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Pavement Preventive Maintenance

Executive Overview

National Highway Institute

U.S. Department
of Transportation
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Executive Overview

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16. Abstract

This Executive Overview highlights the contents of the reference manual developed for a FHWA/NHI training course on pavement preventive maintenance. Preventive maintenance, often summed up as "applying the right treatment to the right pavement at the right time," is becoming increasingly popular in highway agencies interested in overall pavement preservation. The objectives of the course are to introduce the components of a pavement preventive maintenance program, to define potential treatment techniques and materials, to describe the relationship between pavement management and pavement preventive maintenance, and to explain cost/benefit concepts of preventive maintenance to decision makers. The course's target audience is upper management and policy makers in highway agencies.

The training course is organized into seven modules that are intended to meet the above-stated objectives. The first module is an overview of pavement preventive maintenance. This is followed by background information on the current status of preventive maintenance, appropriate definitions, objectives of preventive maintenance programs, and barriers to success. The next module introduces the most commonly used maintenance treatments for both asphalt concrete surfaced and portland cement concrete pavements. Because economic analyses are so important to evaluating the cost effectiveness of treatments, a module on cost analyses is included.

A number of state highway agencies (SHAs) have already implemented or are in the process of implementing preventive maintenance programs. These agencies form the basis for a module on case studies, which summarizes the status of these programs. Module 6 considers the best practices from successful SHAs, as well as information presented in the previous modules, and outlines the steps an agency should consider to begin or improve their own preventive maintenance program. The final module is actually a series of workshops that are intended to emphasize some of the key points of the presentation material and allow course participants the opportunity to work together to establish objectives and program components for their own preventive maintenance program.

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Case Study State	Contact Person(s)
California	Randell H. Iwasaki, Deputy Director–Maintenance and Operations
	Larry H. Orcutt, Program Manager–Maintenance
Georgia	Wouter Gulden, State Materials and Research Engineer
Michigan	Larry Galehouse, Pavement Maintenance Engineer
New York	Ed Denehy, Transportation Maintenance Division
Texas	Joe S. Graff, Director–Maintenance Section

This entire project came about as a result of a joint initiative among several AASHTO states, the Federal Highway Administration (FHWA), and the Foundation for Pavement Preservation (FPP). FPP is a non-profit industry organization whose purpose is to promote research and training in preventive maintenance. Their assistance was supplemented by financial support from the Asphalt Emulsion Manufacturers Association (AEMA), the Asphalt Recycling & Reclaiming Association (ARRA), and the International Slurry Surfacing Association (ISSA). In addition to financial contributions to the project, FPP staff helped to organize and coordinate meetings and facilitate the distribution and evaluation of preliminary draft reports. In that regard, the efforts of John Fiegel, FPP Executive Director, are especially appreciated.

Throughout the course of assembling the technical material for this project, input, feedback, and evaluations have been provided by a Preventive Maintenance Expert Task Group (ETG) and members of FPP. Specifically, input was provided by the following individuals:

Member	Affiliation
Mr. Bill Ballou	FPP and Koch Materials Company
Mr. Jim Chehovits	CRAFCO
Mr. Barry Dunn	International Slurry Surfacing Association
Mr. John Fiegel	FPP
Mr. Larry Galehouse	Michigan DOT
Mr. Jose Garcia	FHWA
Mr. Kent Hansen	National Asphalt Pavement Association
Mr. Jack Hardin	Mariani Asphalt Company
Dr. Gary Hicks	FPP and Oregon State University
Mr. Denny Jackson	FPP and Washington State DOT
Ms. Pat Lees	National Highway Institute
Mr. Bob McQuiston	FHWA
Mr. Jim Moulthrop	Koch Materials Company
Mr. Richard Nelson	Consultant
Mr. John Roberts	ACPA
Mr. Jim Sorenson	FHWA
Mr. Jim Stevenson	Montana DOT

From Applied Pavement Technology, Inc.'s staff, Monty Wade, Chuck Wienrank, Rachel DeSombre, and Adheer Bahulkar worked tirelessly to help produce the training materials. Their contributions are always appreciated.

Finally, the FHWA's leadership, and in particular the contributions of Mr. Jim Sorenson, are recognized for bringing together industry and agency to address system preservation needs. This leadership has offered technical support and funding flexibility to allow the owner agencies to reevaluate their business practices and better manage their infrastructure investments to meet the demands of the next century.

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September 1999

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Introduction

Maintenance plays an essential and integral part in the life of a pavement, and as vehicle miles traveled and traveling speeds have increased that role has only become more important. Preventive maintenance is especially important, as by its very name it implies taking care of assets before deterioration becomes problematic. O'Brien, in NCHRP *Synthesis 153* (1989), notes: "highway maintenance managers recognize the value of timely preventive maintenance. However, because the benefits are often poorly defined, preventive maintenance programs are, in many cases, not able to compete with other programs." This discrepancy between the importance of preventive maintenance and the respect it commands is often summed up with the simple, slightly cynical comment: "There are no ribbon cuttings for pavement maintenance."

In *Synthesis 223* (1996), Geoffroy concludes that "more effort is needed to inform decision makers of the benefits and cost-effectiveness of preventive maintenance for pavements." The recognition of this need is widespread. In 1997, the SHRP Lead State Team for Preventive Maintenance surveyed the fifty states, Washington, D.C., and Puerto Rico on their preventive maintenance practices (Texas DOT 1997). Of the forty-five responses that were received, sixteen states said that they needed assistance in getting top management to buy in to the concept. Sixteen states also said they needed technical assistance with specific treatments, and eighteen states needed assistance in refining the decision-making process for determining the size of the preventive maintenance program needed. Overall, many of the states suggested a two-tiered approach, separating information to present to the legislature and top management from the information to present to field personnel.

To help address the needs of agencies interested in preventive maintenance and to further the concept of system preservation, the Federal Highway Administration (FHWA), the National Highway Institute (NHI), the American Association of State Highway and Transportation Officials (AASHTO), and the Foundation for Pavement Preservation (FPP), a non-profit industry organization, co-sponsored the development of this course and this manual. This manual and the associated presentation are intended to familiarize interested state highway agencies (SHAs) with the currently available tools and technology that make the implementation of a pavement preventive maintenance program feasible. The objectives in developing these materials are to enable readers and participants in the training courses to accomplish the following:

- Become familiar with the concepts of a Pavement Preventive Maintenance (PPM) program.
- Define potential pavement preventive maintenance techniques and materials.
- Describe the interrelationships between pavement management and PPM.
- Explain cost/benefit concepts to decision makers.

The contribution that a preventive maintenance approach can make to an overall pavement preservation program is being increasingly recognized by public agencies. The FHWA and industry have taken a leading role in promoting the benefits of preventive maintenance programs. The material presented in this course continues that collaboration and is intended to help agencies that are interested in developing or improving their own programs.

This *Executive Overview* presents key information from the "Pavement Preservation: The Preventive Maintenance Concept" *Reference Manual*. It is intended to summarize and highlight the points from that document in a succinct manner: the interested reader is encouraged to consult the more comprehensive *Reference Manual* for further information. That document contains 6 modules organized in the following manner:

- Overview.
- Benefits and Challenges.
- Techniques.
- Cost Analyses.
- Case Studies.
- Implementing Preventive Maintenance as Part of a Pavement Preservation Program.

It also contains a series of workshops that are used to facilitate the classroom presentation of this information.

This material is not meant to serve as a guide to preventive maintenance techniques. While a broad overview of some currently used techniques is presented in module 3 of the *Reference Manual*, there are many other sources of more complete information on this topic. Rather, this presentation focuses on the types of information needed to implement or improve a preventive maintenance program, and how those agencies with successful programs reached their current status.

Challenges to Highway Agencies

Two current forces are having a large impact on how highway agencies carry out their work. The first is down-sizing, the shrinking of the staffs (and expertise) of these agencies. The second is a shift toward customer satisfaction, in which agencies are acknowledging that their mandate is to provide the best possible services to taxpayers and the traveling public. While these two forces might seem at odds with each other, taxpayers insist that they be reconciled. Pavement preventive maintenance is one of the tools that more and more agencies are employing to accomplish this.

Every agency has a pavement preservation policy, whether or not it is a formal document. This policy determines what treatments get fixed, how they get fixed, and when they get fixed. But decision-makers should ask themselves the following questions:

- Do I know the long-term implications of our agency's existing pavement policies?
- Are we applying the most cost-effective treatments to our pavements?
- Are their deficiencies in our approach that can be improved upon?
- If our policies need to change, how can we ensure the success of the new policies in terms of:
    - Support within the agency, from legislators, and from the public?
    - Dedicated funding?

This *Executive Overview* highlights some answers to these questions.

Overview of Pavement Preventive Maintenance

Any examination of the numerous reports, studies, and policy statements on preventive maintenance shows that there is widespread disagreement, if not confusion, over how to label different pavement maintenance activities. What is pavement preventive maintenance? What makes it different from other pavement preservation activities? Is it the extent of the work that is important? The type of work? How the work is contracted? Who funds the work? When in a pavement's life the work is performed? The condition of the pavement when the work is performed? A good starting point to understanding this material is to consider the following definitions.

Definitions

Routine maintenance is reactive in nature, fixing a defect once it occurs. Unfortunately, routine maintenance activities–such as the filling of a pothole or sealing cracks on a failing pavement–are what most people think of when they hear the term "maintenance." Routine maintenance is frequently performed on pavements that are failing. It is a stopgap approach that keeps traffic moving, but is rarely thought of as contributing to long-term pavement performance. Routine maintenance is also often performed under harsh conditions; the weather is often bad or the condition of the pavement mitigates against a long-lived repair. These types of repairs historically perform the worst and draw the greatest ire from the traveling public.

Preventive maintenance is a somewhat new concept for most highway agencies. AASHTO's Standing Committee on Highways provides the following explanation of preventive maintenance (FHWA 1999):

> *... 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 increasing structural capacity].*

Geoffroy, in NCHRP 223 (1996), describes a preventive maintenance strategy as "an organized, systematic process for applying a series of preventive maintenance treatments over the life of the pavement to minimize life-cycle costs."

These descriptions suggest that planning is essential, and that a treatment's costs, results (effectiveness), and performance should be considered in treatment selection. These ideas are best summed up by the definition that has been used by AASHTO's Lead State Team on Maintenance (as quoted in FHWA 1999):

Preventive maintenance is applying the right treatment to the right pavement at the right time.

This definition readily differentiates preventive maintenance from reactive or routine maintenance. Preventive maintenance anticipates pavement performance, and suggests the use of treatments that can be applied in a timely manner to improve service to the customer.

Formal definitions can help to create a common basis for understanding the concepts associated with preventive maintenance. Based on the above discussion, the following additional definitions are suggested.

- **Preventive Maintenance** (AASHTO): 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 increasing the structural capacity].

- **Pavement Preservation**: The sum of all activities undertaken to provide and maintain serviceable roadways; this includes corrective maintenance and preventive maintenance, as well as minor rehabilitation projects (FHWA 1999).

- **Pavement Preventive Maintenance**: The application of one or more treatments (such as joint repair, seal coats, shoulder repair, and restoration of drainage systems), generally to the surface of a structurally sound pavement, which are cost-effective methods of preserving the pavement structure (from FHWA 1999).

- **Pavement Rehabilitation** (AASHTO): Resurfacing, restoration, and rehabilitation work undertaken to restore serviceability and to extend the service life of an existing facility. This may include partial [surface] recycling of the existing pavement, placement of additional surface materials or other work necessary to return an existing pavement, including shoulders, to a condition of structural or functional adequacy. [Federal Register 1/13/89, 23 CFR Part 626]

- **Pavement Reconstruction**: Construction of the equivalent of a new pavement structure, which usually involves complete removal and replacement of the existing pavement section including new and/or recycled materials.

While the terms may be used different ways within different agencies, especially as far as funding is concerned, these definitions address the broad distinctions between the different types of pavement activities.

Goals of a Pavement Preventive Maintenance Program

Why would an agency consider implementing a preventive maintenance program? The reasons will vary from agency to agency and even according to who is promoting the concept. While a transportation commission member might be attracted to the reported cost savings, a pavement engineer might be interested in the improvement in the overall pavement condition. Considering cost savings first, the following general treatment costs were reported by the City of Bedford, Texas (Bedford 1997) when their engineering staff was evaluating alternative pavement preservation strategies:

- Cost of microsurfacing one lane-mile (10 ft wide) of pavement in good condition: $10,270
- Cost to perform minor rehabilitation per lane mile: $45,570
- Cost to completely reconstruct a lane mile of street in failed condition: $574,000

In their 1997 summary of pavement conditions, this municipality documented that the cost of microsurfacing, a preventive maintenance treatment, is much less than rehabilitation or reconstruction, and recommended the timely use of these treatments rather than allowing pavements to deteriorate to the level at which rehabilitation or reconstruction was needed.

Bedford, Texas' findings mirror what the Michigan Department of Transportation recently reported. Galehouse (1998) notes that rehabilitation and reconstruction projects cost about 14 times as much as preventive maintenance projects per lane mile and that by implementing a preventive maintenance program Michigan has enjoyed cost savings of more than $700 million since 1992 (based on what would have been needed for more major programs if the network had been allowed to deteriorate).

A related major benefit is longer life and better performance from pavements. Caltrans, in a workshop presented to the California Transportation Commission (CTC 1996), notes that preventive maintenance treatments can restore a pavement surface and "extend its service life by 5 to 7 years.... This added service life will delay the need for the more costly pavement rehabilitation, allowing additional rehabilitation projects to be funded and constructed."

Similarly, Ontario's Ministry of Transportation concluded from an extensive study that crack sealing can cost effectively extend the life of an AC pavement by at least 2 years, "depending on the pavement's original condition, its environment, and the traffic volume." (Ponniah and Kennephol 1996) The timely application of crack sealing was also expected to reduce user delays.

From the results of the 1997 AASHTO Lead State survey of SHAs, it can be inferred that most highway agencies are convinced of the advantages of preventive maintenance. The anticipated benefits from such a program depend on how the program is designed and implemented, but can include one or more of the following:

- Higher customer satisfaction.
- Better informed decisions.
- Improved strategies and techniques.
- Improved pavement condition.
- Cost savings.
- Increased safety.

Although not all of these benefits are currently being realized, these are the ones that appear over and over again in discussions of preventive maintenance. How these benefits are expected to be obtained is described in the following sections.

Higher Customer Satisfaction

In the broadest sense, roads exist to serve the traveling public. Occasionally the connection between the many decisions that are made about pavements, from design to maintenance to rehabilitation, and their effect on the public are forgotten. By focusing on customer (that is, the traveling public) satisfaction, however, agencies recognize that their roads are products, and that their customers have opinions about their product. A nationwide survey of public opinion performed as part of the National Quality Initiative (NQI) (Coopers & Lybrand 1996) showed only a "moderate level of satisfaction with the highway system" and noted that "there is considerable opportunity for improving public satisfaction with the highway system." Desired changes include permanent rather than temporary repairs, and that construction and repairs be completed in a timely fashion.

In a nationwide survey commissioned by the Rebuild America Coalition, it was noted that Americans are willing to invest in improvements or preventive measures, but only if they can see the difference. Even more surprising, almost 70 percent of respondents said that they would be willing to pay 1 percent more in taxes if it mean smooth streets with no potholes and the elimination of road congestion (Luntz 1999).

Gary Byrd, in his 1998 TRB Distinguished Lecture, *Service Life and Life of Service: The Maintenance Commitments*, described five components of a "grand vision" for the future of highway maintenance. The first bears repeating here: "to provide a consistently safe, comfortable, and efficient travelway for highway users, and a safe work environment for maintenance and construction crews." There is a growing trend among highway agencies to explicitly focus on pavement customers and customer satisfaction. One example is the Washington State Department of Transportation (WSDOT), which commissioned a study to evaluate maintenance management and administration. As part of that study they supported a survey of public perception about maintenance (Dye 1996). Among their findings, they reported that the public:

- Rank roadway surface maintenance as the highest priority maintenance activity.
- Would be willing to pay more to achieve their desired levels of maintenance service and to reduce future costs.

The approach that was recommended to improve customer satisfaction involved the definition of Levels of Service (LOS) for different maintenance activities. These were then used to evaluate the public's acceptable or desired Levels of Service. With maintenance levels quantified, WSDOT was able to compare what they currently spend to provide their defined LOS to what was needed to provide a higher LOS. As the study's executive summary noted, WSDOT's approach "establishes a new basis for understanding between the citizens, the Legislature, the Governor, and the WSDOT concerning maintenance..." and provides "a means to ensure that the needs and priorities of the public are understood...."

Caltrans has undertaken a similar study of public perceptions (Survey Research Center 1999), with public opinion polls conducted in 1996 and 1998. Their overall ranking of the public's priorities showed these top four:

1. Maintenance response to accidents and natural disasters.
2. Safety.
3. Pavement conditions.
4. Traffic flow.

Reported findings included the public's desire to limit traffic delays due to maintenance to 15 minutes, and to have potholes repaired with 7 days. The findings were to be incorporated in performance measures as part of Caltrans' maintenance program.

A similar study underway for the Arizona DOT (Dye 1998) suggests a shared level of concern in that state. In a telephone survey of residents and a focus group study, 85 and 74 percent of the respondents respectively rated safety as their number one maintenance priority and preservation as their second. Between 60 and 65 percent of the surveyed residents said that they would be willing to increase taxes to meet improved levels of maintenance service. Even more significantly, 90 percent of the telephone respondents and 84 percent of the focus group participants indicated that they would be willing to spend more money now to save money in the long term on maintenance.

As the NQI Highway User Survey (Coopers & Lybrand 1996) and others have reported, a focus on customer satisfaction should be a part of every preventive maintenance program. The tools used in these programs can quantify improvements in pavement performance and ride quality. They can also be used to measure a reduction in delays from construction and other associated user costs. Highway users have an overwhelming interest in pavement condition and show every indication of being able to understand the impacts on their driving comfort and satisfaction of different approaches to treatment.

In order to achieve greater customer satisfaction, however, it is important that customer satisfaction begin as the agency's objective. Without an explicit commitment to customer satisfaction, it is extremely difficult for an agency to sustain a prolonged commitment to improve pavement performance through preventive maintenance.

Better Informed Decisions

Preventive maintenance programs rely on proper treatment selection and timing of the treatment to be successful. In order to select the right treatment for the right pavement at the right time, the following need to be known:

- What is the structure and condition of the existing pavement?
- What is the expected performance of the pavement?
- How will different treatments affect this performance?
- What other factors affect how the treatments will perform?

The availability of and accessibility to information is an essential part of the process of managing a successful preventive maintenance program. This information can come from many different sources, such as research studies, but it is difficult to obtain over time without a system that monitors pavement condition and predicts pavement needs. This functionality is usually available from an agency's pavement management system (PMS).

While it is not essential that there be a strong link between preventive maintenance and PMS, all of the successful programs appear to have exploited the information that is available from a PMS.

In a presentation at the joint industry/agency Forum for the Future, Clark detailed Montana's integration of preventive maintenance and PMS (1998). These efforts started in 1992, when PMS data were used to identify maintenance needs and obtain an increase in funding from $2 million to $13 million. Montana's objectives included making maintenance a full partner in the pavement preservation process and maximizing the use of Department resources for both maintenance and construction.

Perhaps an even more important aspect of the integration of maintenance and pavement management in Montana is the accurate feedback of maintenance information back into the agency's database. Historically, a major shortcoming of pavement performance models developed from PMS databases has been that the application of maintenance treatments is not accurately tracked by and integrated into those systems. Montana is tracking the location of maintenance treatments, the type of treatment, and the cost of the treatment. This information is crucial to helping them to identify the cost effectiveness of preventive maintenance treatments. Although many other agencies may track this information, they often discover problems when they try to match the maintenance data with the pavement management system. Many agencies discover that sections do not match up or there is no way to differentiate the location of the maintenance activity (such as whether the work was done on the shoulders or the mainline pavement) at a particular station.

Michigan DOT (MDOT) is another agency that has integrated its pavement management and preventive maintenance programs. In 1992, the DOT initiated the Michigan Preventive Maintenance Program (Galehouse 1998), with $8 million dedicated to highway preservation. During the period from 1992 through 1996 a total of $80 million was spent and almost 4,265 route km (2,650 route mi) of trunkline pavement were treated. Using a module of their PMS to project long-term conditions and funding needs under different treatment scenarios, MDOT demonstrated that their preventive maintenance projects were more than six times as cost effective as rehabilitation or reconstruction.

Improved Preventive Maintenance Strategies and Techniques

One of the challenges to highway agencies and industry alike is to develop new and improved treatments to be used in preventive applications. Why are these needed? Conventional maintenance and rehabilitation treatments have evolved over the years to correct observed deficiencies: for example, stockpiled cold mix has been used to patch a pothole. Performance expectations for this type of treatment are low and in its conventional application the material quality and quality control may be poor as well.

Preventive maintenance treatments must provide a better level of performance. Preventive maintenance treatments are applied in anticipation of the way that the pavement will perform over its life; treatments are designed to be applied while the pavement is still in good condition and help to maintain the pavement at a high level of service. Treated pavements are smoother, have improved friction characteristics, and should last longer between rehabilitation or reconstruction. To be effective, these applications often require the use of high quality materials and quality control may play a much larger role than with other types of treatments. As a result, many of today's materials have been designed to provide the improved performance that users seek. While the initial treatment costs may be higher in some cases, the expected life of the treatment is going to be much greater than conventional applications. The net effect is that overall maintenance costs will be reduced.

As part of a changing attitude toward maintenance, higher quality, more durable materials are being evaluated by many agencies, along with new application methods. Innovation in the development of these improved materials and treatment strategies has come from industry, agencies, and researchers. These same sources have helped to bring agencies up to speed. For example, Galehouse (1998) reported that when MDOT implemented their program in 1992 they were specifying some treatments (such as microsurfacing, chip seals, and certain concrete repairs) with which the Department was not familiar. The DOT worked closely with contractors and suppliers to develop and present workshops so that their personnel could effectively use the treatments.

Improved Pavement Condition

Agencies that have implemented preventive maintenance programs are not simply looking for a new way of doing the same old thing. Routine maintenance can be characterized as a reactive process in which immediate repairs are made to existing distresses. As noted previously, over the years this has been the most common approach to pavement maintenance. In contrast, preventive maintenance treatments help to preserve a pavement and extend its useful performance period or cycle. The difference between these two approaches is substantial and is illustrated conceptually in figure 1, in which not only is the timing of a preventive maintenance application different, but the effect (represented by the slopes of the after-treatment performance curves) also is different.

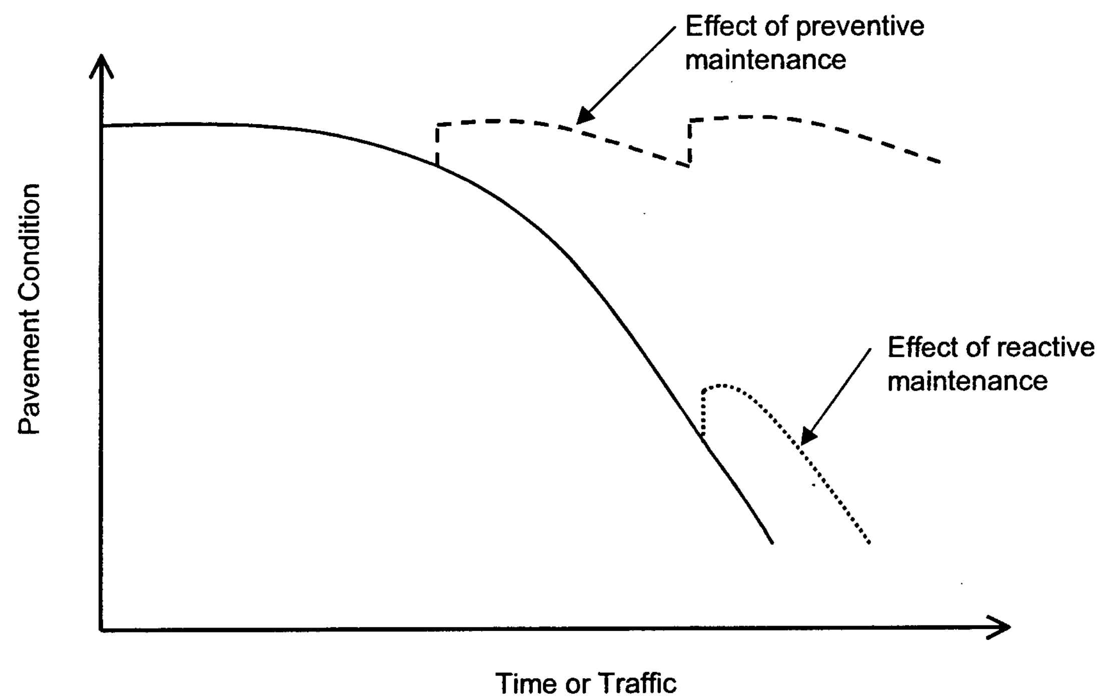


Figure 1. Conceptual illustration of the effects of different approaches to maintenance on pavement condition.

The impact of preventive maintenance on pavement condition has also been illustrated by the New York State Department of Transportation (NYSDOT). Throughout the 1990s, NYSDOT has been moving toward a policy of preventive maintenance, a shift supported in part by a 1995 analysis which showed that over a 5-year program of preventive maintenance, the overall pavement condition was much better than a "worst-first" strategy (for the same funding) (NYSDOT Memos 1995). This is illustrated in figure 2, in which the most notable difference between the 1994 base condition and the two projections of 1999 condition is the large increase in pavements in GOOD condition when the preventive maintenance strategy is employed.

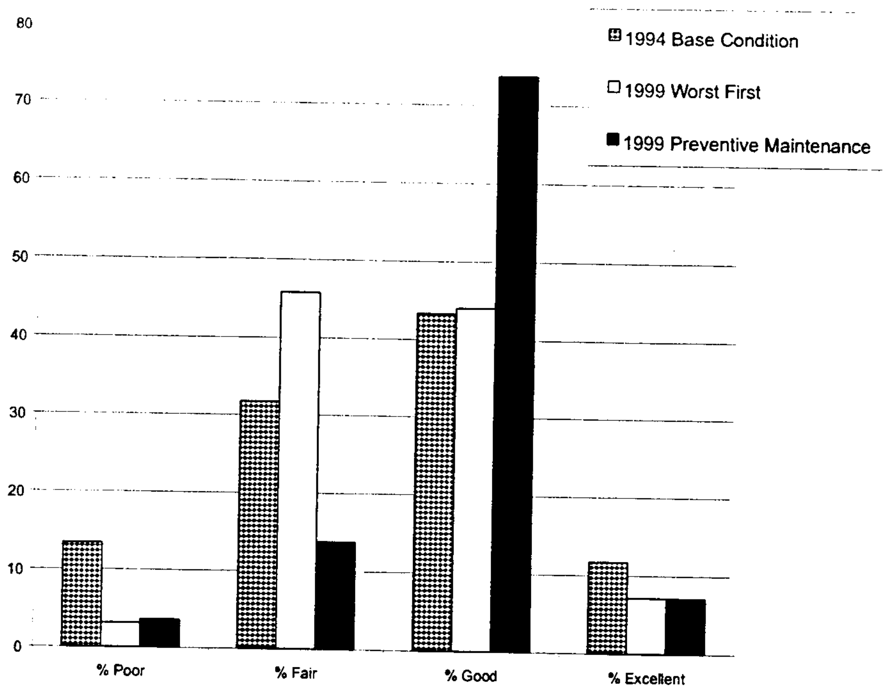


Figure 2. Comparison of worst-first and preventive maintenance program conditions in New York (NYSDOT Memos 1995).

Similar findings about the advantage of preventive maintenance over other strategies (especially "worst first") have been reported by other agencies. In an analysis of Michigan DOT pavement network performance the impact of two competing pavement management strategies were compared. Michigan analyses of network pavement conditions make use of the remaining service life (RSL) concept to describe the overall condition of their pavements (pavements with a very low RSL are nearing failure and require major rehabilitation or reconstruction). In the first strategy (shown as Strategy 1 in figure 3), project funding was made available for 15 years to improve 3 percent of the network from the remaining service life (RSL) category 1 (defined as 0 to 2 years RSL) to category 4 (13 to 17 years RSL), while 2 percent of the network was improved from category 1 to category 6 (23 to 27 years RSL) (from Kuo in FHWA 1997). This corresponds to a strategy of rehabilitation and reconstruction on failed pavements. Strategy 1 was then compared to a slightly modified policy in which 2 percent of the network was moved from category 3 (defined as pavement with a RSL of 8 to 12 years) to category 5 (RSL of 18 to 22 years). That change, shown as Strategy 2 in figure 3, represents a policy of applying preventive maintenance treatments, or applying treatments to pavements in good condition.

The effect on the network condition was dramatic, as shown in the second plot of figure 3. The plot of network health in the first graph shows that over time, when the network does not receive maintenance (and in the absence of substantial funding to apply a "worst-first" program), the percent of the network in poor condition soars. In contrast, the preventive maintenance strategy prevents a project backlog from developing. By applying different approaches to pavement preservation to a pavement network and projecting the results, it was possible to demonstrate that a strategy that included preventive maintenance provided better long term pavement performance.

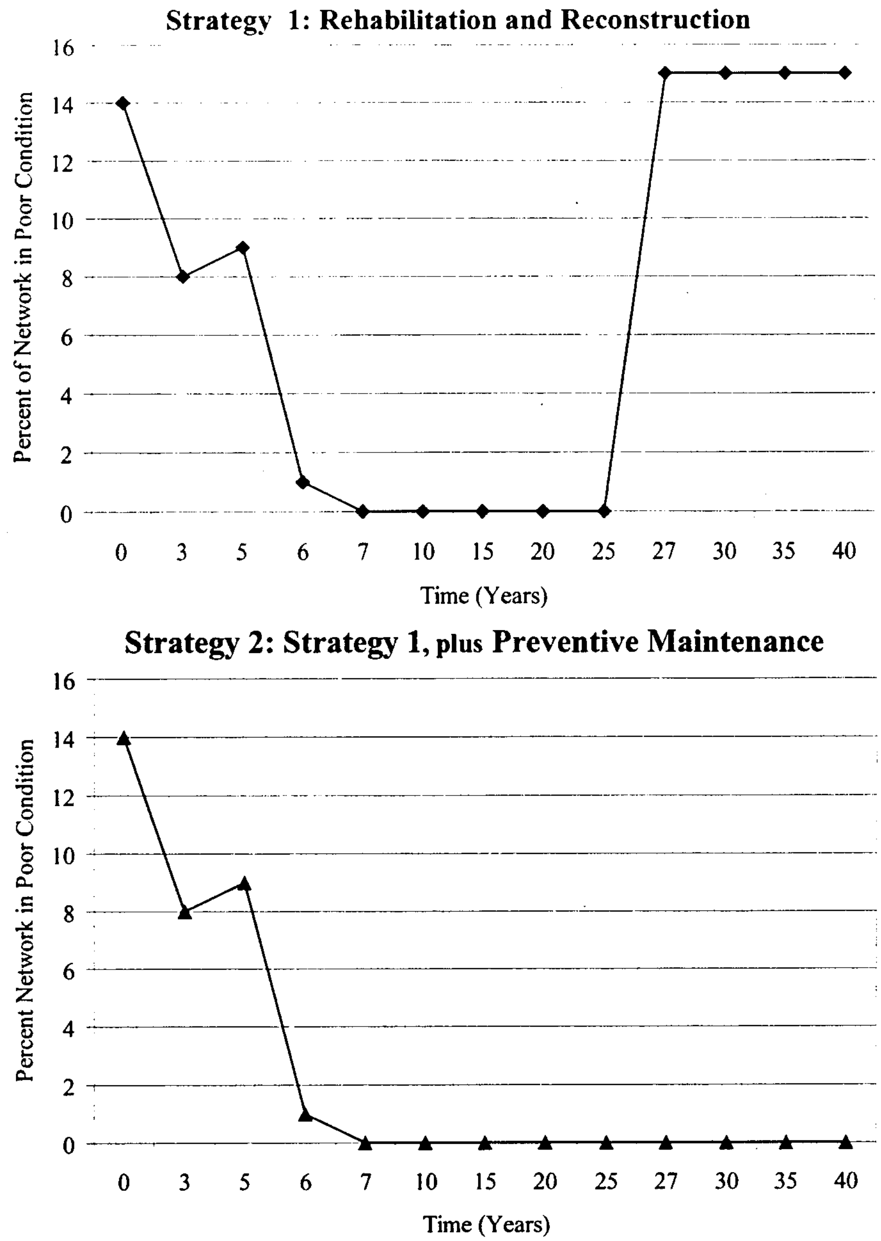


Figure 3. Comparison of network strategies with and without preventive maintenance.

A similar finding is suggested in a simulation performed using Wisconsin's local agency PMS and reported by Geoffroy (NCHRP 1996). Using pavement performance modeling, the 5-year impact of six different pavement preservation strategies are compared, with the constraint of a fixed (and limited) budget over a 400-mile pavement network. The evaluated strategies include:

- Do nothing (no available funding).
- Do all work as it is needed (no financial constraints).
- Do preventive maintenance (crack sealing and seal coating) only.
- Fix the worst pavements first.
- Do preventive maintenance first and fix the worst roads with the remaining funds.
- Only resurface and reconstruct; don't do any preventive maintenance.

To evaluate the results, strategies which performed well would be those that cost less, eliminate the greatest amount of project backlog, and result in the best overall pavement condition. As shown in figure 4, two strategies stand out as being most cost-effective: the unlimited budget strategy, in which all of the needed funding for repair is available whenever pavements reach a certain condition level (this funding scenario is usually thought of as impractical), and the strategy in which preventive maintenance is applied first with remaining funds applied to pavement rehabilitation. Note that the condition rating scale is from 0 to 7, and that the backlog is defined as the maintenance and rehabilitation work that is required due to the pavements' condition but is not performed because of funding constraints.

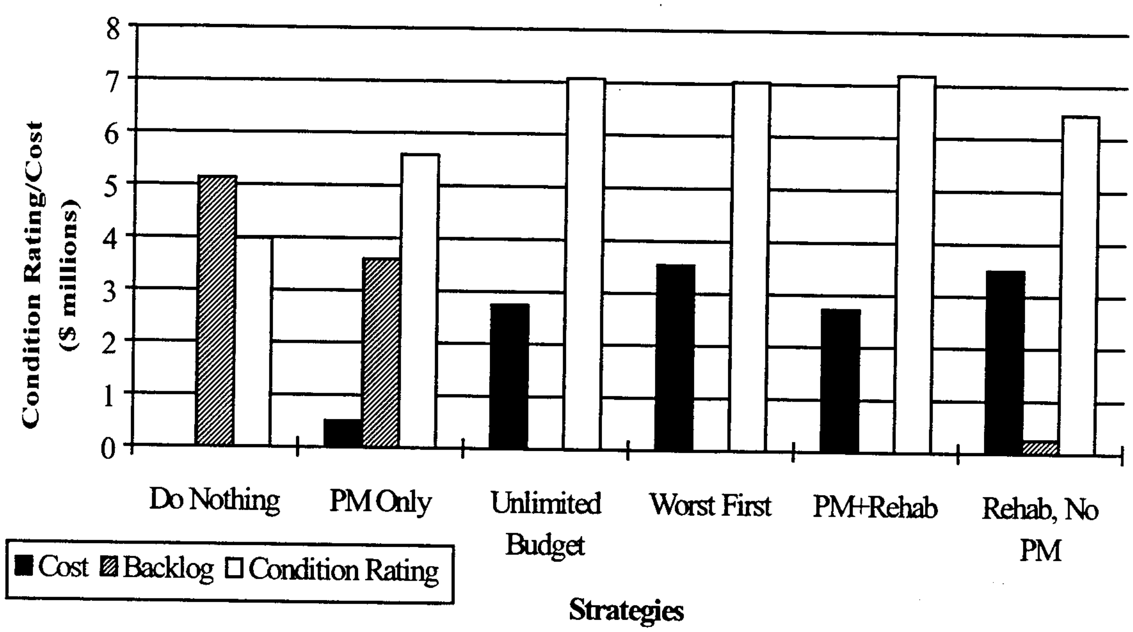


Figure 4. Comparison of effects on network condition and costs of six different approaches to system preservation (after Geoffroy 1996).

Cost Savings

From an agency standpoint probably the most sought after benefit of preventive maintenance is a financial one. Does a strategy of preventive maintenance save money? This is certainly an intended benefit, but one that has been hard to prove. A number of agencies have reported or projected cost savings from preventive maintenance strategies. These savings are both in the form of less expensive treatments and pavements with extended service lives, and are often used as the most persuasive argument to shifting pavement preservation strategies.

One difficulty in documenting the cost savings from preventive maintenance has been in knowing which costs to compare. The question of interest—whether preventive maintenance, however it is applied, is more cost effective than alternate strategies, such as rehabilitation only, doing nothing, or reactive maintenance—is difficult to answer. There are several comparisons of strategy costs over theoretical pavement networks, in which the effects on the overall condition of the pavement network for the given strategies are compared. These comparisons have documented the cost savings of preventive maintenance. But for existing roads, what is usually available is a comparison between the costs of reactive maintenance and the anticipated costs of a preventive maintenance strategy.

The cost savings are easier to document if the agency has made a commitment to providing a certain level of service, such as maintaining a ride quality or distress index. In these cases, it can be shown that pavements really are not able to consistently provide a high level of service without preventive maintenance treatments.

A reduction in user costs may also provide additional cost savings. These result from fewer delays, smoother roads (and lower vehicle operating costs), and enhanced safety (and thus lower accident related costs). (However, it must be noted that this analysis should not be reduced to the absurd level of applying frequent, very thin treatments: at some point the savings are offset by the disruption caused by more frequent treatment applications.)

As noted earlier, the agencies that have been active in preventive maintenance do feel that even after a relatively short period of time they are beginning to see the financial benefits of their practices. Michigan ($700 million since 1992) and California (a 4:1 to 6:1 benefit with preventive maintenance treatments) specifically are reporting savings as they change the way that they take care of their pavements. However, these savings are generally realized in the form of better overall pavement condition, or the same condition for a reduced cost, rather than as a financial windfall to the agency.

Increased Safety

The NQI Highway User Survey (Coopers & Lybrand and ORC 1996) commissioned by the NQI Committee reported that improving safety was the number one stated priority among the respondents. Maintenance studies in Arizona (Dye 1998), California (Survey Research Center 1999), and Washington (Dye 1996), among others, support this finding. Safety is also an extremely important national priority, and the FHWA has a Strategic Plan Goal to reduce fatal and injury crash rates 20 percent over 10 years.

Preventive maintenance programs provide both implicit and explicit safety benefits that address this priority. Explicitly, today's treatments are specifically designed to provide safer surfaces. From better aggregate retention to fewer safety related defects (such as ruts and potholes), the materials and treatments are expected to be an improvement over the treatments of the past. The literature on pavement maintenance treatments abounds with information about these improved treatments, such as documented advances in microsurfacing, slurry seals, and chip seals, that are performing much better than earlier treatments.

Another explicit safety contribution of preventive maintenance treatments lies in the direct contribution of those treatments to safety measures. Pavement surface texture can have a positive effect on the following safety elements: surface friction, wet weather friction, surface water spray, and headlight glare. With a heightened interest in improving roadway safety, many studies are showing the impact that preventive maintenance treatments can have (Larson 1999).

The implicit safety benefits are obtained from keeping the pavement in better overall condition. Pavements with higher condition ratings are smoother and have fewer defects. These are conditions that contribute to safer operating conditions. Pavements in better overall condition also require fewer and less disruptive repairs, which ties in well with other findings of the 1996

National Highway User Survey (Coopers & Lybrand and ORC 1996). Specifically, respondents indicated a desire to do permanent rather than temporary repairs and complete construction and repairs in a timely fashion.

In addition, AASHTO recently developed a comprehensive highway safety plan in which critical strategies for improving highway safety are outlined (AASHTO 1998). One of those strategies is the establishment of a program to evaluate guidelines for highway maintenance activities that enhance highway safety. New York has already taken the next step in this direction. Recognizing that their preventive maintenance program was leaving some safety needs unaddressed, they implemented a program to maintain existing safety features and add appropriate low-cost treatments on preventive maintenance projects either during construction or later, as part of a linked effort (Bray 1999).

Current Funding Status

The success of any pavement program is in large part dependent upon the type and level of funding support it receives. Ever since there has been a Federal policy on funding for pavement maintenance, that policy has shaped the types of treatments, their timing, and the pavements to which they are applied. The original Federal Aid Highway Act of 1916 defined maintenance, but noted that it was the duty of the states or their civil subdivisions. In the past, eligibility for Federal funding required that the pavement be structurally improved; because maintenance treatments were corrective, maintenance activities were never eligible for Federal participation. *NCHRP Synthesis 153* does an excellent job of tracing the history of highway funding as it relates to the maintenance function through 1989.

The 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) extended the eligibility of cost-effective preventive maintenance activities for Federal funding to projects on the National Highway System (NHS), which is composed of about 262,000 km (163,000 mi) of rural and urban roads. However, there were still restrictions; specifically, States had to be able to demonstrate through their PMS that the treatments were a cost-effective means of extending pavement life. An even more formidable barrier to the use of Federal funds in preventive maintenance projects was the requirement that such projects concurrently address safety deficiencies (grades, guard rails, signs, and so on).

But even as there was increasing acceptance of the use of Federal funds for preventive maintenance treatments, this has not become widespread practice. The explanation for this is a combination of many factors, including unclear policy, limited available funds, and many competing demands for those funds. As a nationwide study of maintenance and preventive maintenance reported (FHWA 1995), States have always had 3R needs that exceed the available funding. No matter what the barrier, the result was that "no significant Agency program has been developed to promote preventive maintenance activities."

The latest U.S. Department of Transportation approach to pavement maintenance is addressed in the Transportation Equity Act for the 21st Century (TEA-21). While cost-effective maintenance projects are still eligible for Federal funds, many barriers to the actual use of such funds have been removed and project and program decisions have been delegated to the local FHWA Division Office level. These include permitting more flexibility to address safety concerns through a staged approach (in which the pavement work can be performed initially and any needed safety improvements addressed in subsequent stages), and providing increased funding.

Furthermore, allowable Federal participation on maintenance projects has increased to 80 percent under TEA-21. These changes make a clear statement that the Federal Government has eliminated the obstacles to either initiating or enhancing preventive maintenance programs.

Challenges

The findings reported by agencies that have implemented or are in the process of implementing a preventive maintenance program are extremely positive. By all accounts, there are already several success stories among SHAs that have elected to use Federal funding and these states have a broad range of preventive maintenance treatments and strategies from which to choose. So why aren't preventive maintenance programs being implemented everywhere?
There are a number of barriers, both real and perceived, that face agencies wishing to implement a preventive maintenance program. Some of these are discussed below.

Public Perceptions

Anecdotally, one of the greatest challenges to preventive maintenance programs is the anticipated perception of the public (this is anecdotal because no evidence could be found to support what is widely believed to be true). In the face of limited funding, preventive maintenance programs will steer work toward pavements that are in relatively good condition and away from pavements that are failing. A common lament among maintenance engineers who wish to move away from this so-called worst-first strategy is that the public will never accept the change. This is a valid concern, because an agency is much more likely to receive complaints about the failed road in front of someone's house than about the poor overall condition of a pavement network. How can agencies support preventive maintenance when they know that the public will excoriate them for fixing roads in good condition (assuming that there are insufficient funds to repair all roads)? How can a program intended to keep good roads in good condition succeed when there are so many roads in poor condition?

Put another way, the concern is that the public is unable to place the general good above their own personal interests. Admittedly, such a major change is likely to cause some shock. However, if it can be accepted that the public is interested in sound fiscal practice, improved pavement performance, and shorter and fewer delays, then it should be possible to educate them as to how this can be accomplished. There are signs that the public is able to make this shift, including the findings of customer surveys and focus group input from a number of states.

Management Perceptions

Agencies must also undergo a change in how they perceive maintenance internally. As noted in the 1995 Office of Program Review study (FHWA 1995), the most important ingredient in a successful maintenance program is "a commitment from top management." In the past, highway agencies put little stock in maintenance programs and the FHWA's programs focused on completion of the Interstate system and other National Highway System corridors. While the FHWA considered maintenance to be a state responsibility and a condition for funding initial construction, it was not a priority. It doesn't matter whether one caused the other; the net result is that the status of maintenance has historically been low with most public agency management.

While today the engineering climate may be right to support a greater shift toward preventive maintenance and a strategy of system preservation, management support must be fostered and strengthened. The FHWA and AASHTO can do their part by ensuring that the policies, technical information, and funding are in place to promote preventive maintenance. In addition to management's perceptions about what the public will tolerate, there are also concerns about whether preventive maintenance programs actually work and whether they will cost more. As if the task of persuasion is not difficult enough, the management level in many public agencies is the one that changes personnel the most, requiring that the perceptions of each new generation of managers must be challenged and overcome.

Research Needs

In many cases, the actual data to support and promote the advantages of preventive maintenance practices are difficult to locate, or simply do not exist. Research is needed to document several important aspects of a preventive maintenance program, including:

- When should treatments be applied?
- Which treatments are appropriate?
- What is the life extension gained?

A secondary issue where research is needed concerns improving the performance of existing treatments. For example, how effective is the application of various modified binders in improving chip retention for surface treatments? Can a test for asphalt application rates be developed? Can an end product acceptance test be developed for preventive maintenance treatments? While industry is making great strides in addressing performance concerns, there is a dearth of good information regarding timing of application, appropriateness, and life extension imparted.

Training

Maintenance activities have been performed by owner agencies and contractors for years, but the concept of system preservation and preventive maintenance programs are just emerging. There is no doubt that confusion about many of the issues central to preventive maintenance is widespread. This confusion ranges from the very definitions (e.g., what is preventive versus reactive maintenance), to how to select candidate projects and identify appropriate treatments, timing, and good and bad applications. To date, there has not been a good source of information that addresses this confusion, and thus there is a need for training on this topic.

Nationwide, several training programs have been assembled during the 1990s that address related maintenance topics. In particular, two workshop presentations and associated materials grew out of the SHRP research: *Pavement Maintenance Effectiveness/ Innovative Materials Workshop* (FHWA 1995b) on material and procedure performance, and *Preventive Maintenance Effectiveness–Preventive Maintenance Treatments* (FHWA 1996) on maintenance effectiveness. Neither of these presentations, however, addresses the critical issues of preventive maintenance programs. Furthermore, several states have developed their own maintenance manuals and short courses on related topics (such as Montana, Michigan, and California), and various industries (such as TAI, AEMA, ISSA, ARRA, ACPA, and NAPA) have developed and offer their own training.

New treatments are being developed and are being applied in different ways than their predecessors. Failure to apply such treatments correctly not only leads to a waste of money, but could also cause the failure of these programs. This course is intended to be a starting point for addressing issues of preventive maintenance, but it is recognized that more work is needed. In particular, more detailed information is needed on the treatments themselves and their optimum timing. There is also a need for training contractors and agency forces alike in how some of the more exacting treatments are applied and controlled. As more and more agencies gain experience, industry and public agencies should be able to work together to advance the state of knowledge on these topics.

Data Management

Historically, performance monitoring of maintenance treatments has only been done as a part of research projects. If the status of maintenance in general, and preventive maintenance in particular, is to be raised from its current level then performance monitoring must become a standard practice of highway agencies. The best way for agencies to learn what treatments work in their environment, on their pavements, and with their loadings, is to keep track of the relevant data on their own pavement network. The most obvious method of doing this is with the agency's pavement management system, where related data and the necessary analytical tools are probably already stored. Information that is useful to track includes:

- Condition of the road prior to treatment.
- Environmental conditions at the time of placement.
- Type of treatment and design details, material properties, and characteristics, including QC/QA.
- Performance data following the application of the treatment.
- Cost data, including construction costs and other associated costs.
- Traffic data.

Tracking this information will help agencies to identify what works and what does not. With a system of treatment monitoring in place, the performance of new treatments can also be easily followed to identify which provide a cost-effective benefit. However, this issue deserves a word of caution. In order to collect useful information, either the treatments must be applied over "sections" already defined in the PMS, or the PMS sections must be redefined when they receive a treatment. Furthermore, the system must have a means of separating costs and treatments applied only to the mainline pavement from those which are also (or only) applied to shoulders. In other words, preventive maintenance activities must be accurately reported and integrated into an agency's PMS. This will require changes to most maintenance management and PMS.

Dedicated Funding Challenges

Every public agency which relies upon tax dollars to finance its activities faces funding challenges. Legislators and executives adjust budgets to serve many political ends, and agencies are left to make it work. Even within the agency priorities can change, and what may be a popular program today can be easily derailed by reducing either staffing, funding, or both.

Preventive maintenance programs are particularly susceptible to funding variability. Preventive maintenance treatments are lower cost, systemic treatments applied on a cyclical basis. Agencies project the benefits from such programs by looking at the long-term performance of their pavement network that results from applying these treatments. If the funding for these programs is not dedicated, or if projected needs are not met, the overall benefits may not be realized. This really pushes the agency back to "worst first" programming, because the steps are not being taken to improve the overall condition of the network. Denehy noted the effects of this challenge when funding for NYSDOT's program was temporarily cut back: "because applying preventive maintenance treatments at the proper time in a pavement's life is critical, this budget delay caused either the inappropriate use of some treatments or the deferral of work until the next season." (Denehy 1997). Even a very short delay in applying a needed treatment could result in a significant increase in future costs.

There are many steps that can be taken to overcome these challenges, including innovative contracting, shorter programming cycles, and simplification of the design and procurement process for preventive maintenance treatments. However, there has yet to be a surefire way identified to completely avoid these challenges.

Keys to Successful Programs

One of the primary objectives of this presentation is to introduce the concepts of pavement preventive maintenance to those who are in a position to affect policy change. In the rest of this module, an approach to developing a preventive maintenance program is outlined. The suggested approach draws on the experiences of the agencies that have made preventive maintenance a keystone of their pavement preservation practices. It is intended to help agencies assemble these and other components of preventive maintenance into a working preventive maintenance program. In the process, it also addresses how the obstacles to these programs can be addressed.

Establish Goals

> *"It is evident that the policy objective used to select maintenance strategies has widely varying long-term performance and cost implications on a road network and its users. It is thus essential that a road agency select a long-term objective and structure its maintenance selection policy to achieve its objective."* (Rohde et al. 1997)

> *"Advocating a philosophy of preventive maintenance is the most important factor in developing a successful program."* (Galehouse 1998)

It is difficult to introduce a new program, or sustain an existing one, if it does not have a stated purpose. Rohde's quotation tells us that a maintenance selection policy must exist to meet some objective; Galehouse notes the benefit of a philosophy in the development of Michigan's preventive maintenance program. What sort of purpose might an agency have that requires a preventive maintenance program to accomplish? An objective provides the agency with a justification for its policy decisions as well as a measurable means of tracking progress. An objective also suggests buy-in, and can mean that policy-makers, legislators, public agencies, and the public themselves share a common goal.

In fact, developing a goal can even serve as the impetus for change. One question that should be asked is whether the agency and the public are satisfied with the status quo. If the existing approach to pavement preservation results in an acceptable condition at an affordable cost, then a new program probably is not necessary. Very simply, "if it isn't broken, why fix it?" If, on the other hand, the overall network condition is unsatisfactory to either the agency or the public, or if pavement maintenance or rehabilitation expenditures are increasing without a corresponding improvement in network condition, then an agency might want to improve their performance by reevaluating their pavement preservation programming.

Most of the preventive maintenance programs that are successful today began because of a need to achieve a goal. The goal does not have to be extremely complex. For example, Georgia's goal is to provide a new surface on all of its pavements every 10 years. This goal was developed in the early 1970s in response to the observation of one of their highway commissioners, who believed that Georgia's roads were the worst in the southeast.

California's preventive maintenance program was spurred on by a similar experience, in which their transportation commission questioned whether the agency's practices were leading to a growing backlog of the amount of their system in need of maintenance. In response, Caltrans adopted a goal to improve their overall network from a condition in which about 29 percent of the system needed rehabilitation to one where only 11 percent needed rehabilitation in about 10 years. Caltrans' Maintenance Program also has a Vision Statement, which states that they aim "to be the World Leader in Maintaining a Safe and Efficient Highway System." Furthermore, Caltrans latest 10-year plan describes goals throughout the system: for roadways alone it includes the following (Caltrans 1998):

- Reduce deteriorated pavement needs.
- Switch from "worst-first" to "preventive treatments."
- Use longer life treatments on roadways where ADT is > 150,000 or ADTT is > 15,000.
- Avoid failure through preventive treatment management.

In New York's plan, goals are mandated by legislation that requires the DOT to plan to maintain all of its assets (and not just pavements). As part of the legislation, each year the Department prepares a 5-year plan for the preventive maintenance of state highways and bridges. The plan must report on the existing condition of state highways and bridges, outline the Department's goals for pavement and bridge condition, describe the preventive maintenance treatments that are needed to reach these goals, summarize the preventive maintenance work which could occur if funds are appropriated, and identify the extent to which the prior fiscal year's preventive maintenance plan goals were achieved.

Shober and Friedrichs (1998) write about this concept of identifying objectives as it applies to Wisconsin's practices. Wisconsin has developed a pavement preservation strategy (PPS) to guide decision-making within the Wisconsin DOT (WisDOT). The goal of WisDOT's PPS is stated in their pavement preservation philosophy: "to provide the highest quality service possible to the customer per unit of expenditure." This philosophy is then used to evaluate each maintenance or rehabilitation action, by answering how it affects the customers' comfort, convenience, safety, and costs.

To ensure a program's long-term success, not only is it important to have underlying goals or objectives, but these goals must be measurable. That is, meaningful objectives of a preventive maintenance program should address measures of importance to an agency and the traveling public. Examples of what a goal might address include measures of pavement condition, such as percent of network pavement in various categories (e.g., good, fair, poor), or an overall average numerical rating of the network (based on an aggregated index, for example). Monitoring these is a means of quantifying the benefit of the program.

In most cases, it will not be necessary to create an entirely new tracking mechanism to measure progress toward achieving the agency's goals. Agencies with an active PMS in which regular measures of pavement condition are tracked can provide all of the needed information for most monitoring purposes, including projecting system performance based on the use of preventive maintenance treatments. At most, minor modifications might be needed to track a different variable or to present PMS output in a slightly different format.

Another type of goal might address the cost savings expected from preventive maintenance programs. Over time, these programs are meant to be more cost effective than conventional pavement preservation approaches, and tracking the cost side should be important to the agency and its funding bodies. This information, when presented properly, is especially important to communicate to legislatures and the taxpayer.

Document the Benefits

> "There is a need to conduct and publish the results of formal research on the cost-effectiveness of pavement preventive maintenance techniques." *(Geoffroy 1996)*

It is somewhat of a paradox that part of the process of creating a preventive maintenance program should include documenting the benefits of such a program. After all, how can the benefits of a previously non-existent program be documented and used to support the development of such a program? Nonetheless, this is an important step and one that can be accomplished despite the seeming paradox. With few exceptions, no matter where in an organization the initial push for system preservation is made, at some point the concept needs to be promoted to policy-makers and budget analysts who will decide whether or not to fund the program. The initial question that must be considered, then, is what will be required to convince these decision-makers of the benefits of a particular pavement program? Will additional funds be needed or can existing capital improvement and reactive funds be dedicated for system preservation?

Several approaches have been used. One frequently used approach creates an analogy between the effect of preventive maintenance practices on pavements and similar practices with assets that are more commonly understood by the lay person. The Fram oil filter analogy is probably the most common: "pay me now or pay me later," it says, suggesting that routine and regular maintenance are a lot cheaper than a major engine overhaul. Other analogies that are commonly used to promote pavement preventive maintenance include performing routine oil changes on a car rather than waiting until the engine seizes and painting and caulking a house on a regular basis rather than waiting until the wood rots and the siding must be replaced.

However common and acceptable these analogies may be, they are unlikely to satisfy the need that most decision-makers have for supporting documentation. There is enough skepticism about the linkages among maintenance, pavement life, and expense that more specific information is usually needed (see Geoffroy [1996] for example, in which ten agencies reported that preventive maintenance was not implemented because either the cost-effectiveness of preventive maintenance strategies had not been demonstrated or were demonstrated but not accepted). Often the next step is to go to the graph shown in figure 5.

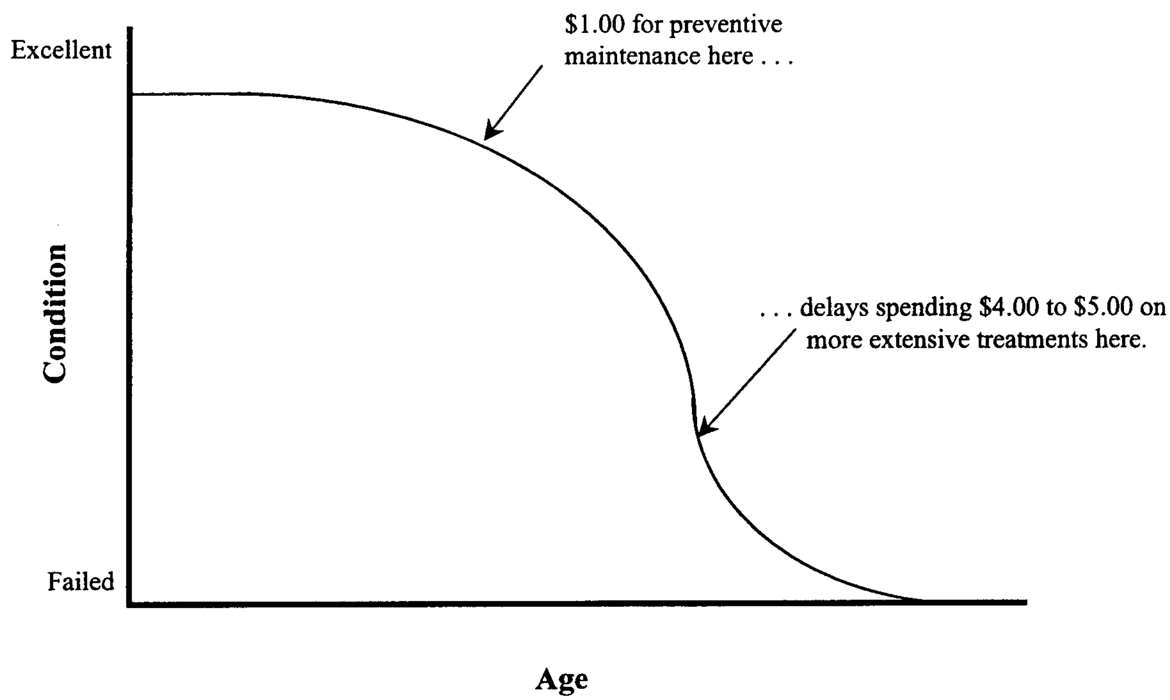


Figure 5. Idealized relationship between treatment costs at different times in a pavement's life.

Figure 5 is a good representation of the concept of preventive maintenance. It shows that spending money to apply treatments to pavements in good condition is much cheaper than waiting until the pavement is in poor condition and more extensive rehabilitation is required. To many this is the very essence of the concept of preventive maintenance. However, this figure is rarely presented with any supporting information to suggest that it is anything other than an idealized representation of the costs of different treatment strategies. Also, it does not consider cost-effectiveness, which is the most important part of preventive maintenance. And it could be argued that this curve is not based on studies of preventive maintenance either, which makes somewhat problematic its use by organizations trying to justify the expenditure of large sums of money for new programs.

To many there is an innate suspicion of studies that aren't local. For preventive maintenance treatments this may be a healthy skepticism, as these treatments are intended to address how particular material types deteriorate under specific conditions of climate and loading. Thus it should not be surprising that the treatments, the materials, and the application rates will vary from area to area. What doesn't work in one location may be an ideal treatment for another, and vice versa. For those agencies that feel that it is imperative to have specific and relevant data of their own that document the benefits of PM, there are a few choices.

One option is that the agency may already have available some of the data that documents the performance of preventive maintenance treatments. For example, in New York's program the impetus for preventive maintenance came from the study of practices in which the state was already engaged. As Denehy (1997) reported, "the Department's maintenance forces have been performing pavement preventive maintenance since the 1970s.... Over time, the efficacy of these treatments became obvious to highway field personnel and their supervisors." In turn, executive management began to tout the advantages of preventive maintenance. The support for the technical merits of the program were bolstered by financial backing, but began with the belief that the program would work in New York.

This is not to say that there wasn't some initial skepticism. As reported in an NYSDOT internal report, "Effectiveness of Pavement Preventive Maintenance," "the transportation literature does not contain much written proof of the cost effectiveness of these strategies." But NYSDOT ran their own analysis comparing a worst-first to a preventive maintenance strategy and showed to their own satisfaction that preventive maintenance provided "a significantly better ending condition profile" and was more cost-effective than alternative approaches. It must be emphasized that this first analysis was based on PMS data and performance models and the results were persuasive.

A similar approach was used in California. In 1995, Caltrans used the results of their regular pavement condition surveys to show that current approaches to managing their pavements were not sufficient to correct the identified deficiencies on the state highway system. By making assumptions about the effect of their maintenance and rehabilitation treatments on pavement condition, Caltrans plotted network condition and showed how an aggressive preventive maintenance program could reduce the amount of distressed lane miles in the state system (see figure 6). This led to the development of the State Highway Operation and Protection Program (SHOPP), accompanied by an additional $100 million in funding for Capital Preventive Maintenance (CAPM) and rehabilitation projects. Incidentally, the need for this funding was demonstrated by reports produced by Caltrans' PMS (Caltrans 1996).

Promote the Benefits

Having an effective means of communicating important parts of a preventive maintenance program is often central to obtaining or continuing to receive funding. There are several graphical tools that enhance the communication of results or needs. Especially effective are those that use graphical representations based on presentation graphics (such as PowerPoint or Excel) with pavement management data. One example, shown in figure 7, comes from Bedford, Texas' Public Services Department. In a presentation of the results of a pavement management study to the City Council, it was noted that the "means of presentation is crucial" (Hutchison 1997). To convince decision-makers, it is important to demonstrate cost savings and use lay terms. The City's engineering staff were seeking to secure a greater investment in a preventive maintenance program, and used their PMS data to show the effects on project backlog of uniform spending (figure 7a) versus an early distribution of funds (figure 7b) for the same total amount of funding. The documentation was persuasive enough that the City came up with an additional sales tax to both provide sufficient funding to bring the network condition up to acceptable levels and to fund ongoing maintenance activities.

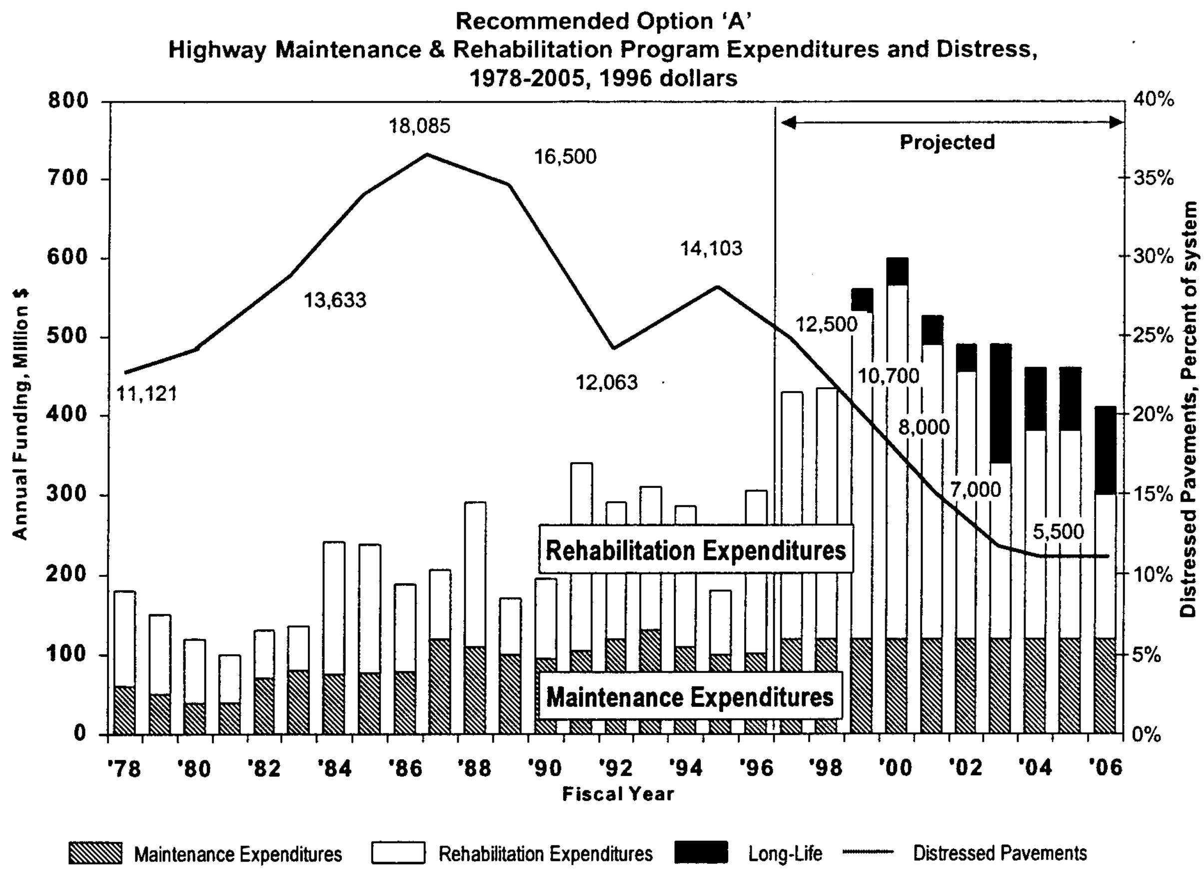


Figure 6. Caltrans highway maintenance and rehabilitation program funding.

Figure 8 shows the integration of GIS display capabilities with Caltrans maintenance program. Prepared for each District in the state, this type of presentation can be used in many different ways to explain and "promote" the program.

As part of the legislation that created and sustains New York's preventive maintenance program, the Department is required to report annually on the status and goals of their preventive maintenance program (NYSDOT 1997). The document that is prepared describes the Department's pavement condition goals and the preventive maintenance activities that are planned to achieve those goals. The plan also illustrates where the agency is in terms of their progress toward the 5-year plan and to what extent the previous year's goals were met. Readers can easily track both the progress in funding and lane miles of placed treatments, as well as the overall effect of these treatments on the pavement condition, such as is shown in figure 9.

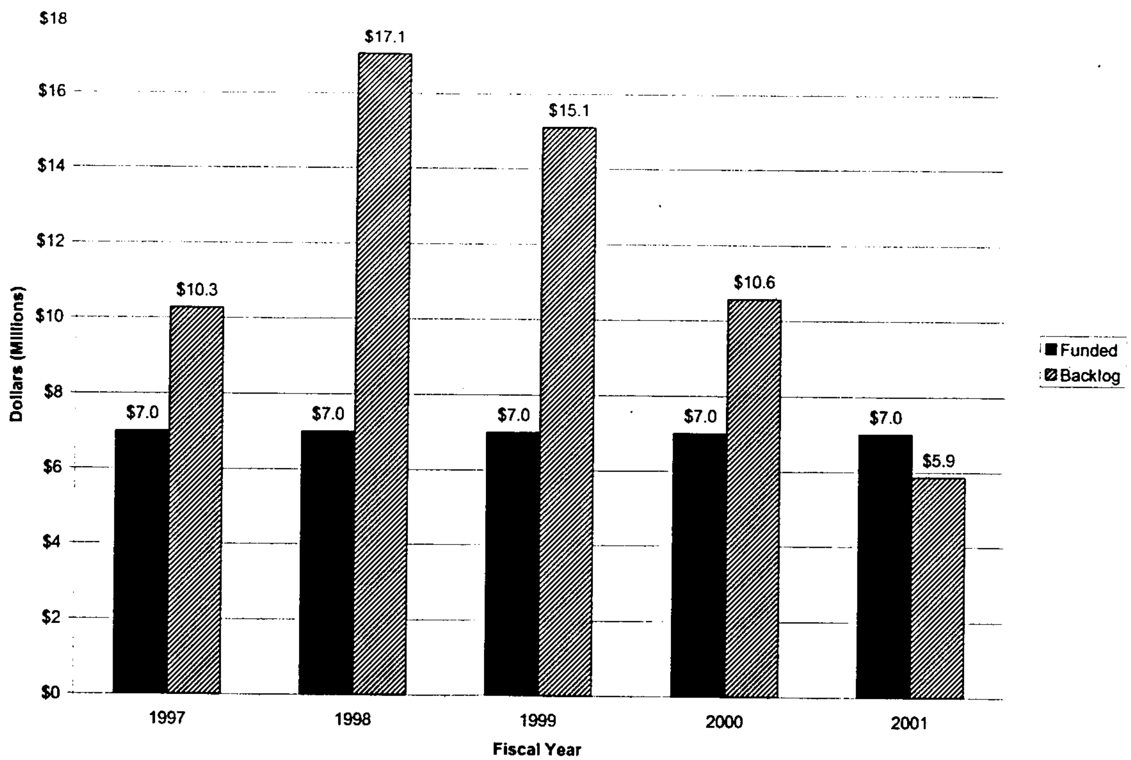


Figure 7a. Effect of uniform annual spending on City of Bedford, Texas network condition (Hutchison 1997).

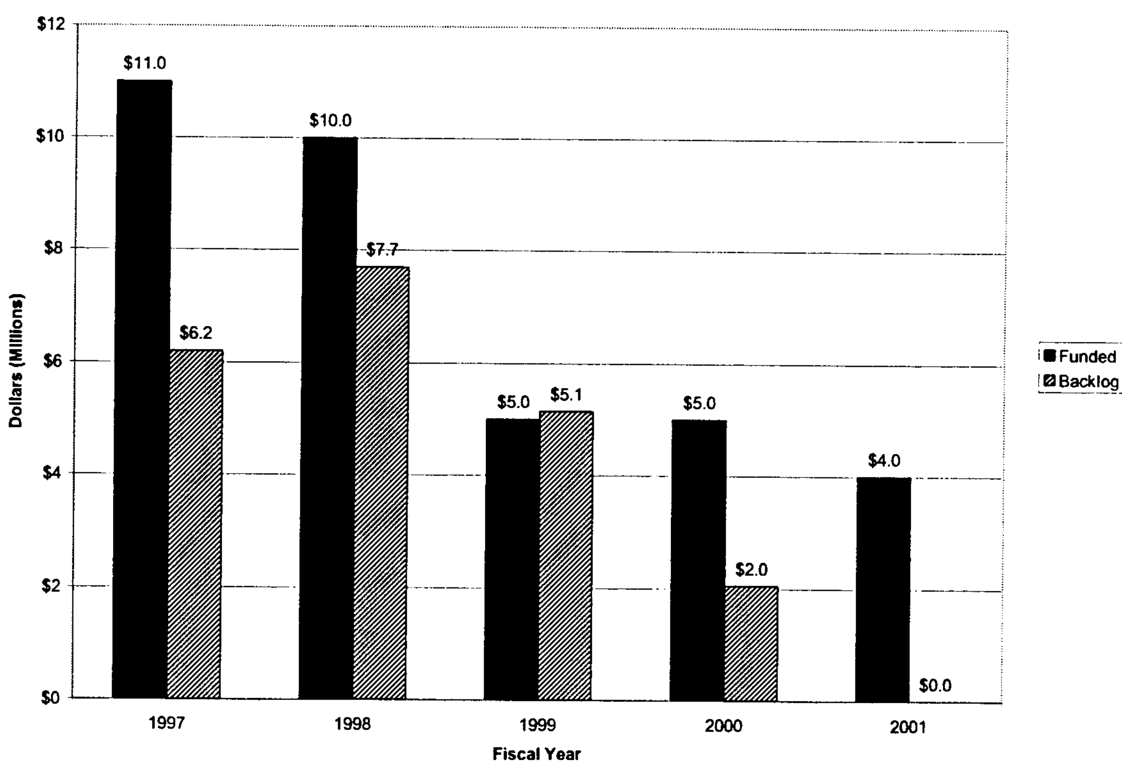
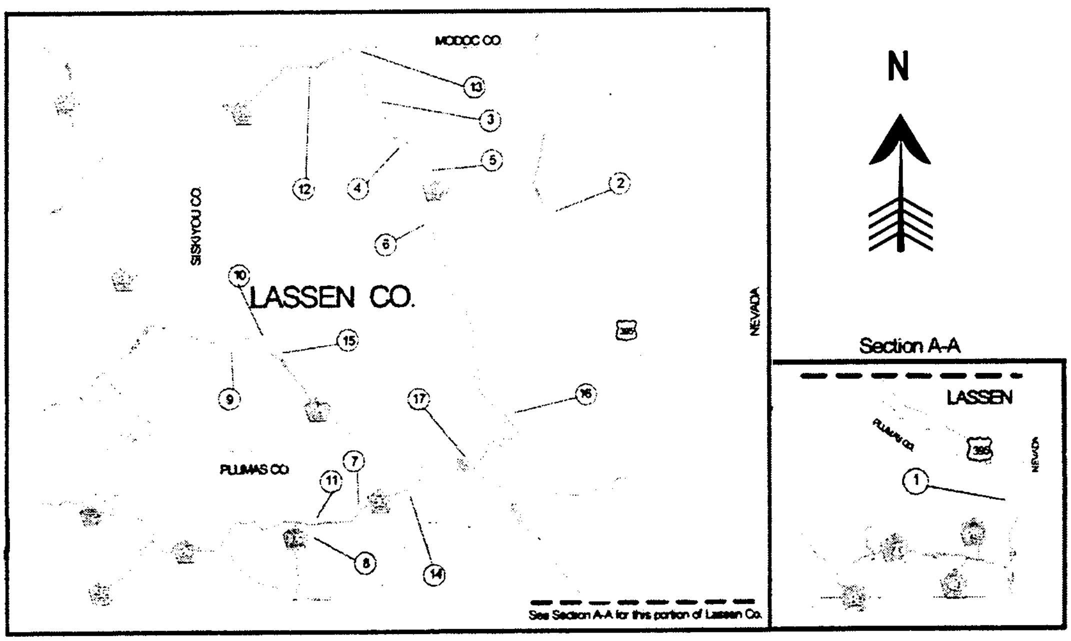


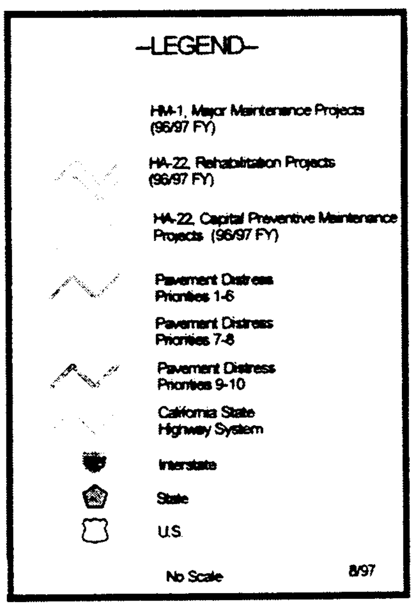
Figure 7b. Effect of early distribution of funds on City of Bedford, Texas network condition (Hutchison 1997).

State of California
Department of Transportation

District 2

Lassen County





Major Maintenance Projects (HM-1)

NO.	EA	RTE	PM	DESCRIPTION	AWARD DATE	COMPL DATE
1	308204	395	9.00/24.80	CHIP SEAL (PME)/FOG SEAL		
2	309304	395	115.00/119.00	RUBBERIZED CHIP SEAL (AR)		
3	316804	139	58.00/62.00	AC SURFACE/FOG SEAL		
4	316804	139	52.30/54.40	AC SURFACE/FOG SEAL		
5	316804	139	47.00/49.00	AC SURFACE/FOG SEAL		
6	316804	139	40.00/44.00	AC SURFACE/FOG SEAL		
7	317004	36	9.90/13.00	AC SURFACE/FOG SEAL	5/31/96	9/26/96
8	317004	147	0.00/1.20	AC SURFACE/FOG SEAL	5/31/96	9/26/96
9	317004	44	4.00/6.10	AC SURFACE/FOG SEAL	5/31/96	9/26/96
10	317004	44	8.00/10.00	AC SURFACE/FOG SEAL	5/31/96	9/26/96
11	319304	36	0.00/9.90	CHIP SEAL (PME)/FOG SEAL	7/16/96	8/26/96
12	321704	299	18.50/R22.50	THIN AC OVERLAYS	3/10/97	
13	321704	299	24.50/25.60	THIN AC OVERLAYS/FOG SEAL	3/10/97	
14	329004	36	10.00/16.00	THIN AC OVERLAYS/FOG SEAL	6/24/97	
15	329004	44	10.00/14.20	THIN AC OVERLAYS/FOG SEAL		

Rehabilitation & CAPM Projects (HA-22)

NO.	EA	RTE	PM	WORK TYPE	DESCRIPTION	AWARD DATE
16	321304	139	1.7/40.00	CAPM	ASPHALT CONCRETE SUFACING	7/31/96
17	328204	36	22.62/24.54	REHAB	RESURFACE ASPHALT CONCRETE	10/8/96

Pavement Distress data is based on the 1995 Pavement Condition Survey

Caltrans

Figure 8. Use of GIS to present maintenance plans.

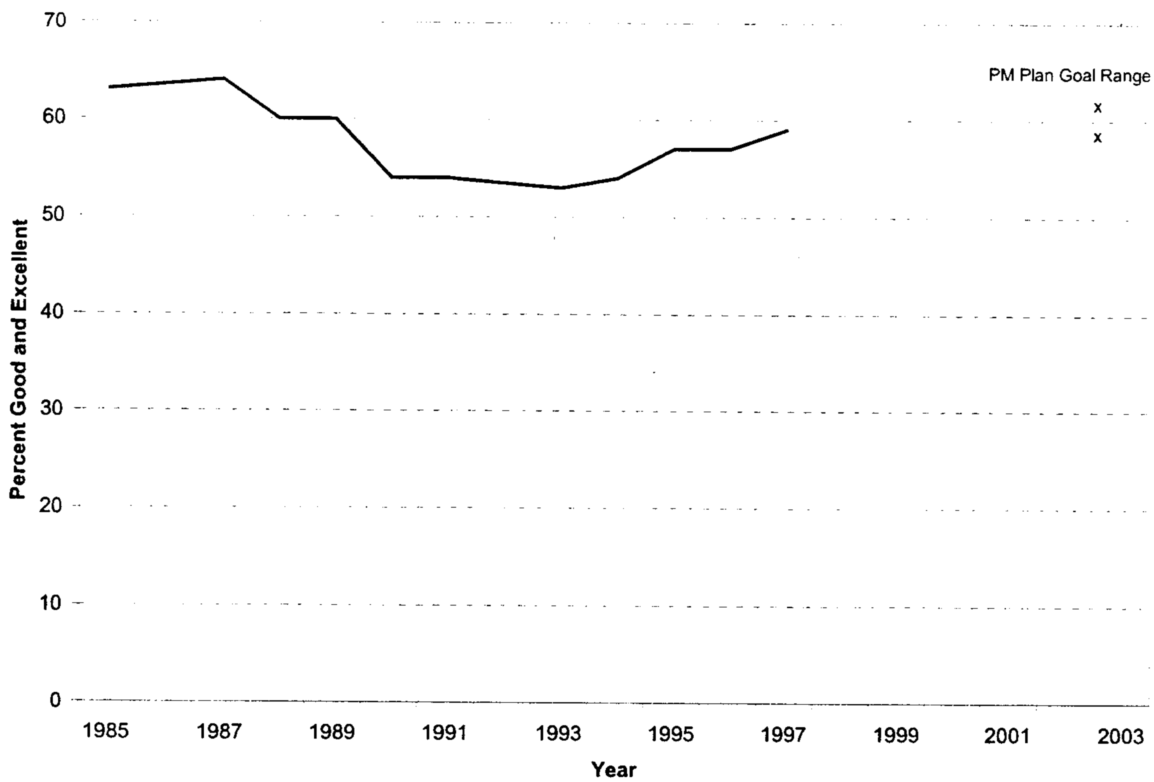


Figure 9. Progress of NYSDOT's Preventive Maintenance program (NYSDOT 1997).

The Contribution of Research

An alternate approach to using existing available data or to performing analyses that simulate pavement condition as a result of expected treatment effects is to design and implement research studies that are specifically intended to study maintenance effects on pavement performance. This approach was the basis for the maintenance effectiveness studies that were initiated under the Strategic Highway Research Program (SHRP) in SPS-3 (AC maintenance cost-effectiveness studies) and SPS-4 (PCC maintenance cost-effectiveness studies). The SHRP research, continued by the FHWA after 1993, is well documented elsewhere (for early performance information, for example, see Raza [1994]).

There is likely to be some guidance that can be gleaned from these SPS studies, but unfortunately they did not resolve the critical questions about maintenance effectiveness as had been hoped. Variables of interest to preventive maintenance, in particular the condition of the pavement when the treatment is applied and the selection of the right treatment and material for a given environmental condition, were not well controlled in these studies. Another critical factor was the decision to minimize the experimental variables by using the same asphalt and aggregate materials throughout each region. With the variability in pavement age, environmental regime, traffic, and in situ pavement conditions and materials, a more appropriate approach would have been to design and select each treatment for the site conditions. As a result, the most useful conclusions from these studies have focused on findings at particular sites, or at best, within single regions.

One resounding conclusion from this research, however, is that preventive maintenance treatments of various types could be successfully to all classes of roads under both low and high volume traffic conditions. The preventive maintenance treatments have contributed to extended pavement performance (compared to the control sections) in nearly every experimental site. The notable exceptions were where the pavements were already extensively aged or were susceptible to stripping. In such cases, when a slurry or chip seal was applied failure was actually accelerated. This reinforces the need for proper project and treatment selection.

More focused, but perhaps less comprehensive, research can provide useful data for maintenance planners, however. For example, a long-term performance study of crack sealing AC pavements was performed in Ontario to determine if the activity was a cost-effective preventive treatment (Ponniah and Kennepohl 1996). This detailed study looked at materials, crack preparation methods, and equipment, on test sections of different ages and structures in this wet-freeze environment. Three of the conclusions from this study were:

- The consequences of not sealing cracks in flexible pavements are increased rehabilitation costs and a shortened service life.
- Routing and sealing cracks can minimize secondary crack growth and increase service life by at least 2 years.
- The life-cycle cost analysis indicates that rout and seal treatments are a cost-effective pavement maintenance procedure.

This study provided valuable information for managing Ontario's pavements, yet also highlights the limitations of specific studies designed for and carried out at specific locations; the sealant materials and configurations used in Ontario are appropriate for their environmental conditions and soils, but are not appropriate for all other agencies.

Some agencies undertake research to help to decide whether or not a particular treatment or class of treatments should be used. An example of this is a study of Novachip® (Estakhri and Button 1995), in which after a 3-year evaluation the researchers concluded that the treatment "is a viable alternative to conventional pavement surfacings" and can be considered as an alternative to chip seals, microsurfacing, plant-mix seals, and thin overlays. Along those same lines a study in New Mexico (McKeen 1996) concluded that cold in-place recycling "is cost effective and provides excellent performance." Whether it is a study initiated to test a new product or an evaluation of existing practices, research can help to further preventive maintenance practices, either in a given locale or nationwide.

Where a "leap of faith" is not possible, and existing research or maintenance efforts are not sufficient to initiate a program, the last option to document benefits is for an agency to design and carry out their own studies to evaluate treatment types, timings, and cost-effectiveness. This is the approach that has been undertaken by the Arizona DOT. Research initiated in 1998 is designed to evaluate the cost effectiveness of a wide range of potential preventive maintenance treatments through the construction and monitoring of an ambitious series of test sites. As the results become available, the DOT should have an excellent source of applicable data on what does and does not work for them.

Similar but more limited studies are underway in Iowa and Minnesota. In Iowa, a test section was constructed on US 69 (between Ames and Des Moines) in 1998. This study is intended to develop guidance on selecting the right pavements, treatments, and timings. It includes Novachip® and variations of a hot sand mix, microsurfacing, and chip seals. In Minnesota, a test of seal coats was also constructed in 1998. Located on TH 21 (north of Faribault), this study is examining the feasibility of using larger size aggregates on high volume roadways, the use of polymer modified emulsions, and the overall performance of several variants of Minnesota's conventional seal coat.

Monitor and Incorporate the Results into Management Systems

For preventive maintenance to be successful in the long run, the performance and cost effectiveness of the treatments must be monitored. A significant challenge to the long-term success of preventive maintenance programs is the difficulty in actually tracking this information. The nature of maintenance projects is such that many agencies are not used to keeping track of much information related to their maintenance treatments. While maintenance management systems might track the type of work that was done, the milepost limits where the work was done, and some general cost information (such as manpower and equipment), this falls far short of the data needed for analytical purposes.

The following list summarizes a "best case" scenario for data collection and monitoring. The importance of each component is further described below.

- Pavement condition prior to treatment application, including information on the structural section and past performance histories.
- Ambient conditions at the time of treatment.
- Design and construction of the treatment.
- Milepost limits of the treatment application.
- Duration of construction (not essential, but useful for tracking user costs).
- Cost of construction (including both in-house and contract costs)
- Performance of the treatment over time, including condition/distress, ride, and friction.
- Long term effects on the pavement's performance.

Knowing the condition of the pavement provides at least two important pieces of information. It is an indication of whether the treatment is truly being applied in a preventive manner, which is useful for later analyses. It is also useful because treatments should provide some benefit, and benefit is commonly measured as a change in the pavement condition. The exact type(s) of condition measurement will vary from agency to agency; what is important is that the measure be meaningful and that the change in condition be measurable and monitored over time.

Certain ambient conditions at the time of treatment placement should also be monitored. When was the treatment applied? What was the temperature? Was the pavement wet or dry? Did it rain or freeze before the treatment cured or set? If treatment performance is to be monitored, having the ability to differentiate between performance caused by wear and loads and performance affected by construction conditions is needed.

Treatment design and construction data ranges from the simple to the complex. An example at the simple end of the range might be diamond grinding, in which the only design data recorded are that 2 to 4 mm (0.08 to 0.16 in) of surface were removed. For a surface treatment, however, design information could include the surface preparation method, and material data such as the type of emulsion and modifier, the type of aggregate and its gradation, and application rates for both binder and aggregate. Recording design and materials information at the onset allows the agency the flexibility later to track performance by treatment type, and thus differentiate between successful and unsuccessful treatments. It also helps to form families of similar treatments on similar pavements to refine either performance models or estimates of service life.

The location of the treatment is a key part of monitoring maintenance applications. The limits must be known so that pavement performance is properly linked to the treatments that affect that pavement performance. Historically, this is an area where agencies have failed to keep good records, so that over time any idea of what treatments have contributed to a pavement's current condition are totally lost.

Similarly, the costs of the specific application should be recorded. What did it cost to apply the treatment at that location, including both agency costs, any contract costs, and any implied costs, such as equipment use? If the construction duration is known, it may also be possible to obtain a rough indication of the user costs associated with the application of the treatment.

Finally, once the treatment is applied, its performance must be monitored. After all, the whole premise for applying preventive maintenance treatments is that they provide some benefit to the pavement and overall network over time. If performance is not monitored, the benefit can not be measured and an agency does not have a realistic means of assessing whether any one treatment or preservation program is more cost effective than any other. Some thought must be giving to which aspect of performance is being tracked, however. Why are treatments being applied? To reduce roughness? To enhance skid resistance? To eliminate cracks? Where a specific benefit is expected from a treatment, the performance monitoring must include a measurement of the condition of interest.

As previously noted, PMS are the most convenient and probably the best tool for preventive maintenance monitoring. In many cases the required data are already being collected. Even if not, most PMS are flexible enough to be adapted for this purpose.

Means of Assessing Benefits

Whether it is an individual treatment or an entire program of treatments, any long-term commitment of funding requires a demonstration of cost effectiveness. Unfortunately, quantifying the benefits of a preventive maintenance treatment to both the users and agency itself, such as improved safety, savings in travel time, reduced liability claims, or improved passenger comfort, can be extremely difficult to quantify without extensive research studies.

Because of the difficulty in quantifying these factors, many state highway agencies rely on the increased service life associated with a treatment as a representation of the benefit, or effectiveness, associated with a treatment. In fact, this is the approach that is used in many PMS as well. The value associated with the increased service life is frequently multiplied by another value (such as ADT or a user-defined traffic classification number) that is representative of the number of vehicles using the road to provide a means of taking user costs into consideration in an indirect way.

After a means has been identified for quantifying the benefits, an agency can use a number of approaches for differentiating between multiple treatments for a pavement section or between multiple needs across an entire network. Five approaches used to conduct these types of cost analyses are shown below:

- First Cost Comparison Analysis.
- Life Cycle Cost Analysis.
- Equivalent Annual Cost Analysis.
- Benefit/Cost Analysis.
- Longevity Cost Index.

Of these, only the benefit/cost analysis takes into account both the cost and the benefit associated with a treatment. Because of this, it is the preferred approach for analyzing pavement preventive maintenance programs. First cost comparisons, with their focus on the cheapest treatments, are probably the least conducive to selecting cost effective treatments.

A PMS can be an important tool in the cost analyses, especially in comparing the results of different programming strategies. These systems can also be helpful in documenting the performance of preventive maintenance treatments over time for use in the life cycle cost analysis or for tracking the cost of various treatments over time for any of the cost studies. This integration with the pavement management system will help to ensure that the results of the cost analyses are documented and supportable if questioned by top management or public interests, or if follow-up analyses are needed.

Obtain Dedicated Funding

"*Long term support and financial commitment are the keys.*" (Wayne Shackleford, Georgia DOT)

"*Support must be substantial and it must be continuous.*" (Mike Lackey, Kansas DOT)

"*Dedicated funding requires a strong commitment to the philosophy of preventive maintenance.*"

Agencies that have succeeded in implementing system preservation programs recognize the importance of obtaining an adequate and secure source of funding. The need for financial support over a long enough period of time to see program results requires support from top management and a commitment to the long-term goals of the program. The importance of funding to the success of the program is well understood by individuals responsible for successful preventive maintenance programs, as illustrated below.

Since a preventive maintenance program requires a continuous level of effort for a period of time before the program's success can be realized, the most successful agencies have established dedicated funds for preventive maintenance. The establishment of dedicated funds helps to ensure that an adequate level of funding is available and helps to guard against "borrowing" from preventive maintenance to fund rehabilitation needs. Dedicated funding also helps to insure that the agency is able to apply preventive treatments in a timely fashion.

In order to establish a dedicated fund for preventive maintenance, the agency must be able to estimate the amount of money that will be needed over an established period of time in order to achieve the agency's goals. This can be done using information from the PMS, or by setting targets for the frequency of resurfacing for the network or the number of miles in various condition categories. In any case, a PMS is an excellent tool to assist in justifying the need for additional funding, or more cost-effectively allocating available funds. The system is extremely valuable because it contains the network deterioration models that are needed to show network conditions over time, and can quickly analyze different maintenance and rehabilitation strategies. Analyses made without the use of a pavement management system are often limited because of the assumptions that must be made in order to simulate the various scenarios.

Securing the Funds Required

Once the level of funding needed for the preventive maintenance program has been identified, the funds should be established in a dedicated fund for preventive maintenance purposes only. Typically, these funds come from one of three sources: new money (such as increased tax levels), a transfer of funds from another program, or from Federal programs. Federal participation on maintenance projects is now funded at an 80/20 split, with fewer restrictions than in the past. The use of Federal aid allows limited maintenance budgets to be stretched much further, but does not mean that there will be additional Federal aid. Other funding mechanisms, such as transfers of funds from another program or tax increases, may be needed; however these can be difficult, or impossible, to achieve without top-level agency support.

The materials provided by the case study states emphasize the importance of securing dedicated funding for preventive maintenance for a sustainable period of time. In order to achieve this, the agency must have top level, institutional support that recognizes that the benefits of a preventive maintenance program may not be immediately obvious. The benefits of preventive maintenance—the expectation of longer pavement lives, less frequent rehabilitation, better overall pavement performance, and improvements in overall safety—are realized over time. If funding is interrupted or compromised, it is unlikely that the benefits will ever be realized. Where funding constraints exist, applying preventive treatments means that some of the previously treated "worst-first" candidates are left to deteriorate. Other pavements will be allowed to deteriorate to the point that a PPM treatment is no longer appropriate. If average network condition is being monitored, the observed effect is an actual dip in performance brought about by the declining condition of failing pavements. Over time, not only does the average condition of the network improve, but so does the distribution of pavement condition.

Dedicated funding is an invaluable tool for maintenance program managers. It provides them with the ability to plan for the future with a comprehensive program rather than piecemeal, stopgap strategies. The benefit that the agency receives—the ability to plan treatment timings and types and manpower needs—is also enjoyed by contractors, who gain the ability to plan for the work that is coming up. Dedicated funding helps to build a healthy highway program and provides the public with a higher level of service.

In New York, the need for dedicated funding was central to the success of their program. They recognized the "need for long-term financing that was stable, predictable, and adequate" (Denehy 1997). The support of the agency's executive management helped to convince legislators and the public of the benefits of this program. They responded with legislation that created a dedicated fund. This fund included both an initial level of funding and provisions for annual increases, but also an additional $88 million to give the program an aggressive beginning during its first year.

The contribution of dedicated funding to program success is also highlighted by Caltrans' experience, as has been shown in figure 5. The only way that the agency can meet the goals that it has set and that have been accepted by their Transportation Commission is by receiving and applying the funding that is projected.

The experiences in Texas and Georgia emphasize that dedicated funding alone may not be sufficient, however, especially if the funding level remains static. While Texas has enjoyed a steady level of financial support for its preventive maintenance program, the funding is distributed by a geographic or district-based formula that is aimed more at equity than at need. Once the money is distributed to the Districts, they are free to use whatever treatments they want and to apply them to any pavements they choose. Unfortunately, the result appears to be that many pavements are still treated in a worst-first mode. As Graff noted in a 1998 presentation to AASHTO, "preventive maintenance funding is still inadequate... pavement condition is substantially deteriorating." This highlights the point that agencies must be allowed to manage a system preservation program unconstrained by restrictive barriers if they are to maximize cost-effectiveness.

Georgia has also received a fairly steady level of funding support over the years (about $72.5 million annually). In recent years, this level of funding has not been sufficient to permit the agency to reach their goal of providing some resurfacing every 10 years, primarily because the dedicated funding levels have not kept pace with the increased costs of pavement maintenance.

Develop and Improve the Available Treatments and Their Application

One of the challenges faced by system preservation programs is simply to prove that various preventive maintenance treatments work. What makes this so challenging is that even in instances where the concept of preventive maintenance is accepted, in some cases the treatments have not always worked as intended. One obvious example of this is chip seals or surface treatments, in which a commonly reported failure mode is poor aggregate retention (often resulting in litigation). Another fairly common complaint is about the poor performance of slurry seals placed on cracked and weakened pavements, or microsurfacing that cracks shortly after placement.

These examples highlight the importance of integrating a proactive research and technical monitoring program with the programming aspects of a preventive maintenance program. As described previously, management systems that track performance of treatments can be used to identify what is or is not working. Where enough information is stored, management system data can be used by an agency as justification to discontinue treatments on certain pavements or in certain locations, or to consider the use of new technologies, materials, or applications.

Monitoring information can also lead to modified guidelines for treatment application or even modified treatments themselves. Treatment improvements come from both the agency and industry. Agencies can standardize their practices, and publish these in manuals or workshops. The Montana DOT developed a *Maintenance Chip Seal Manual* (1996) in order to provide guidance on the proper design and construction of this preventive maintenance treatment. The Michigan DOT is a leader in specifying and documenting the treatments that they have developed. All of the preventive maintenance treatments are described in a manual, *Capital Preventive Maintenance Program* (MDOT 1998). This three-ring binder also describes the overall preventive maintenance program and guidelines, includes special provisions for each treatment, example warranty documents, average treatment costs, and other construction and inspection documentation. Not only is the document comprehensive, but because it is distributed in a three-ring binder it can be easily updated and modified as needed.

Industry has also led initiatives to develop and improve treatments. Advancements include the development of better binders, including those that use polymers to enhance adhesion and aggregate retention, improved sealant materials, and equipment innovations to place the treatments.

Innovative Practices to Promote Program Success

In the development and maturation process of their preventive maintenance programs, several agencies have implemented contracting and warranting innovations in their programs. Incidentally, this concept of contract maintenance and asset preservation contracting are emerging areas of owner and industry interest. These changes to the conventional way of doing business offer several benefits that are particularly appropriate for a preventive maintenance program. Innovations include reduced treatment costs, more timely treatment application, and reduced manpower demands on the agency. Limited agency resources are also freed to be redirected to reduce backlogs. Training has also been an integral part of the implementation process, as agencies identify that some of the challenges to their programs arise out of lack of understanding or misconceptions.

Contracting

Preventive maintenance treatments may not conform well to conventional agency contracting practices. Conventional contracts can rely on extensively engineered plans and specifications, be expensive to administer, and require a long time to approve. The essence of PM requires that the treatments be fairly inexpensive, somewhat standardized, and certainly they must be applied in a timely manner to be effective. Agencies have recognized these needs and responded to them.

Michigan implemented a number of contracting innovations that were essential to the success of their program (Galehouse 1998). Two resulted in substantial project cost savings. The preliminary design costs, which historically were about 5 percent of a project, were limited to 2 percent on their preventive maintenance applications, in recognition of the fact that MDOT's preventive maintenance applications could be specified in a much simpler or abbreviated form than conventional projects. Also, construction engineering costs (field inspection, documentation, and payment processing) were reduced from 15 percent to 5 percent of the project. This reduction was possible because the newly developed treatment specifications make the contractor responsible for quality control and construction documentation. The result of these contracting innovations was that project costs declined and more money became available for preventive maintenance applications.

New York also implemented innovations in their contracting practices in order to expedite delivery of preventive maintenance treatments. One such innovation is vendor-placed paving, in which a combination of state and contractor forces are used to apply lower cost treatments (the state purchased the materials placed in the agency's paving equipment). Another innovation that

NYSDOT developed is termed "simplified contracts." Simplified contracts have a simpler and quicker scoping process, a limited number of pay items, are restricted to less than 1 month of construction, and allow more flexible (longer) construction seasons. A number of preventive maintenance applications are eligible for simplified contracts, including single lift overlays, crack sealing, and drainage cleaning. The agency benefited from these innovations by being able to get more work done under the available funding. The new contracting procedures greatly reduced the percentage of the budget that was going to design and construction inspection; contractors also liked the changes because they gave more flexibility for construction and also sped up the payment process.

Kansas also adopted a simplified contracting procedure in their preventive maintenance program. In the video, *Protecting our Pavements: Preventive Maintenance* (FHWA 1997), Mike Lackey, KSDOT, describes how simplified procedures are appropriate for preventive maintenance treatments. There is far less engineering to do, so the project can usually be summarized on one sheet of paper.

Warranties

Another aspect of preventive maintenance where Michigan has made innovative improvements is in the development and use of warranty specifications for preventive maintenance applications. This initiative grew out of a somewhat unrelated issue: a loss in manpower at the DOT, and especially of field inspection personnel. These losses left the DOT struggling to find ways to inspect all of the construction projects. Warranty specifications are a step toward performance specifications, and have been shown to be a means of bringing contractors onto the agency's "team."

The warranty periods that resulted were specified as a portion of the expected service life of the preventive maintenance treatment, and were intended to last long enough to ensure that premature failures (such as delaminations or wholesale chip loss) related to construction problems were covered. "Chip seals, microsurfacing, slurry seals, crack sealing, and concrete joint resealing were designated to have a warranty period of 2 years," while 3-year periods were applied to nonstructural AC overlays, cold milling and AC overlays, and concrete pavement repairs (Galehouse 1998). A secondary benefit of the warranty process was the assurance that preventive treatments would not be applied on pavements in bad condition. Contractors were concerned that they could not meet the terms of a warranty in such conditions, so a process was initiated in which the contractors were provided a list of upcoming projects and invited to identify to MDOT those that were not suitable candidates. The warranty process was designed to ensure that the contractor was responsible for quality control of workmanship and materials, and not responsible for project selection or design.

In addition to saving agencies the expense of some inspection personnel, warranties have also shifted some of the liability associated with thin surfacings to the contractor. In particular, the fear of chip loss and other types of premature failures are less of an issue where warranties are being used. This is considered a "win-win" program for both the owner and the contractor. More importantly, the traveling public and taxpayers in general benefit by receiving better roads.

Training

Developing and promoting appropriate training activities can be an integral part of a program's success. The concepts promoted in preventive maintenance are often radically different from the usual way of doing business, and long-term success can not be guaranteed unless understanding and buy-in exist at all levels. Areas where training is needed include:

- Creating an awareness of the overall purpose of a pavement preservation program.
- Technical discussions of various treatments or technologies and the appropriate conditions for their application.
- Integration of preventive maintenance with other strategies (MMS, PMS).

Target audiences for these types of training programs range from maintenance managers to field personnel.

Agencies that have implemented PM in the past decade have made effective use of training. Caltrans assembled informational packages for their Transportation Commission in order to communicate the need for PM and the expected benefits. Two presentations, in July 1996 and January 1997, helped to convince the Commission to support preventive maintenance. Having secured funding for their program including over $50 million in new funding in the 1999/2000 fiscal year, the training process is now being directed at District Maintenance Engineers, who in January 1999 attended a *Forum for the Future* in Sacramento.

Michigan also has developed and promoted training programs as a means of shoring up agency understanding where needed. For example, as part of their preventive maintenance program the DOT introduced a number of new treatments for preventive applications that previously had not been widely used by MDOT. By partnering with industry, MDOT was able to receive workshop training to educate their staff in the treatments. In 1997, when the agency was moving toward warranty treatments, training was also provided in the warranty process.

Summary

Since the late 1980s, there has been a growing trend within highway agencies to implement preventive maintenance programs. A few agencies find that they have been following the principles of such a program without using the current terminology. However, for most agencies the philosophy of preventive maintenance—applying the right treatment to the right pavement at the right time—represents a significant departure from the usual way of doing business. In the more common approach to project selection within a network, often called worst-first programming, the pavements that are triggered for treatment are those that are closest to failure. As such, the treatments that are applied are more expensive, more time-consuming to construct, and are generally short lived.

Pavement preservation programs begin with the concept that there are cost-effective preventive maintenance treatments that can be applied earlier in a pavement's life. These treatments are thinner, constructed comparatively rapidly and with much less disruption to the traveling public, and reach or exceed their design lives because they are applied to pavements in relatively good condition. Agencies that use a preventive maintenance approach speak of the extension to pavement life realized by applying these thin treatments at the proper time, as well as providing the traveling public a higher level of service with smoother, safer roads.

Most public agencies face financial constraints and must make choices about how to spend their limited transportation dollars. Even with dedicated preventive maintenance funding, a choice must be made as to how to maintain pavements: where constraints are present, preventive maintenance and worst-first approaches are mutually incompatible. This point can not be over-emphasized. A program in which the worst pavements are treated first, and then leftover funding goes to preventive treatments, is doomed to failure. The failing pavements will require the lion's share of the funding and the treatments applied to them will not perform well, discrediting the overall program. With insufficient funds to apply the right treatment to the right pavement at the right time, program failure is all but assured.

Admittedly, the barriers that prevent agencies from making a shift to this system preservation or preventive maintenance approach to pavement preservation are formidable. But these barriers are being challenged and brought down. Studies have shown that the public is ready to embrace this philosophy. Any changes that result in better riding pavements, improved safety, and fewer delays due to continuous maintenance and rehabilitation are welcome. At the same time, research is proving the benefits of both a number of individual treatments as well as the overall contribution of preventive maintenance programs to pavement network health. These results have been used to secure and augment dedicated funds to continue the programs.

The likelihood of success of pavement preservation programs can be improved by following a well-planned out implementation process. While every agency will approach the process in a manner that is best suited to surmounting their known obstacles, the most successful approaches have included the following steps:

- Develop a measurable goal for the program.
- Implement a means of assessing and documenting the benefits of the program to the agency, legislature, and public.
- Seek and obtain dedicated and continuous funding.

Several lead states have introduced innovative practices such as simplified contracting procedures and warranties as a means of further ensuring the success of their programs. These concepts are well on their way to full implementation.

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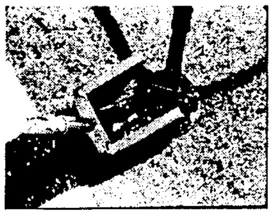
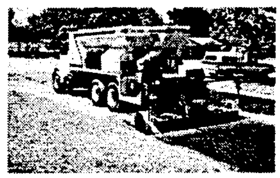
Appendix A—Presentation Graphics

Slide 1

Pavement Preservation: The Preventive Maintenance Concept

- Executive Overview-

Slide 2

Sponsorship

Federal Highway Administration

NHI National Highway Institute

Foundation for Pavement Preservation

Slide 3

Preventive Maintenance

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.

- AASHTO's Standing Committee on Highways

Slide 4

Philosophy of Preventive Maintenance

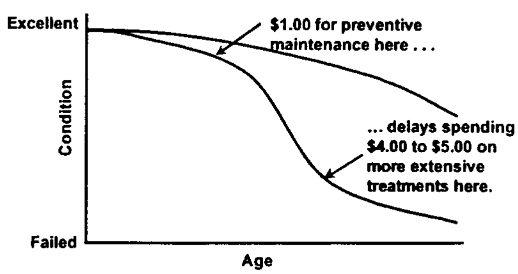
Applying the right treatment

. . . To the right pavement

. . . At the right time

Slide 5

The Concept of Preventive Maintenance



Slide 6

Objectives of a Preventive Maintenance Program

- Lower overall preservation costs
- Improved overall level of service
- Improved customer service

An agency must be able to demonstrate these benefits in order to initiate and sustain the program

Slide 7

Treatment Types (Michigan example)

- AC Pavements
  - Thin overlay
  - Mill and overlay
  - Chip seal
  - Microsurfacing
  - Crack treatment
  - Shoulder ribbons
  - Ultrathin Overlay
- PCC Pavements
  - Joint resealing
  - Spall repair
  - Crack sealing
  - Diamond grinding
  - Shoulder ribbons
  - Drain cleanout
  - Dowel retrofit
  - CPR

Slide 8

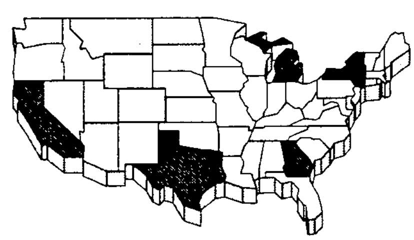
Importance of Preventive Maintenance

As we move towards the 21st century, it is clear that the Federal-Aid highway program is undergoing a significant transition from its original focus on new construction to that of preservation of the highway system.

- FHWA Program Development Office

Slide 9

State Initiatives In Preventive Maintenance



Slide 10

Washington State Survey

- Roadway surface maintenance is the highest priority maintenance activity
- Public is willing to pay more:
  - to achieve desired levels of maintenance
  - to reduce future costs

Slide 11

Arizona Survey

- #1 priority: safety (85 %)
- #2 priority: preservation (74 %)
- Over 60 % would be willing to pay more taxes to improve maintenance service levels
- 90 % would be willing to spend more now to save money in the long term

Slide 12

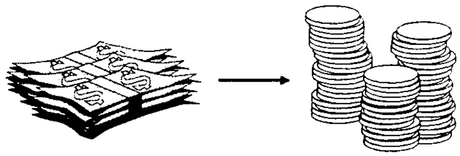
California Survey

- Ranking of public priorities
  - Maintenance response to accidents/disasters
  - Safety
  - Pavement conditions
  - Traffic flow

Slide 13

One Objective of Preventive Maintenance

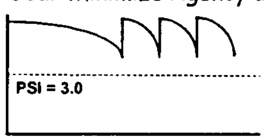
- Reduce the overall life cycle cost of preservation



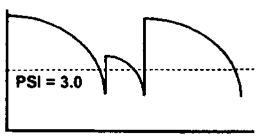
Slide 14

Indiana Preventive Maintenance Study

Goal: Minimize Agency and User Costs



If seal coat when PSI > 3.0, then apply 3 chip seals



If seal coat when PSI < 3.0, then apply 1 chip seal

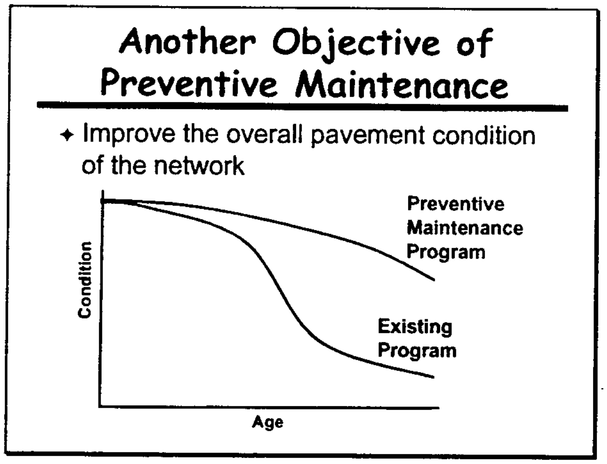
Slide 15

Michigan DOT Example

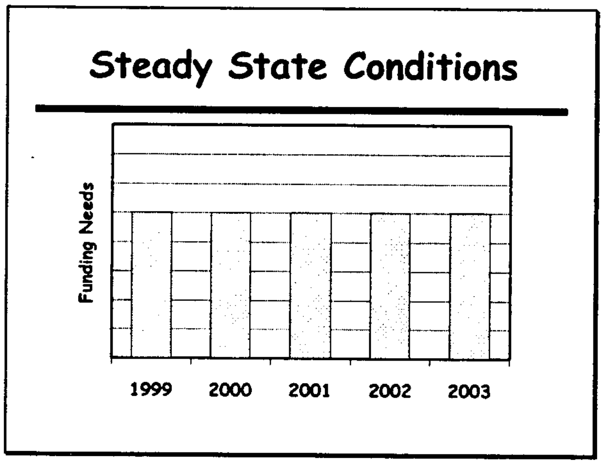
$315 million Rehabilitation and Reconstruction = $190 million Rehabilitation and Reconstruction + $10 million Preventive Maintenance

Achieved same results for $115 million less

Slide 16



Slide 17



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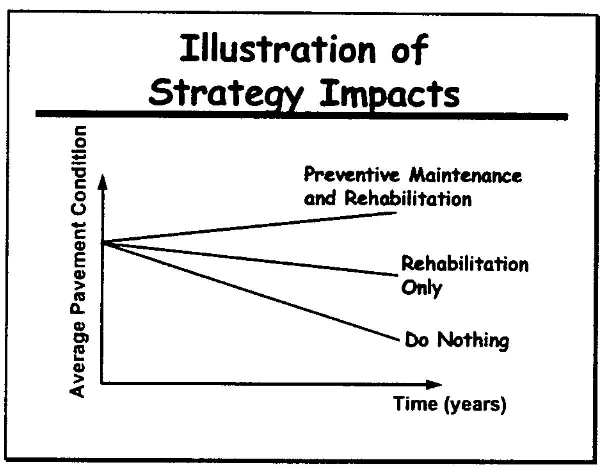
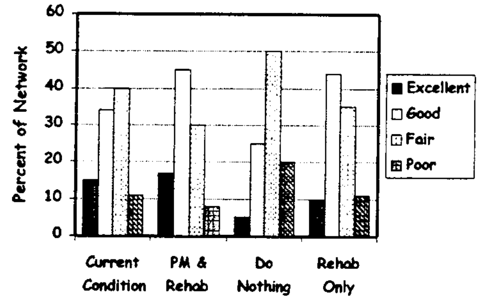


Slide 19

Sample Network Distribution In 5 Years



Slide 20

Implementing a Pavement Maintenance Program

Slide 21

Major Benefits

- Improved pavement condition
- Safer roads
- Lower life cycle costs
- Reduced congestion
- Customer satisfaction
- More cost effective use of funds

Slide 22

Challenges

- Dedicated funding challenges
- Management resistance
- Management's perception of public reaction
- Poor data tracking
- Lack of applicable research
- Absence of relevant training

Slide 23

Keys to Successful Program

- Establish goals
- Document the benefits
- Promote the benefits
- Obtain dedicated funding
- Develop guidelines
- Identify champion
- Obtain top management support

Slide 24

Establish Goals

It is essential that a road agency select a long-term objective and structure its maintenance selection policy to achieve its objective.

- Rohde et al. 1997

Advocating a philosophy of preventive maintenance is the most important factor in developing a successful program.

- Galehouse 1998

Slide 25

Simple, Effective Goals

- California - reduce pavements in need of rehabilitation (from 29 to 11 percent)
- Wisconsin - provide the highest quality service possible per unit of service
- Michigan - keep good roads good

Slide 26

Measurable Goals

- Pavement condition
- Average rating
- Percent of pavements in condition category
- Cost savings

Slide 27

Document the Benefits

There is a need to conduct and publish the results of formal research on the cost-effectiveness of pavement preventive maintenance techniques.

- Geoffroy 1996

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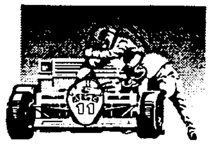
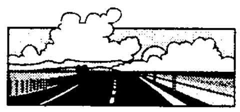
Benefits of Maintenance



People understand the importance of preventive maintenance on their cars.



Why is it so hard to understand the same benefits on roads?

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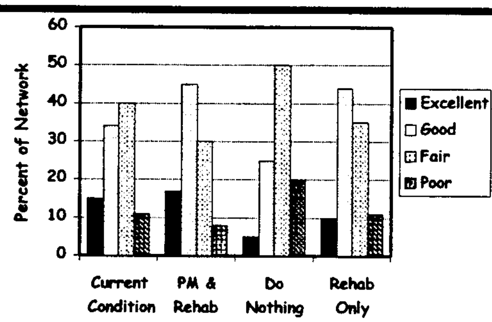
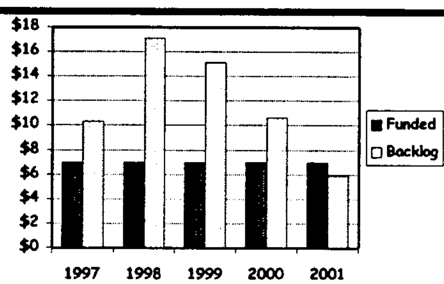
Promote The Benefits



Slide 30

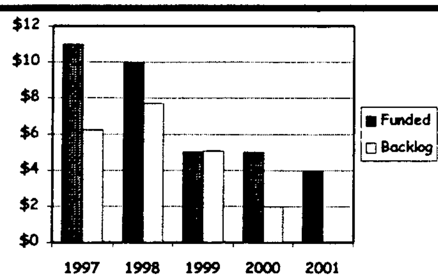
Uniform Funding



Total Expenditure = $35 million

Slide 31

Early Distribution of Funds



Total Expenditure = $35 million

Slide 32

Obtain Dedicated Funding

Long-term support and financial commitment are the keys.

- Wayne Shackleford

Dedicated funding requires a strong commitment to the philosophy of preventive maintenance.

Slide 33

Importance of Dedicated Funding

- Benefits take time to realize
- Allows for improved asset management

Funding levels should match preventive maintenance needs

Slide 34

Use of a Pavement Management System

- Determine funding level to achieve an agency goal
- Determine the most cost-effective strategy for a given funding level
- Integrate with preventive maintenance (feedback)

Slide 35

Sources of Funding

- New money (revenue enhancement)
- Transfer of funds from another program
- Increased flexibility with Federal funds

Slide 36

Develop and Improve Treatments and Timing

- Don't become complacent because it works; it could be better
- Monitor feedback
- Modify guidelines
- Develop Manuals of Practice
- Industry is constantly developing new treatments and better materials

Slide 37

Innovative Practices to Promote Success

- Contracting
- Incentive-based financing (warranties)
- Innovative materials and techniques
- Training approaches
- Partnering

Slide 38

Contracting

- Michigan
  - Simplified designs
  - Contractor responsible for quality control
- New York
  - Vendor-placed paving
  - Simplified contracts

Reduce costs for design and engineering

Slide 39

Warranties (Michigan)

- Developed due to limited manpower
- Warranty periods of 2 to 3 years
- Contractors select projects suitable for preventive maintenance
- Benefits
  - Cost savings
  - Shift in liability

Slide 40

Training

- Concepts of preventive maintenance are different than typical projects
- Training needs
  - Overall purpose
  - Treatments and timing
  - Integration with other strategies

Slide 41

Summary

- Must get away from a worst-first policy
- Preventive maintenance can extend pavement life and reduce costs
- Keys to success
  - Measurable goal
  - Assessing and promoting benefits
  - Dedicated and continuous funding
  - Feedback from PMS

Appendix B—Glossary

AADT – The average 24-hour traffic volume counts collected over a number of days greater than 1 but less than a year, at a given location. AADT can also be approximated by adjusting the ADT count for daily (weekday versus weekend) and seasonal (summer versus winter) variations.

ADT – The average 24-hour traffic volume counts collected over a number of days greater than 1 but less than a year, at a given location.

ADTT – The average 24-hour truck traffic volume counts collected over a number of days greater than 1 but less than a year, at a given location. ADTT may be expressed as a percentage of ADT.

Annual Costs – Any costs associated with the annual maintenance and repair of the facility.

Asphalt Emulsion Mix – A mixture of emulsified asphalt materials and mineral aggregate usually prepared in a conventional hot-mix plant or drum mixer at a temperature of not more than 127 °C (260 °F). It is spread and compacted at the job site at a temperature above 93 °C (200 °F).

Cape Seal – A surface treatment that involves the application of a slurry seal to a newly-constructed surface treatment or chip seal. Cape seals are used to provide a dense, waterproof surface with improved skid resistance.

Chip Seal – A surface treatment in which a pavement surface is sprayed with asphalt (generally emulsified) and then immediately covered with aggregate and rolled. Chip seals are used primarily to seal the surface of a pavement with non load-associated cracks and to improve surface friction, although they also are commonly used as a wearing course on low-volume roads.

Cold In-Place Recycling (CIR) – A process in which a portion of an existing bituminous pavement is pulverized or milled, the reclaimed material is mixed with new binder and virgin materials, and the resultant blend is placed as a base for a subsequent overlay. Emulsified asphalt is especially suited for cold in-place recycling. Although not necessarily required, a softening agent may be used along with the emulsified asphalt.

Cold Milling – A process of removing pavement material from the surface of the pavement either to prepare the surface (by removing rutting and surface irregularities) to receive overlays, to restore pavement cross slopes and profile, or even to re-establish the pavement's surface friction characteristics.

Crack Filling – A maintenance procedure that involves placement of materials into non-working cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement. Working cracks are defined as those that experience significant horizontal movements, generally greater than about 2 mm (0.1 in). Crack filling should be distinguished from crack sealing.

Crack Sealing – A maintenance procedure that involves placement of specialized materials, either above or into working cracks, using unique configurations to reduce the intrusion of incompressibles into the crack and to prevent intrusion of water into the underlying pavement layers. Working cracks are defined as those that experience significant horizontal movements, generally greater than about 2 mm (0.1 in).

Dense-Graded Asphalt Overlay – An overlay course consisting of a mix of asphalt cement and a well-graded (also called dense-graded) aggregate. A well-graded aggregate is uniformly distributed throughout the full range of sieve sizes.

Diamond Grinding – A maintenance procedure for concrete pavements that involves the removal of a thin layer of concrete (generally no more than 6.4 mm [0.25 in]) from the surface of the pavement to remove surface irregularities (most commonly joint faulting), to restore a smooth riding surface, and to increase pavement surface friction.

Diamond Grooving – The establishment of discrete grooves in the concrete pavement surface using diamond saw blades to provide a drainage channel for water and thereby reduce the potential for hydroplaning and wet weather accidents.

Discount Rate – The rate of interest reflecting the investor's time value of money, used to determine discount factors for converting benefits and costs occurring at different times to a baseline date. Discount rates can incorporate an inflation rate, depending on whether real discount rates or nominal discount rates are used.

Emulsified Asphalt – An emulsion of asphalt cement and water, which contains a small amount of an emulsifying agent. Emulsified asphalt droplets, which are suspended in water, may be either the anionic (negative charge) or cationic (positive charge) type, depending upon the emulsifying agent.

Equivalent Uniform Annual Cost (EUAC) – The net present value of all discounted cost and benefits of an alternative as if they were to occur uniformly throughout the analysis period. Net Present Value (NPV) is the discounted monetary value of expected benefits (i.e., benefits minus costs).

Fog Seal – A light application of slow setting asphalt emulsion diluted with water. It is used to renew old asphalt surfaces and to seal small cracks and surface voids.

Heater Scarification – A form of Hot In-Place Recycling in which the surface of the old pavement is heated, scarified with a set of scarifying teeth, mixed with a recycling agent, and then leveled and compacted.

Hot In-Place Recycling (HIR) – A process which consists of softening the existing asphalt surface with heat, mechanically removing the surface material, mixing the material with a recycling agent, adding (if required) virgin asphalt or aggregate to the material, and then replacing the material back on the pavement.

Hot Mix Asphalt (HMA) – High quality, thoroughly controlled hot mixture of asphalt cement and well-graded, high-quality aggregate thoroughly compacted into a uniform dense mass.

Hot Surface Recycling – See hot in-place recycling.

Inflation rate – The rate of increase in the general price levels, caused usually by an increase in the volume of money and credit relative to available goods. The inflation rate is also reflective of the rate of decline in the general purchasing power of a currency.

Initial Costs – All costs associated with the initial design and construction of a facility, placement of a treatment, or any other activity with a cost component.

International Roughness Index (IRI) – A ratio of the accumulated suspension motion to the distance traveled obtained from a mathematical model of a standard quarter car transversing a measured profile at a speed of 80 km/h (50 mph). Expressed in units of meters per kilometer (inches per mile), the IRI summarizes the longitudinal surface profile in the wheelpath.

Joint Resealing – The resealing of transverse joints in concrete pavements to minimize the infiltration of surface water into the underlying pavement structure and to prevent the intrusion of incompressibles into the joint.

Joint Sealant Reservoir – The channel sawed or formed at a joint that accommodates the joint sealant.

Load Transfer Restoration (LTR) – The placement of load transfer devices across joints or cracks in an existing jointed PCC pavement. LTR is used on existing jointed PCC pavements that were constructed without dowel bars at transverse joints.

Life Cycle Costing – An economic assessment of an item, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars.

Microsurfacing – Microsurfacing is a mixture of polymer modified asphalt emulsion, mineral aggregate, mineral filler, water, and other additives, properly proportioned, mixed and spread on a paved surface.

Mineral Filler – A finely divided mineral product, at least 70 percent of which will pass a 0.075 mm (No. 200) sieve. Pulverized limestone is the most commonly manufactured filler, although other stone dust, hydrated lime, portland cement, and certain natural deposits of finely divided mineral matter are also used.

Nominal Dollars – Dollars of purchasing power in which actual prices are stated, including inflation or deflation. Hence, nominal dollars are dollars whose purchasing power fluctuates over time.

NOVACHIP™ – A maintenance treatment for AC pavements, sometimes called an ultrathin friction course: it consists of a layer of hot-mix material placed over a heavy, polymer modified emulsified asphalt tack coat; the total thickness of the application being typically between 10 and 20 mm (0.40 and 0.80 in). It can be used to reduce deterioration caused by weathering, raveling, and oxidation, and can be used to fill ruts and to smooth corrugations and other surface irregularities.

Open-Graded Friction Course (OGFC) – An overlay course consisting of a mix of asphalt cement and open-graded (also called uniformly-graded) aggregate. An open-graded aggregate consists of particles of predominantly a single size.

Partial-Depth Recycling – See cold in-place recycling.

Pavement Preservation – The sum of all activities undertaken to provide and maintain serviceable roadways; this includes corrective maintenance and preventive maintenance, as well as minor rehabilitation projects.

Pavement Preventive Maintenance – Planned strategy of cost-effective treatments to an existing roadway system and its appurtenances that preserves the system, retard future deterioration, and maintains or improves the functional condition of the system (without increasing the structural capacity).

Pavement Reconstruction – Construction of the equivalent of a new pavement structure which usually involves complete removal and replacement of the existing pavement structure including new and/or recycled materials.

Pavement Rehabilitation – Work undertaken to extend the service life of an existing pavement. This includes the restoration, placing an overlay, and/or other work required to return an existing roadway to a condition of structural and functional adequacy.

Pavement Serviceability Index (PSI) – A subjective rating of the pavement condition made by a group of individuals riding over the pavement.

Periodic Costs – Costs associated with rehabilitation activities that must be applied periodically over the life of the facility.

Present Worth Method – Economic method that requires conversion of costs and benefits by discounting all present and future costs to a single point in time, usually at or around the time of the first expenditure.

Real Dollars – Dollars of uniform purchasing power exclusive of general inflation or deflation. Real dollars have a constant purchasing power over time.

Recycling Agents – Organic materials with chemical and physical characteristics selected to address any binder deficiencies and to restore aged asphalt material to desired specifications.

Rejuvenating Agent – Similar to recycling agents in material composition, these products are added to existing aged or oxidized AC pavements in order to restore flexibility and retard cracking.

Retrofitted Load Transfer – See Load Transfer Restoration.

Rubberized Asphalt Chip Seal – A variation on conventional chip seals in which the asphalt binder is replaced with a blend of ground tire rubber (or latex rubber) and asphalt cement to enhance the elasticity and adhesion characteristics of the binder. Commonly used in conjunction with an overlay to retard reflection cracking.

Salvage Value – The remaining worth of the pavement at the end of the analysis period. There are generally two components of salvage value: residual value – the net value from recycling the pavement and serviceable life – the remaining life of the pavement at the end of the analysis period.

Sand Seal – An application of asphalt material covered with fine aggregate. It may be used to improve the skid resistance of slippery pavements and to seal against air and water intrusion.

Sandwich Seal – A surface treatment that consists of application of a large aggregate, followed by a spray of asphalt emulsion that is in turn covered with an application of smaller aggregate. Sandwich seals are used to seal the surface and improve skid resistance.

Scrub Seal – Application of a polymer modified asphalt to the pavement surface followed by the broom-scrubbing of the asphalt into cracks and voids, then the application of an even coat of sand or small aggregate, and finally a second brooming of the aggregate and asphalt mixture. This seal is then rolled with a pneumatic tire roller.

Shape Factor – The width to depth ratio of a joint sealant reservoir. A proper shape factor is required to allow the sealant to effectively withstand repeated extension and compression as the temperature and moisture in the slab changes. Most commonly available sealants require a shape factor between 1 and 2.

Slurry Seal – A mixture of slow-setting emulsified asphalt, well-graded fine aggregate, mineral filler, and water. It is used to fill cracks and seal areas of old pavements, to restore a uniform surface texture, to seal the surface to prevent moisture and air intrusion into the pavement, and to provide skid resistance.

Stockpiled Cold Mix – An asphalt maintenance mix consisting of aggregate and emulsified asphalt, which once prepared can be stored and readily used for a period up to six months depending on the formulation of the emulsion used and the aggregate characteristics.

Stone Mastic Asphalt Overlay – An overlay course consisting of a mix of asphalt cement, stabilizer material, mineral filler, and gap-graded aggregate. A gap-graded aggregate is similar to an open-graded material but is not quite as open.

Surface Texture – The characteristics of the concrete pavement surface that contribute to both surface fiction and noise.

Undersealing – Also called subsealing, pressure grouting, or slab stabilization: this process consists of the pressure insertion of a flowable material beneath a PCC slab used to fill cavities beneath PCC slabs and occasionally to correct the vertical alignment by raising individual slabs.

User Costs – Costs incurred by highway users traveling on the facility and the excess costs incurred by those who cannot use the facility because of either agency or self-imposed detour requirements. User costs typically are comprised of vehicle operating costs (VOC), accident costs, and user delay costs.