic-volume facilities because of an agency's prior experience with performance issues when used on pavements with a higher volume of traffic. For example, chip seals are often restricted to use on hot-mix asphalt pavements with an average daily traffic count of fewer than 5,000 because cover aggregate loss can damage vehicles. There are exceptions, particularly with advances in the use of polymer-modified binders for this technique.

## Treatment Selection

Pavement condition data are collected by trained observers or with automated equipment that is capable of measuring a number of different pavement characteristics. Agencies acquire these data with their own forces and evaluate them in pavement management systems or they contract the work to consulting engineers. Some agencies have not developed the ability to share pavement management data among their divisions, and as a result decisions about specific treatments are made without adequate information.

A number of factors are generally considered by agencies in selecting a pavement maintenance treatment including the following (*2–4*):

- Surface type and extent of distress,
- Traffic type and volume,
- Climate,
- Expected life,
- Cost-effectiveness of treatment,
- Time of year of placement,
- Availability of qualified contractors and quality materials, and
- Facility downtime (user delays).

A procedure, or policy, is usually established by an agency in order to choose the appropriate treatment and this may include guidelines, goals, and strategies. Current practice is quite variable and ranges from choosing the treatment based on past experience to using comprehensive computer programs that incorporate data analysis and modeling procedures. For example, if permanent deformation in a flexible pavement is determined to be the primary distress and it is confined to the surface layer, some treatments would be better suited to match this distress than others—for example, microsurfacing or thin hot-mix asphalt overlays instead of fog seal or surface dressing. For rigid pavements, treatment selection is determined primarily by the type and extent of distress. For example, joint faulting is often addressed by grinding or by using dowel bar retrofit, although several agencies in the United States have used this technique as a preventive maintenance treatment on undoweled pavements in advance of joint faulting. Cracks in the slab can be maintained for a short time by using crack sealants, whereas longer term solutions may incorporate cross-stitching or dowel bar retrofit.

## Performance of Pavement Maintenance Treatments

The performance of maintenance treatments is difficult to assess because the same treatment can be used under

**TABLE 2 Current Preservation Treatments Used for Flexible and Rigid Pavements**

| Flexible Pavements | Rigid Pavements |
|---|---|
| • Crack sealing | • Joint and crack sealing |
| • Profile milling | • Joint and spall repairs |
| • Fog seals | • Longitudinal crack and joint repair |
| • Sandwich seals | • Dowel bar retrofit |
| • Sand seals | • Diamond grinding |
| • Surface dressing (chip seals) | • Full and partial depth repair |
| • Slurry seals | • Thin PCC resurfacing |
| • Microsurfacings | |
| • Cape seals | |
| • Thin and ultra thin hot mix asphalt overlays | |

NOTE: PCC = portland cement concrete.

**TABLE 3 Typical Lifetimes for Various Flexible Maintenance Treatments: Flexible Pavements (5)**

| Treatment | Range of Expected Life, Years |
|---|---|
| Crack Treatments | 2 to 3 |
| Fog Seals | 3 to 4 |
| Slurry Seals | 4 to 6 |
| Microsurfacings | 5 to 7 |
| Chip Seals | 4 to 6 |
| Thin HMA | 2 to 12 |

NOTE: HMA = hot-mix asphalt.

a variety of pavement conditions. For instance, a chip seal can be used as a preventive maintenance treatment on a flexible pavement in good condition or as a stopgap maintenance treatment on a flexible pavement in poor condition. In the case of diamond grinding, the performance of this treatment is highly dependent on the quality and type of aggregates in the existing pavement. In 1996, the Portland Cement Association sponsored a research study on the longevity and performance of diamond-ground pavements, performed by ERES Consultants. Although many questions were answered, some were not, and more research is warranted. Geoffroy (5, 6) noted that a number of factors can affect the performance of maintenance treatments and he provided the performance expectations of various treatments as reported by a number of agencies. Typical lifetimes for the various treatments are presented in Tables 3 and 4 for flexible and rigid pavements, respectively. However, when the agencies try to use life-cycle cost analysis, the life extension provided by a treatment at a given time is essential information that generally is not readily available.

## Cost-Effectiveness Evaluation

A number of different procedures are used to evaluate cost-effectiveness when potential treatments are evaluated (5), and this step is fundamental to the process. Some procedures are simple and straightforward; others require significant amounts of input data. Although the techniques follow a logical process, some of the information needed to calculate the cost-effectiveness of the treatment includes cost of treatment, life of treatment, cost of traffic control, user costs during application, maintenance and rehabilitation costs over an analysis period, and user benefits for a specific treatment. Data that can be difficult to obtain include the following:

- Estimated life for the various treatments as a function of the existing pavement condition,
- User delays associated with the various treatments, and
- User benefits associated with the various treatments.

Determining which factors to include in the analysis and developing the evaluation procedures are generally the responsibilities of the specifying agency. Most agencies do not yet perform a cost analysis for maintenance treatments.

**TABLE 4 Typical Lifetimes for Various Flexible Maintenance Treatments: Rigid Pavements (3, 4)**

| Treatment | Range of Expected Life, Years |
|---|---|
| Joint and Crack Sealing | 2-10[a] |
| Diamond Grinding | 10-20[b] |
| Dowel Bar Retrofit | 10-15[c] |
| Full and Partial Depth Repair | 10-15 |
| Thin PCC Resurfacing | 15-25 |

NOTE: PCC = portland cement concrete.

[a] Depending on the type of joint sealant used, life can range from 2-10 years; 2 years for bituminous-based materials, 4-6 for polymer modified bituminous materials, and 8-10 years for silicon materials.

[b] The ERES study indicated that the average life of diamond grinding is dependent on environmental and loading factors.

[c] Yet to be determined. Several states have studies under way.

## Mix-Design Procedures

Standardized mix-design procedures for many of the asphalt treatments presented in Table 2 are available and published by AASHTO, the American Society of Testing and Materials, and other worldwide standards organizations. In addition, many agencies and suppliers have developed their own design procedures that are based on local knowledge of materials and procedures. However, mix-design techniques for most pavement maintenance techniques are still considered by many to be more of an art than a science. For some asphalt pavement treatments (fog seals and sand seals), the principal determinant is the condition of the existing pavement, which in turn affects the application rate for the treatment; thus there is no design procedure per se. Similarly, mix-design procedures for full and partial depth repairs in rigid pavements vary widely across the United States with various degrees of performance. Mix-design procedures for a number of pavement maintenance systems still need to be developed if these techniques are to be widely accepted.

### *Materials Selection*

Many flexible pavement maintenance treatments are thin (25 mm or less) and others must bond to the existing materials; thus, the selection of high-quality, compatible aggregates, binder, and other essential ingredients (cement, fly ash) for the treatments is imperative to achieve the anticipated performance. Adequate friction resistance and durability are desired properties for many of these treat-

ments and selecting aggregates that exhibit these features is an important safety consideration. In addition, the use of polymers to modify emulsions, asphalt cements, and portland cement concrete mix designs has generally provided longer pavement lifetimes at a higher initial cost. The cost-effectiveness of the modified binders and chemical admixtures still needs to be quantified.

The materials used to repair and maintain portland cement concrete pavements vary as well. Most agencies have developed materials and techniques to suit their individual needs. A major effort has been identified to consolidate the available information documenting the best practices for design and materials selection so that maintenance-free service for up to 20 years can be achieved that allows for rapid repair and restoration.

### *Mixture Evaluation*

The tests used to evaluate most maintenance treatments cannot be used to predict the performance of those treatments. For maintenance treatments to be more widely accepted, performance tests that evaluate the benefits imparted by the treatment need to be developed. This is true for both flexible and rigid pavement maintenance treatments.

## Construction Procedures

Although most of the construction procedures in pavement maintenance activities have remained essentially the same for a number of years, there have been notable advances in the use of automation to control pavement smoothness, material application rates, proportioning of materials in mix plants, patching machines, and other uses, and this has become standard practice in many agencies. As a result of studies conducted during the SHRP, significant improvements in some treatment application procedures (crack sealing techniques, pothole patching techniques, and equipment) have taken place and implementation has been widespread.

## Specifications

Materials and method specifications predominate in the pavement maintenance field, but a number of agencies, in the United States and elsewhere, have developed performance-based specifications while others are using end-result specifications with warranties (*7*). Much of the emphasis for this development is due to the move to have more pavement maintenance work performed by private contractors and less done by department forces. In addition, some agencies have privatized total maintenance (right-of-way to right-of-way) of portions of their systems by contracting maintenance to firms for 5 years or more.

## Funding for Maintenance

Most agencies have not been able to rely on dedicated funding for pavement maintenance. This makes it difficult to plan for preventive maintenance and pavement preservation activities. Part of the problem is associated with making the paradigm shift from worst first to a preventive maintenance or pavement preservation approach. Administrators and legislators need to be taught about the importance of preventive maintenance with examples that relate to them directly (maintenance of vehicles or homes) before they commit money to pavement maintenance.

# Challenges for the Future

As the pavement maintenance community moves into the 21st century, a number of significant issues must be addressed. Many agencies worldwide are faced with the daunting task of managing pavement assets with reduced staff and shrinking budgets. At the FHWA Forum for the Future (*8*), sponsored by a number of public and private sector groups and held in late 1998, a group of practitioners set out to develop a roadmap for the future in order to develop strategies in pavement maintenance procedures that will result in greater safety, convenience, and customer satisfaction to the traveling public. The major issues identified in the forum (plus others) are discussed here. Similarly, the portland cement concrete industry laid out a blueprint for portland cement concrete pavement research (*9*) that included work on maintenance and rehabilitation. These are also addressed here.

## Better Understanding of Pavement Preservation and Preventive Maintenance

Because of limited resources, the move toward preserving our pavements by providing the "right treatment, to the right road, at the right time" is a concept that must be adopted if agencies are going to minimize costs while meeting customer expectations. Agencies must do a better job of defining the benefits of preservation programs and preventive maintenance techniques. This concept must be communicated to the customer—that is, the traveling public. Pavement preservation is an inclusive term and considers all the "activities undertaken to provide and maintain serviceable roadways"(*5*); this includes correc-

tive and preventive maintenance as well as some rehabilitation. Preventive maintenance as defined by AASHTO's Subcommittee on Maintenance "is the planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system without substantially increasing structural capacity." Simply put, pavement preservation is a global term relating to protecting and preserving the pavement assets in place by using a number of different strategies that may include structural improvement to address those pavements that are structurally deficient, while preventive maintenance is keeping good roads in good condition (*10*). Without a basic understanding of these approaches, few agencies will be able to garner support for pavement preservation and preventive maintenance programs from the traveling public, contracting industry, and legislative representatives. Current trends in a number of states indicate that pavement preservation concepts are being endorsed and implemented. The AASHTO Pavement Preservation Lead State Team confirmed this with a recent survey.

## Eliminating Art and Introducing Science

As mentioned previously, many perceive the mix-design and evaluation process for maintenance techniques to be "black magic." Current mix-design procedures do not use measures of basic material properties that can be used to predict performance. As a result, only experienced material suppliers and contractors using their knowledge base are able to generate products that consistently perform well. Even in these instances, it may not be possible to transfer this knowledge into other regions without considerable development work. Performance-related testing is vital to ensuring quality products in all parts of the United States and the world. Considerable research is needed to develop performance-based mix-design procedures and specifications.

## Integrating Pavement Performance Data

Data on the benefits or effectiveness (life or improved life) of pavement maintenance treatments are sorely lacking. Although data may be collected by a number of different methods within an agency, documentation is sparse, data may not be transferable, and often the data are not analyzed in an organized fashion. Performance data for each treatment are essential if an agency wants to make decisions about the most cost-effective treatment to apply.

Integration of various management systems that currently exist (pavement management, maintenance management, project management) is necessary for effectively managing pavement information that can lead to improved pavement maintenance planning, programming, and scheduling. Integration of management systems is under way in some agencies but more is needed, and this is impeding the advancement of pavement preservation. There is an urgent need to develop performance models that clearly show the impacts of the various maintenance treatments.

## Need for Dedicated Funding

Funds for pavement maintenance are often allocated based on money that is left over after funds for all other programs are committed. In addition, if a natural disaster occurs, funds for cleanup and restoration of services are often taken directly from the pavement maintenance budget, which reduces the amount available for preventive maintenance activities. To maintain a pavement system to meet customer demands and expectations, funding must be dedicated to these preventive maintenance and pavement preservation activities so that planning, programming, and scheduling can be performed in order to do the "right treatment at the right time." Educating legislators and customers about the needs for dedicated funding for pavement preservation including preventive maintenance is an essential element of an effective pavement preservation program.

Of all the program needs in the pavement preservation area, this is most essential. If funds are not available for a sustainable preventive maintenance program, it is doomed to failure.

## Performance Specifications and Quality Assurance

In light of the downsizing of agencies, emphasis on performance-based specifications and quality assurance, including training, is essential for improved strategies. New ideas specific to pavement maintenance activities must be considered in order to advance the technologies needed to meet customer demands. Although there have already been efforts to develop performance specifications, a much broader range of materials and processes used in pavement maintenance activities should be included. With few exceptions, only hot-mix asphalt and portland cement concrete specifications have been advanced in the past 20 years or more. Quality assurance in pavement maintenance activities is in the same predicament or at the same low level of advancement and use as performance specifications. A few agencies have adopted quality assurance for maintenance but much remains to be done. As more agencies change from using agency maintenance forces to contract maintenance, better specifications and quality assurance become more important (*7*).

Downsizing, new contract employees, and job changes all affect the ability to keep a well-trained workforce. The change from agency maintenance forces to contract maintenance requires that remaining department personnel change from maintenance "doers" to contract managers, which requires different skills. Some training programs targeted to enhance these skills are currently being developed by the National Highway Institute but additional training programs are needed and the existing programs need to be updated.

## Research and Training

Although advances in materials and techniques for pavement maintenance have occurred, more research and training are essential in the areas of policy development for effective management of pavement maintenance, mix designs, specification development, cost-effectiveness of treatments, and the best application timing of various treatments. Immediate research and training needs are noted below.

### *Mix Design*

Research to develop better and more comprehensive mix-design procedures that are based on basic material properties are related to performance and can be used in the quality assurance process as needed for most pavement maintenance techniques. Procedures to evaluate thin treatments of various types must be developed with sound engineering principles.

### *Materials Selection*

Aggregate specifications for pavement maintenance treatments need to be evaluated. Often the materials specified follow standard construction specifications; however, during the placing of thinner courses in maintenance, as previously noted, more durable aggregates may be required to obtain expected performance. Many of the maintenance treatments are constructed with emulsified asphalt cements, and the compatibility of the aggregate to the emulsion becomes vitally important in some material mixtures. When materials are used in patching, they must bond to the existing pavement layer materials and perform as a part of the existing material. Often they also must be exposed to traffic shortly after installation. These types of specialized requirements need to be considered in the selection and specifications of maintenance materials.

### *New Technologies*

Continued efforts are needed (by industry) to develop improved technologies that improve performance or are most cost-effective. Many of the new technologies come from Europe (or elsewhere) where agencies and industry work in partnership to do their jobs better. This same sort of partnership activity is needed in the United States.

### *Timing of Pavement Maintenance Treatments*

Although SHRP research in determining the best time to apply various maintenance treatments to obtain the greatest return on the funds expended was begun, much analysis of the existing data is needed, and the SHRP studies need to be followed through to conclusion. Additional studies should be undertaken to determine the correct timing for placing pavement maintenance treatments in localized environmental conditions with locally available materials. As noted previously (Table 1), an NCHRP study to determine the optimal timing of maintenance treatments has recently been initiated.

### *Construction Practices*

Maintenance activities are much more time dependent than construction, and the development of equipment and methods that facilitate the application of maintenance treatments in a timely manner while providing the desired quality level needs to be undertaken. Although SHRP studied some aspects of pavement maintenance techniques and equipment, much remains to be done. There is a need to expand on simplified practices for maintenance-type activities, such as those developed by the Kansas Department of Transportation (*11*).

### *Specifications*

As noted previously, some work in this area has been done but different approaches need to be explored for maintenance activities. Simply adopting construction specifications in the maintenance area is not appropriate in most instances. Research in performance-based specifications and end-result specifications with warranties for maintenance activities is sorely needed.

### *Performance of Pavement Maintenance Techniques*

The industry must begin to develop comprehensive techniques to document the performance characteristics of the various pavement maintenance procedures that can be used to predict performance. Although the performance of some maintenance treatments was investigated in the SHRP studies, additional studies need to be completed with other treatments, locally available materials, and performance-based mix designs to provide the performance information needed to permit incorporation of

pavement maintenance treatments into pavement management systems. If agencies cannot explicitly demonstrate to their customers that their pavement preservation strategy is cost-effective and provides a safe, smooth, roadway, they will not obtain the support to continue this type of program.

### Urban Maintenance Issues

A major challenge in the next century is finding new and improved ways to maintain roadways in urban areas without causing undue delays or hardships to users. Increased nighttime work is needed, and techniques that allow maintenance to be accomplished more quickly and under normal traffic conditions must be found.

## Summary

Information has been presented about the current state of practice with regard to pavement maintenance as well as some of the challenges facing the industry for the 21st century. Pavement maintenance (or preservation) needs to be elevated in stature so that highway systems can be kept at a level demanded by the users.

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