JOINT TRANSPORTATION RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION &
PURDUE UNIVERSITY

BENEFITS AND ASSESSMENT OF ANNUAL BUDGET REQUIREMENTS FOR PAVEMENT PRESERVATION

Makarand Hastak
Professor of Civil Engineering
Purdue University
Corresponding Author

Jusang Lee
Research Engineer
Office of Research & Development
Indiana Department of Transportation

Hiral Shah
Graduate Research Assistant
School of Civil Engineering
Purdue University

Yoojung Yoon
Graduate Research Assistant
School of Civil Engineering
Purdue University

SPR-3416
Report Number: FHWA/IN/JTRP-2011/06
DOI: 10.5703/1288284314620

RECOMMENDED CITATION

Hastak, M., Lee, J., Shah, H., & Yoon, Y. *Benefits and Assessment of Annual Budget Requirements for Pavement Preservation*. Publication FHWA/IN/JTRP-2011/06 Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2011.
DOI: 10.5703/1288284314620

CORRESPONDING AUTHOR

Prof. Makarand (Mark) Hastak
School of Civil Engineering
Purdue University
(765) 494-0641
hastak@ecn.purdue.edu

JOINT TRANSPORTATION RESEARCH PROGRAM

The Joint Transportation Research Program serves as a vehicle for INDOT collaboration with higher education institutions and industry in Indiana to facilitate innovation that results in continuous improvement in the planning, design, construction, operation, management and economic efficiency of the Indiana transportation infrastructure.
https://engineering.purdue.edu/JTRP/index_html

Published reports of the Joint Transportation Research Program are available at: http://docs.lib.purdue.edu/jtrp/

NOTICE

TECHNICAL REPORT STANDARD TITLE PAGE

<table>
<tr><td colspan="2">1. Report No.

FHWA/INDOT/JTRP-2011/06</td><td colspan="2">2. Government Accession No.</td><td colspan="2">3. Recipient Catalog No.</td></tr>
<tr><td colspan="4" rowspan="2">4. Title and Subtitle

Quantification of the Benefits of Pavement Preservation</td><td colspan="2">5. Report Date
2011</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="4">7. Author(s)
Hiral Shah
Yoojung Yoon
Makarand (Mark) Hastak
Jusang Lee and Todd Shields</td><td colspan="2">8. Performing Organization Report No.

FHWA/INDOT/JTRP-2011/06</td></tr>
<tr><td colspan="4" rowspan="2">9. Performing Organization Name and Address
Indiana Department of Transportation
Office of Research and Development
1205 Montgomery Street
West Lafayette, IN 47906

School of Civil Engineering
Purdue University
West Lafayette, IN 47907</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.

SPR-3416</td></tr>
<tr><td colspan="4" rowspan="2">12. Sponsoring Agency Name and Address
Indiana Department of Transportation
Office of Research and Development
1205 Montgomery Street
West Lafayette, IN 47906</td><td colspan="2">13. Type of Report and Period Covered

Final Report</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="6">15. Supplementary Notes

Prepared in cooperation with the Federal Highway Administration</td></tr>
<tr><td colspan="6">16. Abstract
This research identifies methods and best practices that can be used by the Indiana Department of Transportation (INDOT) in performing various strategies for pavement preservation. It also identifies various methods of calculating the benefits of pavement preservation and a methodology for allocation of funds for pavement preservation, which are the two main objectives of this research. In order to achieve these objectives, several tasks were performed: literature review, data collection through Surveys and telephone interviews, data analysis and recommendations. For the data collection process, all the DOTs across the US and three Canadian provinces were sent a Survey. A total of 26 responses were received, and by analyzing them thoroughly, seven state DOTs were identified as candidates for telephone interviews.

In order to quantify the benefits of pavement preservation, a method called Annualized Costs was identified and recommended to INDOT. Furthermore, a methodology was developed for budget allocation. This methodology was developed to create more consistent demands for resources (i.e., budget) by using a resource leveling algorithm. This algorithm overcame the discrepancies in the budget requirements, providing more balanced budgetary needs over the entire life cycle of the projects. With this model, INDOT will know in advance how much budget will be needed or should be allocated for optimum results. All these recommendations were made on the basis of collected data and literature review performed by researchers during the course of this project.</td></tr>
<tr><td colspan="3">17. Key Words

Pavement Preservation</td><td colspan="3">18. Distribution Statement

No Restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.</td></tr>
<tr><td>19. Security Classification (of this report)

Unclassified</td><td colspan="2">20. Security Classification (of this Page)

Unclassified</td><td colspan="2">21. No. of Pages

33</td><td>22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-69)

CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

BENEFITS AND ASSESSMENT OF ANNUAL BUDGET REQUIREMENTS FOR PAVEMENT PRESERVATION

Introduction

The capacity and condition of highways has been deteriorating due to low maintenance budgets, environmental effects, poor weather conditions, and a rapid growth in the use of highways by consumers. It has become increasingly important to take steps that would both meet the nation's needs and satisfy consumers; however, allocating more funds for pavement rehabilitation or reconstruction is not the solution (NCPP 2010). Instead, most agencies have begun to allocate funds for pavement preservation. According to the Federal Highway Administration (FHWA), pavement preservation is "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations." The Indiana Department of Transportation (INDOT) has already begun a Pavement Preservation Initiative. The two main objectives of this research are: 1) to determine the benefits of pavement preservation techniques; and 2) how much budget to allocate for these activities. To satisfy these objectives, research was conducted in three stages:

- Data collection through literature review, surveys, and telephone interviews.
- Data analysis and recommendations.
- Development of a methodology to determine allocation of funds.

Findings

Initiatives for pavement preservation by U.S. Departments of Transportation (DOTs) have significantly increased. Pavement preservation has offered various benefits, including life extension of the pavement, cost benefits, consumer satisfaction, improved pavement condition, enhanced safety, and fewer construction delays. This research seeks to enable INDOT to quantify these benefits and find an optimum budget that should be allocated for pavement preservation activities. In order to fulfill these objectives and collect the required data, various DOTs were contacted through Surveys and telephone interviews.

Quantification of the Benefits of Pavement Preservation

DOTs use various methods to calculate the benefits of pavement preservation. INDOT uses lane mile years. It was determined that the Michigan DOT uses a Road Quality Forecasting System (RQFS), Louisiana uses a Highway Health Index, Maine uses DTIMS software, Maryland uses lane mile years, and New Mexico and Washington use an Annualized Costs method to quantify the benefits of pavement preservation. After analysis of these methods, the research team recommended that INDOT use an Annualized Costs method for calculating and quantifying the benefits of pavement preservation. A detailed description of the method is presented in this report.

Budget Allocation for Pavement Preservation Activities

Allocation of budget for pavement preservation activities is another objective of the research. Discrepancy still exists in the budget requirements from one year to the next. In order to overcome this, the concept of resource leveling was adopted, which would level budget requirements over the entire life cycle of a project. A model was established based on the concept of resource leveling and the minimum moment algorithm. INDOT then conducted a case study comprising 196 projects to be completed in three years, between 2010 and 2012. All of the projects had different duration and costs associated with their respective maintenance treatments. Performance of all the treatments was projected over a period of 15 years based on frequency of use and estimated life of the treatment. The algorithm was run for these projects and leveled budgetary requirements were obtained. The algorithm reduced the variance in the budgetary requirements from one year to the next and offered a more consistent budget requirement.

Implementation

This research provides significant advantages for INDOT in implementing pavement preservation strategies. The research provides an overview of how to quantify all the benefits of pavement preservation and also how to allocate an optimum budget for preservation activities. It includes some of the new methods of calculating benefits from pavement preservation which are not currently implemented by INDOT. The budget allocation methodology was developed by the research team can be implemented by INDOT for their budget allocation purposes. All the data collected would thus be used by INDOT for various implementation activities. The findings and recommendations will be introduced to the INDOT Pavement Preservation Subcommittee for assisting the network level pavement preservation strategy.

1. INTRODUCTION

1.1. Background and Problem Statement

Today consumers are accustomed to hassle-free, smooth and safe mobility on the roads of the US. To experience easy mobility, roads or highways have to be well-maintained, which would in turn reinforce growth in transportation, thus playing a critical role in the nation's economy. A 29% increase in the use of our nation's highways was noticed during the 1990's, and even more growth is expected in coming decades. Large commercial truck traffic increased by nearly 40% and more than 95% of personal travel is by automobile since 1990 (Galehouse 2003). In short, use of highways in the US is increasing rapidly. The United States maintains nearly 3.95 million miles of public roads (Federal Highway Administration 2003); however, these pavements, made out of Asphalt Concrete (AC), Portland Cement Concrete (PCC), and even a composite of asphalt and concrete, deteriorate as a result of several factors, including increased traffic, environmental effects, and lack of proper maintenance (Galehouse 2003).

Poor construction and low quality materials used for pavements also contribute to faster pavement deterioration when compared to the expected service life for which they were originally designed. The United States highway system, which is an important component of the nation's economic well-being, is valued at $1.75 trillion but is steadily deteriorating (National Center for Pavement Preservation 2010). Highway agencies are also facing the chronic problem of financing in spite of their best efforts to keep up with ever-present reconstruction or rehabilitation needs.

With this rapid growth, the capacity and condition of our present highways must be maintained and well–preserved; however, allocating more resources or budget to rebuild or rehabilitate more roadways more quickly is not the solution (National Center for Pavement Preservation 2010). In fact, agencies should be putting in constant efforts to preserve current pavement or newly rebuilt roadways by implementing pavement preservation activities. Thus, agencies should allocate a significant proportion of highway expenses to preserving the system, that is, to a pavement preservation program.

According to the Federal Highway Administration (FHWA), pavement preservation is "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations" (Geiger 2005). Pavement preservation is a long-term strategy of applying a varied range of treatments that are applied to the pavement. Pavement preservation gives highway agencies an economical alternative for addressing pavement needs (Galehouse 2003). Implementing a strategic plan for pavement preservation will give highway agencies the ability to improve pavement conditions and increase pavement life with minimal use of funds.

For the purpose of this research, the concept of pavement preservation is considered a preventive maintenance strategy for pavements that would maintain roads in good condition and entail long-term cost savings. According to the American Association of State Highway and Transportation Officials (AASHTO), preventive maintenance is the planned strategy of cost effective treatments to an existing roadway system without increasing structural capacity. Pavement preservation focuses on minimizing the deterioration of pavement assets while maximizing the economic efficiency of the investment. Some of the benefits of pavement preservation include: higher customer satisfaction, with smoother rideability and better appearance; enhanced safety with enhanced friction; improved pavement performance while reducing water infiltration and retarding pavement aging; and cost savings with a reduction in overall maintenance costs and construction delays.

After the release of the original Pavement Preservation Compendium in September 2003, plans were undertaken by FHWA, the National Center for Pavement Preservation (NCPP), and State Departments of Transportation (DOTs) to reinforce the implementation of pavement preservation as one of several effective asset management tools (Geiger 2006). A variety of surveys and questionnaires were sent out to determine the current state of practice in pavement preservation. For example, in 1999 the AASHTO Lead States Team surveyed DOTs on pavement preservation in the 50 States, the District of Columbia, Puerto Rico, and six Canadian Provinces (AASHTO 1999). Since 2005, the FHWA has initiated comprehensive technical interviews with the help of the NCPP in order to conduct a national evaluation of pavement preservation programs in state DOTs and FHWA field offices. The concept of "applying the right treatment to the right road at the right time" is becoming widely established across various DOTs in the US. Thus, most Departments of Transportation (DOTs) across the US have now adopted the philosophy of pavement preservation.

Just like other DOTs, INDOT has also adopted the practice of pavement preservation. In order to justify continuous allocation of budget for pavement preservation, benefits gained by preservation activities have to be well-documented and calculated. INDOT should also have information regarding how to allocate the budget for preservation strategies in order to achieve optimum results. Accordingly, this research provides various preservation treatments, their optimal timing, budget allocation to preservation activities, benefits of preservation and much more insight into this topic.

1.2. Objectives

The two objectives of this research are as follows:

- To document the economic viability of pavement preservation; and

- To develop a methodology for INDOT to determine the amount of funding that should be dedicated to preservation.

The data presented in this research documents and justifies the economic viability of pavement preservation as well as how other state DOTs quantify the benefits of pavement preservation. It also documents a methodology for allocating budget to a pavement preservation program.

1.3. Research Methodology

In order to achieve the above research objectives, the entire methodology has been divided into four tasks as shown below.

Task 1: Literature Review

This task explores an extensive literature review that was conducted to analyze various facets of pavement preservation. The history of pavement preservation—what it includes, the benefits of pavement preservation, the current state of practice, different preventive maintenance treatments, annual funding for these treatments, who makes decisions regarding preservation, case studies of different state DOTs, etc.—were identified during the literature review. In order to form a basis for comparison, similar information in a much more detailed manner was collected through a survey followed by telephone interviews, as discussed in the next section.

Task 2: Survey and Telephone Interviews

The objective of sending out the Survey was to establish the pavement preservation practices among various state DOTs. The purpose of conducting telephone interviews was to understand more in-depth the best practices from other states that were identified through the survey. Telephone interviews provided the research team insight into these issues and provided potential models that could be implemented by the Indiana Department of Transportation (INDOT) in their pavement preservation program. Some of the ideas could be incorporated by INDOT based on recommendations made by the research team.

A total of 26 responses were received in response to the survey. Candidates for the telephone interview were identified by the research team and SAC members after a thorough analysis of the Survey. The candidates for the telephone interview were Indiana, Michigan, Minnesota, New Mexico, Maryland, California and Washington DOTs.

Task 3: Development of Methodology for Budget Allocation

A model of a balanced allocation of funds for pavement preservation over a planning period was developed for INDOT. Usually, the budgetary needs differ from one year to the next. In order to have more consistent budgetary needs, a resource leveling algorithm was developed for the case study provided by INDOT. This resource leveling model identified which projects should be completed first and also leveled resources needed for maintenance over a life cycle of 15 years.

Task 4: Development of Final Report

After completing the tasks above tasks, a comprehensive report consisting of all the data collected through the literature review, the survey, and telephone interviews were compiled. Regular quarterly meetings took place with INDOT SAC (Study Advisory Committee) members, who were continually updated with the progress of the research and the type of data collected over the course of the research. Their feedback was considered and implemented at all times. The work performed and the data collected will be finalized in a detailed report to the SAC members for review. The comments provided by INDOT will be incorporated, and a final report will be submitted to INDOT by the completion date of the project.

1.4. Expected Outcomes and Benefits

This research compiled a significant bank of knowledge regarding the current state of practice of pavement preservation among other DOTs. This will help INDOT identify good practices that could be implemented within the state of Indiana. This study recommends a procedure for documenting the benefits of pavement preservation and a methodology for allocation of funds for preservation.

Some of the outcomes of the study are listed below:

- The research identifies the current state of practice for pavement preservation and methods of quantifying the benefits as gained by preservation strategies.
- The study identifies the age and history of pavement preservation in particular state DOTs, different preventive maintenance treatments and the typical frequency of those treatments, annual funding for these treatments, and the authorities that help in making these decisions.
- It identifies various tools and software that DOTs use for budget allocation.
- A methodology is recommended to INDOT for budget allocation for pavement preservation.

1.5. Report Organization

The literature review is documented in the next chapter, Chapter 2. Data collection from the survey and telephone interviews is documented in Chapter 3. Analysis of the data is presented in Chapter 4 and is followed by a proposed methodology for budget allocation in Chapter 5. Summary and conclusions for the entire study are presented in Chapter 6.

2. LITERATURE REVIEW

2.1. Introduction

Today, demands on the highway network and transportation funding are greater than ever (Davies and Sorenson 2000). These demands are growing along with the public's expectation of easy mobility on safe, smooth, and well-maintained roads. With this increase in usage, a great deal of money is invested in maintaining these roads. During the 1990's, US highways experienced a 29% increase in use, and usage will certainly continue to escalate in the coming years (Galehouse, Moulthrop, and Garyhicks 2003). The problem that highway agencies now face is that many roads are wearing out because of increased traffic, environmental effects, and lack of proper maintenance (Galehouse, Moulthrop, and Garyhicks 2003). More than $1.75 trillion has been invested in our nation's highway system (Sorenson 2006). According to FHWA, the United States maintains nearly 3.95 million miles of public roads (Galehouse, Moulthrop, and Garyhicks 2003). It is therefore important to increase and maintain the capacity and condition of these highways in order to meet the nation's needs. However, this raises several important issues, such as identification of need, possible solutions, economic viability, and budget requirement, among others. To resolve these issues, many state agencies have developed and implemented a strategic plan called pavement preservation (Galehouse, Moulthrop, and Garyhicks 2003).

2.2. Definitions for Pavement Preservation Terminology

2.2.1. Pavement Preservation

According to FHWA, pavement preservation is "a program employing a network level, long-term strategy that enhances pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety and meet motorist expectations" (Geiger 2005). Pavement preservation includes a variety of treatments like chip seal, crack seal, fog seal, joint resealing, and diamond grinding. Preservation is a long-term strategy of applying these treatments to pavement in order to extend pavement life and value. Every Department of Transportation (DOT) across the US has now adopted the philosophy of pavement preservation.

Pavement preservation gives transportation agencies a cost-effective alternative for addressing pavement needs. Pavement preservation allows highway agencies to improve pavement condition and also increase the life of pavement with minimal use of funds. The focus of preservation is on minimizing deterioration of pavement assets while maximizing the economic efficiency of the investment.

What does Pavement Preservation include?

FHWA classifies pavement preservation into three main categories:

Preventive maintenance is "a 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 significantly increasing the structural capacity" (FHWA Memorandum 2005). Preventive maintenance is the major component of pavement preservation and is the application of a variety of treatments on the pavement surface depending on whether it is asphalt or concrete pavement. Some of the preventive maintenance treatments are:

- Asphalt: Crack sealing, chip sealing, slurry or micro-surfacing, Ultrathin bonded wearing course, thin and ultra-thin hot-mix asphalt overlay.
- Concrete: concrete joint sealing, diamond grinding, dowel-bar retrofit, and isolated, partial and/or full-depth concrete repairs.

Routine maintenance "consists of work that is planned and performed on a routine basis to maintain and preserve the condition of the highway system or to respond to specific conditions and events that restore the highway system to an adequate level of service" (FHWA Memorandum 2005). Routine maintenance includes regular treatments (day to day activities) that are applied on the pavement surface by a maintenance staff, thus ensuring a reasonable level of service from the pavement. Some of the routine maintenance treatments are: cleaning up roadside ditches and cracks, filling cracks with bituminous material and reinforcing adjacent top-bottom cracks, pothole patching and many more.

Minor rehabilitation "consists of non-structural enhancements made to the existing pavement sections to eliminate age-related, top-down surface cracking that develops in flexible pavements due to environmental exposure. Because of the non-structural nature of minor rehabilitation techniques, these types of rehabilitation techniques are placed in the category of pavement preservation" (FHWA Memorandum 2005). Some of the minor rehabilitation treatments are: grinding, spall repair, full-depth concrete patching, etc.

What pavement preservation does not include

- Major rehabilitation
- Reconstruction

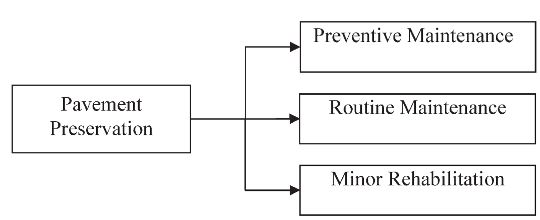

Figure 2.1 Components of Pavement Preservation

- New pavement construction
- Corrective maintenance

Pavement rehabilitation consists of “structural enhancements that extend the service life of an existing pavement and/or improve its load-carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays” (FHWA Memorandum 2005).

Rehabilitation projects extend the life of existing pavement structures either by restoring existing structural capacity through the elimination of age-related, environmental cracking of embrittled pavement surfaces or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions (FHWA Memorandum 2005).

Major rehabilitation “consists of structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability” (FHWA Memorandum 2005).

Corrective maintenance “activities are performed in response to the development of a deficiency or deficiencies that negatively impact the safe, efficient operations of the facility and future integrity of the pavement section. The corrective maintenance activities are generally reactive, not proactive, and performed to restore a pavement to an acceptable level of service due to unforeseen conditions” (FHWA Memorandum 2005). Activities such as pothole repair, patching of localized pavement deterioration, for example edge failures and/or grade separations along the shoulders, are considered examples of corrective maintenance of flexible/asphalt pavements. Examples for rigid/concrete pavements might consist of joint replacement or full-width and depth slab replacement at isolated locations.

Pavement reconstruction “is the replacement of the entire existing pavement structure by the placement of the equivalent or increased pavement structure. The reconstruction usually requires the complete removal and replacement of the existing pavement structure” (FHWA Memorandum 2005). Reconstruction is required when a pavement has either failed or has become functionally obsolete.

Benefits of pavement preservation

There are many benefits that accumulate with pavement preservation activities. Starting pavement preservation treatments early can create a domino effect of benefits (AASHTO Lead States’ Work Plan 1999). With early treatments, pavement may survive longer without major rehabilitation or reconstruction. By reducing the life cycle cost, the service life of the pavement may be extended. Most of the pavement preservation treatments, including chip seal, fog seal, crack sealing, etc., can be applied in a very short period of time, resulting in less interruption of traffic and postponement of rehabilitation and reconstruction; thus, user delays and inconveniences may be reduced. A few of the benefits of pavement preservation are mentioned below.

Higher Consumer Satisfaction: The public is interested in pavement conditions and in seeing that these conditions are improved (Smith, Hoerner, and Peshkin 2008). Preventive maintenance treatments are less expensive than rehabilitation or reconstruction and consume less time. Higher consumer satisfaction can be expected due to the shorter closure time required by pavement preservation activities. There will be less congestion on roads, safety will be maintained, and roads will be smoother, resulting in greater satisfaction among road users.

Ability to Make Better Informed Decisions: A successful pavement preservation program should be based on the right treatment for the right pavement at the right time. In order to determine the right treatment, various factors, including the existing condition of the pavement, the expected performance of the pavement, performance of treatment techniques, and weather conditions, play an important role (Smith, Hoerner, and Peshkin 2008). All this information is stored in the Pavement Management System (PMS), which will help in the decision making process. For example, Caltrans uses PMS to prioritize the projects for rehab, routine maintenance and Capital Preventive Maintenance (CAPM) (Caltrans 1996). As the timing of preventive maintenance treatments is very important, the data from PMS helps authorities prioritize their projects and make better decisions.

Improved Pavement Condition: As described earlier, routine maintenance is a reactive process in which distresses on the pavement are repaired. Rehabilitation is programmed to follow the “worst first” principle, where capital rehab projects are implemented only when the pavement has deteriorated completely (Kercher, n.d.). The conventional approach consists of both routine and rehabilitation actions implemented in combination. However, the concept of preventive maintenance, as shown in Figure 2.2, is not to wait until pavement deteriorates, but to maintain it when it is still in good condition, thus keeping already good pavement in good condition and delaying the need for rehabilitation or reconstruction (Smith, Hoerner, and Peshkin 2008).

Cost Savings: A number of highway agencies have reported on the extension in service life and the projected cost savings gained from preventive maintenance treatments (Smith, Hoerner, and Peshkin 2008). Preventive maintenance treatments cost less compared to rehabilitation or even reconstruction investments. In addition, preventive maintenance treatments also slow down the deterioration rate of pavement, thereby delaying the need for rehabilitation or reconstruction projects (Sims, n.d.). More and more agencies are adopting pavement preservation and are beginning to document its financial benefits. The Michigan DOT has saved $700 million over a five year period due to pavement preservation strategies (Smith, Hoerner, and Peshkin 2008). According to the Concrete

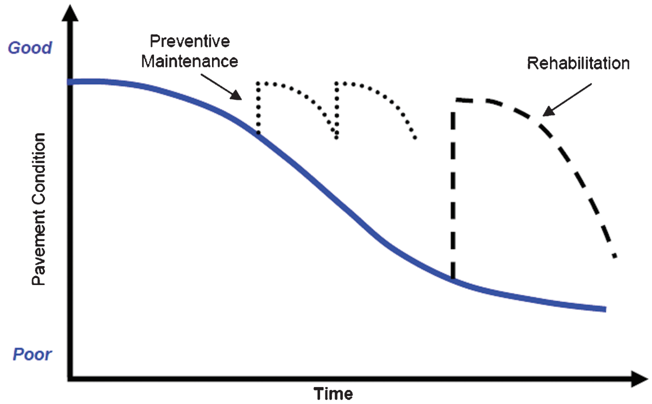

Figure 2.2 Typical effects of Preventive Maintenance and Rehabilitation on Pavement Surface (Concrete Pavement Preservation Reference Manual 2008)

Pavement Reference Manual, as a result of preservation strategies there will be fewer delays as well as safer and smoother roads resulting in lower user costs (Smith, Hoerner, and Peshkin 2008). Studies from the California DOT found that pavement preservation will delay the need for costly rehabilitation (typically 6 to 10 times the cost of preservation) or reconstruction (20 to 50 times the cost of preservation) (Gary 2010). When the same section of pavement is considered and a comparison of the project life-cycle costs with and without preventive maintenance treatments is made, the benefits of pavement preservation are clear (Galehouse, Moulthrop, and Garyhicks 2003).

Increased Safety: Highway users expect safety as they travel. Also, FHWA has recently established a Strategic Plan Goal to reduce fatalities and accident rates by 20% within ten years (Smith, Hoerner, and Peshkin 2008). Preventive maintenance treatments provide safety benefits that would address this issue. These activities will lead to safer surfaces, and other safety-related defects like spalling will be cured as a result of the use of preventive treatments (Smith, Hoerner, and Peshkin 2008). The use of preservation activities can lead to smoother roads and fewer construction delays, which will in turn provide higher customer satisfaction (Illinois DOT 2010). The research shows that pavement preservation treatments have a positive impact on pavement (Larson 1999). According to the Texas Pavement Center, the goals of a Preventive Maintenance Program are to extend the life of pavement, improve safety, and reduce cracking and other failures (Yildirim 2009).

Thus all the benefits of pavement preservation can be summarized as follows:

- Higher customer satisfaction
- Ability to make better, more informed decisions
- Improved pavement performance
- Improved pavement condition
- Cost savings
- Enhanced safety
- Smoother ride / Reduced roughness
- Fewer construction delays
- Better appearance
- Increased mobility
- Lower taxpayer cost
- Improved friction
- Reduced water infiltration
- Reduced overall maintenance costs

2.3. Philosophy of Pavement Preservation

2.3.1. The Three R's

In order to implement a successful pavement preservation program, an agency simply needs to follow the three R's of applying the right treatment to the right place at the right time. This is adopted from "Preventive Maintenance Part-3" by Kercher (2004).

Select the right treatment: It is extremely vital to use the right treatment for the best possible results. With different climate zones and pavement conditions, the best treatment type also differs. So it is important to consider the prevailing weather conditions to determine the best possible treatment for a pavement.

Select the right road: Pavement conditions vary from road to road and should be evaluated before applying any treatments by performing a pavement condition survey, which would evaluate the roughness, aging, cracking, rutting and other distresses in the pavement. An evaluation will determine the best suitable candidate for application of the treatment.

Timing is everything: Appropriate timing is essential to a successful pavement preservation program (Kercher 2004). Figure 2–3 presents a generic pavement deterioration curve (pavement condition vs. age). There are different repair categories, each applied in an ideal scenario, which are superimposed on this curve. Say, for example, preventive maintenance is delayed for a few years, or a treatment is missed and not performed in the proper time frame; in this case, the cracks will increase considerably and the rate of deterioration of the pavement will increase as well. This will result in expensive treatments, thereby increasing the budget. Thus, it is very important to apply the right treatment on the right pavement at the right time.

2.4. Concept of Pavement Preservation

Today, the public expects safety, smooth ride quality, and efficient traffic flow. In order to address growing demands from travelers, highway agencies are redefining their objectives to concentrate on strategies that would preserve or maintain existing roads or highways instead of the typical strategy of fixing the "worst first." For years, agencies have realized that the "worst first" strategy consumes a great deal of budget and that the final condition of the pavement is not consistent with the amount of money spent. In the traditional approach the original pavement usually deteriorates from fair to poor condition. Rehabilitation is assumed once it has

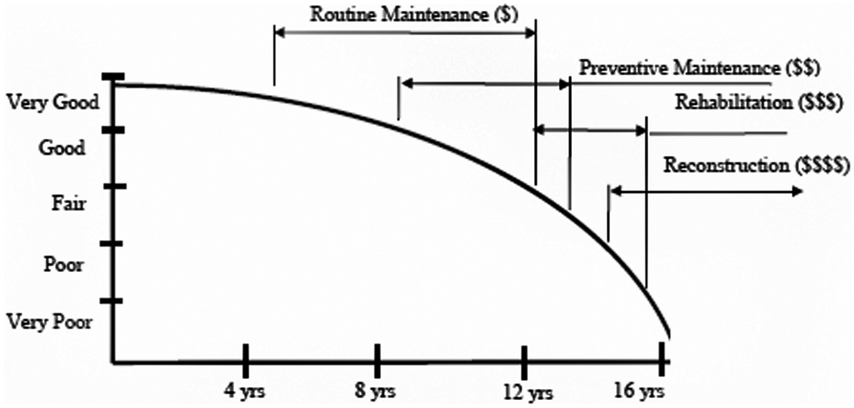

Figure 2.3 Maintenance and Rehabilitation strategies (Kercher 2004)

reached a point that structural damage has occurred, but it is generally expensive and time-consuming. Thus, managing high quality pavement conditions within stringent budgetary regulations is an important issue for highway departments. Hence, preventive maintenance, the proactive strategy of pavement preservation, was adopted in lieu of the traditional one.

2.4.1. Non-Traditional Approach/ Preventive Maintenance

In this approach, agencies do not wait until pavement deteriorates and starts to lose its structural capacity. Instead, a variety of preventive maintenance treatments are applied to the pavement. A series of regular and timely applications of non–expensive preventive maintenance treatments are done, which would improve the condition of the pavement, thus increasing the life of the pavement at the same time. FIGURE 2.4 illustrates this approach:

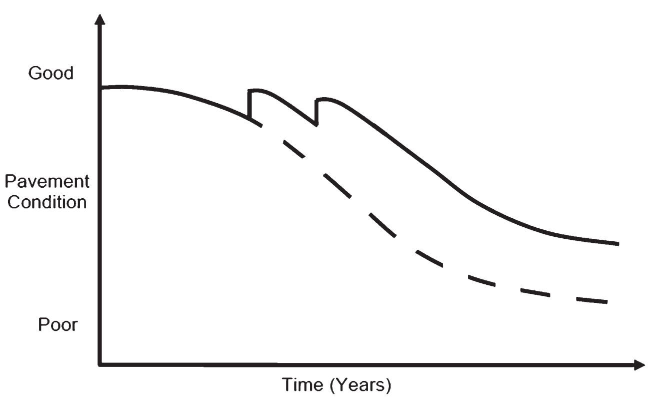

Figure 2.4 Concept of Pavement Preservation

2.4.2. Pavement Performance Extended by Preventive Maintenance (Illinois DOT, 2010)

The FIGURE 2.4 is adapted from "The Bureau of Design and Environment Manual". It depicts how the application of successive preventive maintenance treatments (shown as the solid line) can help maintain pavement in good condition for a longer period of time compared to a pavement without preventive treatments (depicted by the dashed line performance curve). The figure above depicts a proactive strategy of pavement preservation in contrast to the traditional approach. In the traditional approach, the original pavement deteriorates from fair to poor condition without applying any preventive maintenance treatments. At this point, structural damage has already occurred, which triggers the need for expensive and time-consuming rehabilitation. However, if a pavement preservation strategy is implemented, that is, if comparatively low-cost preventive maintenance treatments are applied at more regular intervals, then a much greater interval between pavement rehabilitations or even reconstruction will result. Thus, the treatments and strategies of pavement preservation can significantly slow the rate of deterioration and increase the service life of pavement.

2.4.3. "Worst First" vs. "Best First" Approach

Studies have proven that "Best First" is better than worst first (Kercher, n.d.). Usually, it is common practice to repair only those streets that are in the worst shape, having deteriorated and showing a maximum limit of serious structural damage. However, researchers argue that instead of waiting for a pavement to deteriorate, authorities should adopt an approach that would keep good streets in good condition. Since the cost of reconstructing or rehabilitating roads is markedly expensive, it is much more cost-effective to prevent the pavement from deteriorating by applying preventive maintenance treatments.

2.4.4. "Mix of Fixes" Approach

The Michigan DOT implements a widespread strategy for pavement preservation, thus satisfying the public's needs and expectations. Michigan has a two-pronged approach:

- A pavement preventive maintenance program: This includes application of a variety of cost-effective surface treatments, increasing the service life of the pavement and meeting the public expectation of having safe, smooth and well-maintained roads.

The Michigan pavement management system doesn't focus on conventional treatments but instead combines strategies in a "mix of fixes" approach. This strategy includes:

- Long-term fixes: reconstruction
- Medium-term fixes: rehabilitation
- Short-term fixes: preventive maintenance

In this "mix of fixes" approach, each fix has a critical role to play to increase the service life of a road and enhance the future condition of the highway system.

2.5. Pavement Preservation vs. Rehabilitation

This example is adopted from the "Best First" policy by Kercher. The following example shows how preventive maintenance not only increased the life of the pavement but was also cost-effective. A few assumptions were made in the following example:

- A 20-year design life (before reconstruction)
- Good original construction
- Routine maintenance /regular repairs were ignored (for simplicity in calculations)

In FIGURE 2.5(A), the pavement is allowed to deteriorate over the course of 15 years; at this time a $60,000 overlay is done. In FIGURE 2.5(B), the pavement receives the preventive maintenance treatment of Microsurfacing while the pavement is still in good shape at the end of year 10. A second round of application is done at year 20. Option (B), where treatment application was done twice, was still more cost effective than option (A).

Increasingly, state departments of transportation (DOTs) have reported that the proactive approach of preventive maintenance, known as pavement preservation, cuts the need for more costly, time-consuming rehabilitation and reconstruction projects and reduces associated traffic disruptions. As a result, the public is seeing improved mobility, reduced congestion, and safer, smoother, longer-lasting pavements, in short, the goals of pavement preservation.

2.6. Case Studies

2.6.1. Michigan Case Study

A study from the Michigan Department of Transportation (MDOT) illustrated preventive maintenance as a good investment. According to this study, Michigan DOT's preventive maintenance is six times as cost effective as rehab and reconstruction. According to "Insights into Pavement Preservation: A Compendium 2000," Michigan implemented a preventive maintenance strategy in 1992 in order to maintain its 9,580 miles of highways in the best shape possible despite budgetary constraints. Since then, Michigan has successfully practiced its preventive maintenance strategy on 2,650 miles of asphalt and concrete pavements at the cost of $80 M. Had preventive maintenance not been implemented, MDOT would have spent $700 M on rehabilitation

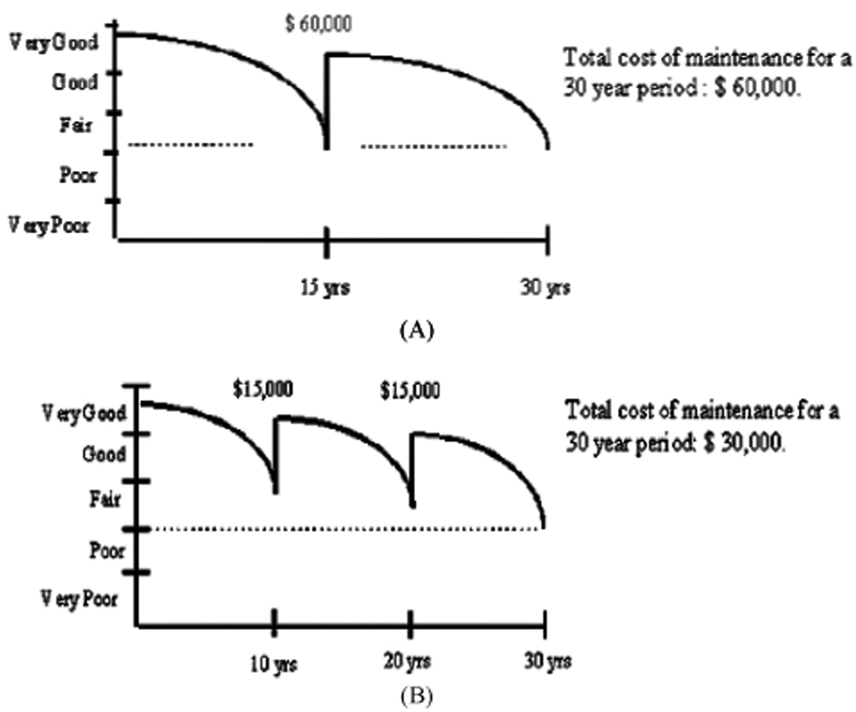

Figure 2.5 Comparison of Rehabilitation and Preventive Maintenance: (a) rehabilitation (Overlay); (b) preventive maintenance (Microsurfacing) http://www.kercherei.com/pw_institute/prev_maint/best.html (last visited: January 2011)

and reconstruction projects to bring these highways up to their current condition, which is approximately eight times the cost of preventive maintenance treatments (Galehouse and Friend 1996).

Furthermore, according to the research paper "Savings from Preventive Maintenance" by Larry Galehouse and Al Friend (1996), MDOT saved a total of $700M by applying maintenance treatments as opposed to rehabilitation. According to this paper, MDOT uses a Pavement Management System (PMS) module known as the Road Quality Forecasting System (RQFS). RQFS uses a Remaining Service Life (RSL) concept to estimate long-term network conditions and funding needs. The forecasting system uses current condition data to predict the future network conditions at different levels of investment.

To estimate the savings from Michigan's preventive maintenance program, the Road Quality Forecasting System (RQFS) was used to estimate the amount of a traditional Rehabilitation and Reconstruction (RR) program needed to match the performance of a program containing both Preventive maintenance (PM) projects and Rehabilitation and Reconstruction projects.

In 1996, two different scenarios were tested using RQFS and taking into consideration past performance data of rehabilitation, reconstruction and preventive maintenance.

Analysis: As shown in TABLE 2.1 above, Case 2 illustrates that $315M is needed to match the long-term performance of a $200M annual program that includes a series of preventive maintenance activities. This would indicate that there was a savings of $115 M annually if preventive maintenance was practiced. Each $1M of PM provided a savings of $11.5M in Reconstruction/ Rehabilitation funds.

Analysis: As shown in TABLE 2.2 above, Case 2 indicates that $455M is needed to match the long-term performance of a $175M annual program that includes a series of preventive maintenance activities. This would indicate that there is a savings of $280M annually when preventive maintenance is practiced. Each $1M of PM investment provided a savings of $11.2 M in RR funds.

Summary of the two cases: Using RQFS, the total amount of savings was calculated as follows:

Table 2.3 shows that if preventive maintenance treatments were not used then an extra amount of $700M would need to be spent. Hence, with the use of treatments, Michigan saved total of $700M.

This information was obtained from the papers by Galehouse and Friend (1996), Galehouse (2003), and Smith, Hoerner, and Peshkin (2008). However, information about the condition of the pavement when these treatments were applied, whether the costs were annualized, whether MDOT included a discount factor in the calculations, etc., were not available in any of these papers. Therefore, a detailed analysis of this case study was not done.

2.6.2. New Mexico Case Study

New Mexico has been a very active player in the pavement preservation program and have successfully quantified its benefits of pavement preservation. This case study is adopted from New Mexico's maintenance preservation manual.

TABLE 2.1
Test Scenario-1

Test 1	Preventive Maintenance	Rehab/Recon	Rehab/Recon	Total
Case 1 (with PM)	$10M	$190M	-	$200M
Case 2 (without PM)	-	$190 M	$125M	$315M

TABLE 2.2
Test Scenario-2

Test 2	Preventive Maintenance	Rehab/Recon	Rehab/Recon	Total
Case 1 (with PM)	$25M	$150M	-	$175M
Case 2 (without PM)	-	$150 M	$305M	$455M

TABLE 2.3
Final results of savings gained

Year	PM funding	Savings	Approximation of savings (being conservative)
1992	$6M	$67.2M	$50M
1993	$16M	$179.2M	$150M
1994	$16M	$179.2M	$150M
1995	$16M	$179.2M	$150M
1996	$24M	$268.8M	$200M
TOTAL		**$873.6M**	**$700M**

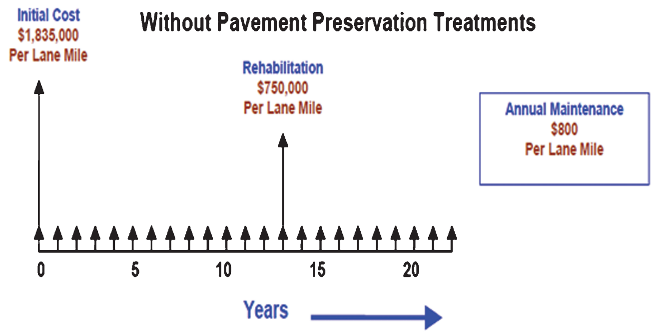

Figure 2.6 Annualized Costs without Pavement preservation Treatments (New Mexico DOT, 2007)

In the first scenario, shown in FIGURE 2.6, the pavement is allowed to deteriorate till up to 15 years before rehabilitation is performed on the pavement. At this stage, the pavement shows several distresses and is not structurally fit. When rehabilitation is done, it will be expensive, as the original pavement has deteriorated to the worst possible condition. Thus, when treatment is done, it will be both time-consuming and expensive.

In the second scenario, presented in FIGURE 2.7, preventive maintenance treatments are applied at regular intervals. When the pavement first starts to show small cracks or other distresses, it is immediately treated with a variety of treatments before the pavement has deteriorated completely. So, as shown in FIGURE 2.7, fog seal, chip seal, and thin HMA overlay are applied regularly over the service life of the pavement. Research shows that the pavement life increased from 22 to 35 years. The costs related to these treatments are shown below.

In order to present consistent comparison, Equivalent Uniform Annualized Costs (EUACs) were calculated.

Case 1: Rehabilitation (No pavement preservation)

$$\begin{aligned}&\textit{Equivalent Uniform Annualized Cost }(EUAC)\\&\quad = P(A/P,i,n) + F\ (P/F,i,n)\\&\quad (A/P,i,n) + A\end{aligned}$$

Where,

$$\begin{aligned}&P = \text{Present Worth};\ A = \text{Annual Cost};\\&F = \text{Future Worth};\\&i = \text{Interest Rate; and}\\&n = \text{number of years}\\&EUAC = 1{,}835{,}000(A/P,3.3\%,22)\\&\quad + 750{,}000(P/F,3.3\%,13)\\&\quad (A/P,3.3\%,22) + 800\\&\quad = \$151{,}220.7\end{aligned}$$

Case 2: Pavement preservation (No Rehabilitation)

$$\begin{aligned}EUAC = {}& P(A/P,i,n) + F(P/F,i,n)(A/P,i,n)\\&+ F(P/F,i,n)(A/P,\ i,\ n)\\&+ F(P/F,i,n)(A/P,i,n)\\&+ F(P/F,i,n)(A/P,i,n)\\&+ F(P/F,i,n)(A/P,i,n)\\&+ F(P/F,i,n)(A/P,i,n)\\&+ F(P/F,i,n)(A/P,i,n) + A\end{aligned}$$

$$\begin{aligned}&= 1{,}835{,}000(A/P,3.3\%,35)\\&\quad + 1{,}156(P/F,3.3\%,3)(A/P,3.3\%,35)\\&\quad + 22{,}493(P/F,3.3\%,7)(A/P,3.3\%,35)\\&\quad + 7{,}893(P/F,3.3\%,12)(A/P,3.3\%,35)\\&\quad + 80{,}960(P/F,3.3\%,17)(A/P,3.3\%,35)\\&\quad + 1{,}156(P/F,3.3\%,22)(A/P,3.3\%,35)\\&\quad + 7{,}893(P/F,3.3\%,25)(A/P,3.3\%,35)\\&\quad + 7{,}893(P/F,3.3\%,30)(A/P,3.3\%,35)\\&\quad + 500 = \$\ 72{,}090.6\end{aligned}$$

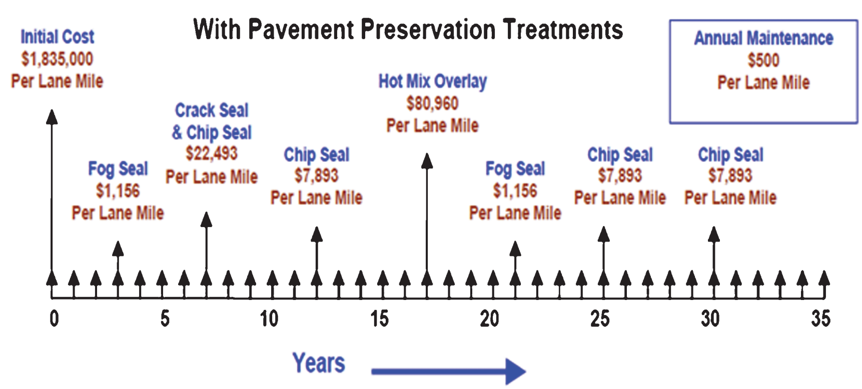

Figure 2.7 Annualized Costs with Pavement preservation Treatments (New Mexico DOT, 2007)

Thus, the calculations clearly show that pavement preservation is less expensive and also increases the life of the pavement.

2.7. Leveling Budget for Pavement Preservation Activities

2.7.1. Need for Leveling

If abundant resources are available, a project can be completed ahead of time. On the other hand, if resources are limited, project completion could be delayed (Pennsylvania State University 2005). When a project plan is first prepared, there will be some variance in the resource requirements; that is, it is possible to have a large peak in resource demands for some years whereas for other years resource requirements may be quite low. However, if the availability of resources is limited, then peak resource needs can be difficult to meet. To overcome the challenges of ever-increasing demands for resources with limited availability, many companies focus on more efficient usage of resources (Gather, Zimmermann, and Bartels 2010). Ideally, there should be an even demand for resources throughout the duration of a project, with a leveled increase at both the beginning and end of any project (Pennsylvania State University 2005). This is called Resource Management (leveling demands on available resources).

2.7.2. Resource Management

There are two main methods for resource management. The first method is resource allocation and the second method is resource leveling (Harris 1978). Both of these methods are used in different scenarios.

- Resource allocation: best used when resources are limited.
- Resource leveling: best used when project duration is fixed, i.e., duration of the project cannot be altered.

Resource allocation

There are two methods of resource allocation: the series method (or Brooks method) and the parallel method (Hinze 2004). In the series method, as soon as a preceding activity is completed, its succeeding activity is started. In this method, once the activity has started it is neither stopped nor interrupted, since it is assumed that productivity might be reduced if the activity is interrupted (Hinze 2004). The parallel method is similar to the series method with one basic difference: activities may be interrupted or stopped. In a construction project, scheduling and resource allocation are very important, as they will impact the total duration of the project and its costs. In any given scenario, resources such as tools, equipment, machines and human resources are needed to complete a project. All these resources are definite; that is, they have a limited capacity. As a result, at certain moments an activity may be delayed due to resource constraints, even if all its predecessor activities are finished.

Resource leveling

When the duration of the project is fixed, resource leveling is implemented. Resource leveling is not constrained by limited resources. Leveling tends to reduce maximum demands for a given resource on any given day/month/year and distribute them over the course of a day/month/year, creating lower and more level demands for resources. Resource leveling is thus an approach that will allow reorganizing project activities in such a manner that resource requirements are more uniform for the duration of a project, as well as for float years. Thus, resource leveling is an effective means of smoothing out the utilization of resources over the duration of a given project.

As mentioned by Harris (1978), there are three advantages of resource leveling, which can be grouped as follows:

- The physical limits of the resources are achieved.
- Day-to-day fluctuations in resource demands are avoided.
- There is a smoother demand for each day and hence a uniform distribution of the utilization of resources is achieved.

In construction projects, which are basically large projects, the need for leveling is more prominent than in smaller projects because there is greater economic gain in making the adjustments (Harris 1978). In extensively large projects the need and so the quantity of the resources is quite big. So to obtain and operate these resources is a tough job and a project might fail if these resources are not utilized correctly and efficiently. Hence, many attempts and research have been done in order to develop methods to level these resources in the most optimum way including the development of heuristic processes that would lead to optimal results for leveling the resources.

2.7.3. Various Methods Proposed by Researchers for Leveling

Petrovic (1969) suggested a multistage dynamic programming approach to overcome the classic resource leveling problem. Ahuja (1976) later proposed a method that would minimize demands for resources from one period to the next by calculating all feasible combinations of activity start and finish times. Easa (1989) then offered a linear programming approach that would minimize any fluctuations from an average resource level. In the classic resource leveling problem the total squared utilization cost has to be minimum in order to achieve leveled resource consumption (Burgess and Killebrew 1962). This objective is of particular importance in resource leveling. Due to the combinatorial mathematics of this problem, exact approaches turned out to be suitable only for small projects with

10–15 activities. As a consequence, mostly heuristic approaches are found in the literature. Bandelloni, Tucci, and Rinaldi (1994) applied non-serial dynamic programming to find a minimum for the squared deviation from the average resource utilization. Alfares and Bailey (1995) presented a method to simultaneously determine the start dates, duration, labor needs and a reduced-cost and on-time schedule for a project. Leu, Yang, and Huang (1999) came up with a computational optimization technique using genetic algorithms (GAs) to overcome the constraints of a traditional resource leveling program. Genetic algorithms (GAs) provided an optimal combination of multiple project resources as well as the start and finish dates of activities. More recently, Neumann and Zimmermann (2000) have proposed several heuristic approaches suitable also for projects with general time constraints (Gather, Zimmermann, and Bartels 2010).

2.8. Summary of Previous Surveys

2.8.1. AASHTO Lead States Team Survey 1999

In 1999, the AASHTO Lead States Team surveyed DOTs in all 50 States, the District of Columbia, Puerto Rico, and six Canadian provinces on pavement preservation to determine the current state of practice of their pavement preventive maintenance (PPM) programs and practices (Lead States Team 1999). (Data collected from the provinces are not included here).

This survey was conducted to estimate the growth in pavement preservation programs since the previous survey by the Strategic Highway Research Program (SHRP) Lead State Team was conducted in 1996 (SHRP Lead States 1996). The survey asked each transportation agency whether it had a PPM program, what the age of the program was, what the budget allocated on an annual basis was, which preventive maintenance treatments were used, and at what pavement condition they were applied. A total of 41 States responded. Their summary is discussed briefly below:

- A total of 36 agencies had established preservation programs and two were in the process of developing programs.
- All 41 DOTs had begun using preventive maintenance treatments. For asphalt pavements, approximately 38 agencies used mill and overlay, and 33 used asphalt overlay. Also, 36 agencies used full-depth concrete pavement repair and concrete joint resealing for concrete pavements.
- 17 agencies out of 33 reported having a program for more than ten years.
- 20 agencies characterized the administration of their programs as centralized and decentralized. Out of which only six were centralized.
- 36 agencies out of 41 had a dedicated budget for pavement preservation, and eight had a budget of more than $75 million.

The Michigan DOT used a total of 25 preventive maintenance treatments. Other leading players were Minnesota, Georgia, Maryland and Wisconsin with 22 treatments each; Utah and Idaho with 21 treatments each; and California, Kansas and Texas with 20 treatments each. All of these treatments were combined for both asphalt and concrete.

2.8.2. Colorado Department of Transportation 2002

In January 2002, the Colorado Department of Transportation distributed a four-question survey on pavement management practices to the Materials Engineer in every state (Peshkin and Hoerner 2005). The questions asked about the size of the agency's pavement network, the annual surface treatment budget, the preventive maintenance budget, and the method used to allocate funds. Twenty-eight responses were received, and the average of those responses is presented below:

- The responding agencies were responsible for an average of 36,329 centerline miles.
- They spent an average of $164.4 million annually on surface treatments, or $3,516/centerline-km ($5,658/centerline-mile).
- The average annual preventive maintenance budget was $51.8 million.

2.8.3. NCHRP Project No. 20-07 by Peshkin, 2005 Survey

Many state highway agencies (SHAs) were in the process of developing and improving their pavement preservation programs. National Cooperative Highway Research Program (NCHRP) Project No. 20-07 addressed the needs of SHAs by preparing a questionnaire, which was distributed to all 50 state transportation agencies and four Canadian provinces. Thirty-three states and two provinces responded. This survey asked them about the current status of ongoing pavement preservation activities. A brief outline of the responses is summarized below:

- Of the 35 respondents, 30 stated that they had a pavement preservation program in place.
- Ten agencies out of 29 said that the program was more than ten years old.
- Six of the 31 responding agencies indicated that they were in the beginning stages of their programs; the other 25 had preservation programs that were well-established.
- 20 agencies responded out of 35, from which around six had a budget between $25 and $50 million. Seven had a dedicated budget for pavement preservation of more than $75 million.
- 11 of 21 DOTs indicated that their agency's programs were centralized, three reported that they were decentralized, and seven reported that they were a combination of the two.
- 24 agencies mentioned that they typically applied more than one preventive maintenance treatment before rehabilitation

- Agencies were asked under what circumstances they applied preventive maintenance treatments. Most of the agencies reported that they applied preservation techniques to reduce the rate of deterioration, to seal surfaces, to reduce water infiltration, and to increase smoothness. It is clear that most of the transportation agencies used maintenance treatments to extend the life of pavement through sealing and controlling moisture infiltration.
- The most frequently used treatments were diamond grinding, crack sealing, chip seal, and full-depth repair.

2.9. INDOT pavement preservation practices

INDOT has been implementing a Pavement Preservation Initiative (PPI) since 2009. The FY 2011 plan covers 1,726 lane miles of 103 road projects using $30.7 million. PPI treatments for asphalt surface pavements include crack sealing/filling, seal coating, micro-surfacing, ultrathin-bonded wearing course, and 4.75 mm HMA. INDOT developed treatment guidelines for pavement preservation and has been implementing the guidelines since 2010 (Lee and Shields 2010). The list of treatments in the guidelines is shown in TABLE 2.4.

INDOT uses the lane mile year concept to quantify the benefit of pavement preservation. In FY 2010, INDOT covered over 10,000 lane miles of pavement, from crack seal to reconstruction, for a total of over $355 million. Of that, 7,800 lane miles received preservation activities (crack sealing/filling and surface treatments) for a cost of $19 million. As of 2010, INDOT's overall pavement program had approximately 34,000 lane mile years (LMY) of life, while INDOT's preservation program was 14,000 LMY. This translates to a cost of $10,441/LMY for our overall program, while preservation was $1,357/LMY. This translates to $1 in preservation spending being worth $7.7 overall.

2.10. Conclusions

It is a well-documented fact that the cost of repairing pavement increases dramatically if maintenance is not done at the optimal time. The worst-first approach, which allows pavement to deteriorate excessively, is not recommended. A simple annualized cost comparison of various construction techniques, shown above, illustrates the importance of keeping pavement in good shape by utilizing routine and preventive maintenance measures.

Thus, pavement preservation gives highway agencies an economical alternative for addressing pavement needs. Moreover, with pavement preservation, highway agencies gain the ability to improve pavement conditions and extend pavement life and performance without increasing expenditures. The focus is on preserving pavement assets while maximizing the economic efficiency of the investment. Pavement preservation provides greater value to the highway system and improves the satisfaction of highway users. Pavement preservation is not about a single treatment, nor is it a one-size-fits-all philosophy. Instead, preservation must be tailored to each highway agency's system needs in the most cost-effective manner. This involves using a variety of treatments and pavement repairs to extend pavement life.

3. DATA COLLECTION

3.1. Introduction

This chapter illustrates the steps taken to collect the required data to satisfy the two objectives of this research. The data presented in this chapter documents the economic viability of pavement preservation and how other state DOTs quantify the benefits of pavement preservation. It also documents the funding allocated to pavement preservation as opposed to rehabilitation by different state DOTs.

Relevant data with respect to pavement preservation was solicited from all 50 state DOTs in the US and three Canadian provinces including Alberta, Saskatchewan and Manitoba. Data was collected with respect to various treatments applied to the pavement to prevent them from deteriorating, frequency of these applications, amount spent on these treatment applications, overall budget allocated for pavement preservation activities versus rehabilitation, and the means to document the benefits of pavement preservation. The subsequent tasks were executed in order to achieve the objectives stated above:

TABLE 2.4
List of pavement preservation treatments (Lee and Shields, 2010)

Asphalt or Composite Pavement	Portland Cement Concrete Pavement (PCCP)
• Crack Sealing/Routing and Filling	• Crack Sealing/Filling
• Fog Seal	• PCCP Joint Resealing
• Scrub Seal (Sand Seal)	• Retrofit Load Transfer
• Seal Coat (Chip Seal)	• Cross-stitching
• Flush Seal	• PCCP Profiling (Diamond Grinding)
• Microsurfacing	• Partial Depth Patching
• Profile Milling	• Full-depth Patching
• Thin Hot Mix Asphalt Overlay with Profile Milling (HMA Overlay)	• Undersealing
• Ultra-thin Bonded Wearing Course (UBWC)	
• Thin Hot Mix Asphalt Mill/Fill (Thin HMA Inlay)	

- Survey of all 50 state DOTs in the US and three Canadian Provinces.
- Telephone interviews with selected state DOTs from the US.

3.2. Survey

A survey was sent out to all 50 state DOTs within the United States to obtain data regarding their current state of practice in regards to pavement preservation and rehabilitation activities.

3.2.1. Objectives of Survey

The main objectives of the survey were to gather data with respect to:

- When they implemented pavement preservation
- Current state of practice of different state Dots regarding pavement preservation activities
- Different pavement preservation treatments, year initiated, and typical frequency of treatment application
- Annual funding dedicated to these prescribed treatments
- Methods used to determine user costs for Life Cycle Cost Analysis
- Method used to measure or quantify the benefits of pavement preservation

A copy of the survey questions can be found in Appendix A. All the questions were reviewed by the Study Advisory Committee (SAC) members with respect to the two research objectives before it was sent out to state DOTs. Various pavement preservation engineers and state research engineers participated in this survey.

The survey was mainly divided into two parts, and each part targeted and addressed one of the research objectives. The first part of the questionnaire asked about the state of practice, including the pavement preservation treatments and their benefits over the service life of the pavement, and how preservation increased the life of the pavement by improving its condition. The second part included questions about the budget for these treatments.

3.2.2. State of Practice for Pavement Preservation

In the first part of the questionnaire all the state DOTs were asked two basic sets of questions which fell under the following two topics:

- The state of practice of their pavement preservation programs
- The methods they used to quantify the benefits of pavement preservation

States that have a pavement preservation program were required to follow the set of questions including age of program, treatments used, frequency of application, and procedure for documenting the benefits of pavement preservation. If the age of the program was known, then it could be easily determined of how they have evolved over the years in terms of practicing pavement preservation. It was important to know how various DOTs calculated the benefits of preservation and to further document those benefits. This could assist in justifying continuous budget allocation for pavement preservation activities.

3.2.3. Budget allocation for preventive maintenance treatments

The second part of the questionnaire addressed budget allocation and included questions such as:

- Does your state assign a dedicated budget for the pavement preservation program?
- Which treatments are used for preventive maintenance?
- When were treatments initiated, and what was the frequency of application thereafter?
- What is the level of annual funding dedicated to these treatments?

Lists of treatments were identified based on the literature and are shown in TABLE 3.1. Depending on pavement type, agencies were asked to check all the treatments that they applied to their pavement as well as their expected service lives. In addition, there were two more columns in the questionnaire that requested information about their initial treatment year and the typical frequency of each treatment, which together indicate the life expectancy of each treatment.

During one of the review meetings, the SAC recommended the inclusion of questions about user costs and methods to calculate them, as these data play a significant role in the Life Cycle Costs Analysis (LCCA) calculations.

3.2.4. States Divided into Regions

For simplicity and standardization purposes, all 50 States were divided into regions. This was adopted from NCPP. In the analysis section, comparison is made

TABLE 3.1
Treatments applied on Pavement Surfaces

Asphalt	Concrete
Asphalt Overlay	Crack Sealing and Filling
Chip Seal	Cross-stitching
Cape Seal	Diamond Grinding
Crack Sealing and Filling	Drainage
Cold in Place Bituminous Recycling	Dowel Bar Retrofit
Hot in Place Bituminous Recycling	Joint & Surface Spall Repair
Hot Chip Seal	Partial/Full Depth Patching
Flush Seal	Joint Resealing
Fog Seal	Slab Stabilization
Microsurfacing	
Ultrathin bonded wearing course	
Sand Seal	
Slurry Seal	
Scrub Seal	
Shoulder Seal	
Thin HMA Milling	
Thin HMA Milling and Filling	

TABLE 3.2
Regional Pavement Preservation Partnerships

Midwestern	South-eastern	Western	Rocky Mountain	Northeast	Canadian Provinces
Indiana	Alabama	California	Alaska	Connecticut	Alberta (MW)
Minnesota	Arkansas	Hawaii	Arizona	Delaware	Saskatchewan(MW)
Michigan	Florida	Oregon	Colorado	Massachusetts	Manitoba (MW)
Missouri	Georgia	Washington	New Mexico	Maryland	Nova Scotia(NE)
Kansas	Kentucky		Idaho	N. Hampshire	British Columbia
North Dakota	Louisiana		Nevada	New Jersey	
Nebraska	Mississippi		Texas	New York	
Iowa	N.Carolina		Montana	Pennsylvania	
Ohio	S.Carolina		Utah	Rhode Island	
Illinois	Tennessee		Wyoming	Vermont	
South Dakota	Virginia			Maine	
Wisconsin	West Virginia				
	Louisiana				

SOURCE: THE NATIONAL CENTER FOR PAVEMENT PRESERVATION
http://www.pavementpreservation.org/partnerships/

between the NCPP survey results and the results from this research.

States have been grouped into five regions, as shown in TABLE 3.2. The Canadian provinces were shown in a different column; however, according to NCPP they fall into one of two regions and so their respective region is shown in parentheses.

3.2.5. Conclusions

This survey went through a number of reviews by the research team and the SAC. All comments and recommendations were incorporated and finally sent out to 50 state DOTs and three Canadian provinces. Out of 50 DOTs, 26 state DOTs and one Canadian province responded, resulting in a response rate of approximately 50%. A detailed analysis of the responses is provided in the data analysis chapter.

3.3. Telephone Interviews

3.3.1. Introduction

After evaluating responses to the survey, telephone interviews with several state DOTs were conducted to obtain a more detailed understanding of their current state of practice in regards to pavement preservation activities. These interviews were conducted to determine their current status of pavement preservation, its benefits, budget allocation for preservation activities, and to determine who made these funding decisions, how many funds were allocated and how, and finally what barriers existing to allocating such funds. Telephone interviews provided the research team deeper insight into these issues that could be considered by INDOT in regards to their own pavement preservation program. This exercise of conducting telephone interviews yielded a great deal of information on the many details related not only to preservation activities but also rehabilitation and reconstruction, and various policies adopted by other state DOTs.

3.3.2. Candidates for Telephone Interview

As mentioned earlier, a total of 26 responses were received. Candidates for the telephone interview were identified by the research team and SAC members after a thorough analysis of the survey. Candidates for the telephone interview are shown below in TABLE 3.3.

Three candidates were chosen from the Midwestern region because of the similarities in geography and weather conditions. Two candidates from the Western region were selected because of their action plans for pavement preservation and because they had already been practicing preservation activities for a long time. One state each was selected from both the Rocky Mountain and Northeast regions.

All these decisions were made based on the experience of SAC members, their recommendations, responses received to the survey and the State DOTs involvement in preservation activities, the age of DOT's pavement preservation program as well as analysis of the survey and literature review conducted by the research team.

3.3.3. Questions for Interview

In order to collect data regarding the benefits of pavement preservation and budget allocation a base set of questions was asked of all the interviewees. The list of questions is provided in the Appendix B. Overall, the questionnaire used for the interviews was divided into three segments, as shown below,

TABLE 3.3
Selected state dots for telephone interviews

Midwestern	Western	Rocky Mountain	Northeast
Indiana	California	New Mexico	Maryland
Michigan	Washington		
Minnesota			

General Information

According to FHWA (as discussed earlier in the literature review), pavement preservation is divided into three main categories: routine maintenance, minor rehabilitation, and preventive maintenance. However, it was evident from both the interviews and the responses to the survey that not every state followed the same definition.

Pavement preservation includes a large spectrum of topics and every state may use a variation of the FHWA definition. To ensure that every state was compared on the same base, interviewees were asked to define new pavement and major rehabilitation as per the definition used by their State DOT. In addition, they were asked about the type of their pavement and how many lane miles they preserved.

Economic Viability of Pavement Preservation

Interviewees were asked about the methods they used to calculate the pavement preservation benefits they experienced over the life of the pavement.

Methodology for INDOT Budget Allocation for Pavement Preservation

With respect to the second objective of budget allocation a range of questions were asked. According to the literature review, lists of treatments were identified for both asphalt and concrete pavements. Depending on the pavement type, agencies were asked to mark all of the treatments they applied to their pavement as well as their expected service lives. In addition, there were two more columns in the questionnaire to document their initial treatment year and the typical frequency of each treatment. This information was obtained from the questionnaire that was sent out before conducting the telephone interviews. In accordance with their responses, interviewees were then asked how they established trigger points to help them make decisions regarding when to apply treatments. The initial year and frequency of an application would establish the expected life of the treatment and also of the pavement. A brief description of the questions asked is tabulated below; the questions are discussed in detail in the analysis chapter.

TABLE 3.4
Data collected from Mid Western state DOTs

No.	Question	Indiana	Michigan	Minnesota
	General Information and Objective 1: To document the economic viability of pavement preservation			
1.	Included in the pavement preservation program?	Routine Maintenance (RM) Preventive Maintenance(PM) Minor rehab (MR)	Pavement maintenance can be classified into 3 groups: Preventive, Reactive, and Routine Maintenance.	NA
2.	Define: New Pavement Major Rehab	New modernized interchanges/ New alignment Pavement replacement and reconstruction		Pavement replacement and reconstruction
3.	Type of pavement?		10,800 (Asphalt) 5,750 (Concrete) 11,800 (Composite)	6600 (Asphalt) 4500 (Concrete) 18000 (Composite)
4.	Lane miles preserved?	1300–1400	4000	570
5.	Method to measure the benefits of PP?	Lane-mile years	Road Quality Forecasting System (RQFS)	Based on the area between the projected curves conditions with and without treatments.
	Objective 2: To develop a methodology for INDOT to determine the amount of funding that should be dedicated to preservation			
1.	Method of establishing trigger point (e.g., IRI, OPI) to decide frequency and initial year of application?	There are guidelines for Asphalt pavements, of age (8–12 years) and roughness (IRI $<$ 130).Then they use PMS to screen out the candidates meeting these criteria	Guidelines	Decision trees
2.	Method of determining budget for PP vs. RR? Authority charged with decision?	Needs are submitted by Districts which goes to the Roadway Asset Committee and executive staff who then make the decision of how much to allocate the funds	Software called Road Quality Forecasting System	A means process
3.	Budget for PP vs RR?	$136M $18M	$375M $91M	No specific budget PP: $23M
4.	Budget allocation: project or network level?	Network level	Both	Project level
5.	Source of money (federal vs. state)?		Fed: 80% State: 20%	

3.3.4. Data Collected

Midwestern State DOTs

TABLE 3.4 illustrates the data collected from interviewees from Midwestern state DOTs. (The first column shows the questions and the second column shows the responses collected from them.)

Data collected from north east State DOTs (Table 3.7)

3.4. Conclusions

All the data has been briefly discussed in this chapter. A detailed analysis of responses to the survey and responses from telephone interviews are discussed in Chapter 4.

4. DATA ANALYSIS

4.1. Introduction

The collected data was analyzed to determine the economic viability of pavement preservation and how much budget has to be allocated to preservation activities as opposed to rehabilitation activities. In addition to this, the history of pavement preservation in a particular state, current state of practice in preserving pavement, different treatments and the typical frequency of those treatments, annual funding for these treatments and methods to quantify the benefits of pavement preservation activities were also identified. In the end, recommendations were formed on the basis of the analysis that INDOT could incorporate in their future work. The entire chapter is divided into two parts:

- Analysis of responses to survey
- Analysis of responses to telephone interviews

The following subsections provide a detailed subjective and comparative analysis with respect to the collected data.

4.2. Analysis of Responses from Survey

This subchapter presents a detailed analysis of the current state of practice of different DOTs throughout the US. As discussed in the survey, the response rate for this survey was approximately 50%. A total of 26 DOTs responded to the survey.

TABLE 3.5
Data collected from Western State DOTs

No.	Questions	California	Washington
	General Information and Objective 1: To document the economic viability of pavement preservation		
1.	Included in pavement preservation program?	Maintenance: (Contract Maintenance): Base and preventive maintenance Minor Rehab: Capital Preventive Maintenance(CAPM) Minor Rehabilitation is what they call as CAPM for Capital preventive maintenance within their capitally funded projects, along with Roadway Rehabilitation.	Preventive maintenance and Rehab included
2.	Define: New Pavement Major Rehab	Lane or entire roadway additions, totally new alignments or routes/ roadways. Work undertaken to overhaul/renovate an existing roadway to latest standards w/an expected service life of 20 years.	New alignment Removing/replacing/ resurfacing the entire pavement
3.	Type of pavement?	33,000 (Asphalt) 16,000 (Concrete)	11,638 (Asphalt) 2,422 (Concrete) 4,425 (Chip Seal)
4.	Lane miles preserved?	2700	
5.	Method to measure the benefits of PP?	Benefits/costs ratio GIS pictures	Annualized Costs
	Objective 2: To develop a methodology for INDOT to determine the amount of funding that should be dedicated to preservation		
1.	Method to establish trigger point (e.g., IRI, OPI) to decide frequency and initial year of application?	IRI (International Roughness Index) RQI(Ride Quality Index) Guidelines and Decision trees	Guidelines
2.	Method of determining budget for PP vs. RR? Authority charged with decision?	Needs are submitted by Districts, which goes to the Caltrans. Caltrans then make a decision of how much to allocate the funds. PMS	PMS
3.	Budget for PP vs RR?	Maintenance: $71M Minor Rehab(CAPM): $180M Rehab: $1,089M	11–13 Biennium is currently $292.6 million
4.	Budget allocation: project network level?	Network/ Statewide level	Project level
5.	Source of money (federal or state)?	Fed: 85% State: 15%	Fed: 86% State: 14%

TABLE 3.6
Data collected from Rocky Mountain State DOTs

No.	Questions	New Mexico
	General Information and Objective 1: To document the economic viability of pavement preservation	
1.	Included in pavement preservation program?	Routine Maintenance (RM) Preventive Maintenance(PM) Minor Rehab (MR)
2.	Define: New Pavement Major Rehab	New alignment Removing/replacing/resurfacing the entire pavement; "structural enhancements that extend the service life of an existing pavement and/or improve its load carrying capacity. Rehabilitation techniques include restoration treatments and structural overlays."
3.	Type of pavement?	94% (Asphalt) 5% (Concrete) 1% (Composite)
4.	Lane miles preserved?	27,853
5.	Method to measure the benefits of PP?	Annualized Costs
	Objective 2: To develop a methodology for INDOT to determine the amount of funding that should be dedicated to preservation	
1.	Method to establish trigger point (e.g., IRI, OPI) to decide frequency and initial year of application?	Guidelines and Decision trees
2.	Method to determine budget for PP vs. RR decided? Authority charged with decision?	American Recovery and Reinvestment Act of 2009 (ARRA) governs distribution formulas and overall spending
3.	Budget for PP vs RR?	$58,406,036 for PP (2009) $31,158,943 rehab (2010)
4.	Budget allocation: project network level?	Network level
5.	Source of money (federal or state)?	Fed: 50% State: 50%

TABLE 3.7
Data collected from Northeast State DOTs

No.	Questions	Maryland
	General Information and Objective 1: To document the economic viability of pavement preservation	
1.	Included in pavement preservation program?	Routine Maintenance (RM) Preventive Maintenance(PM) Minor rehab (MR)
2.	Define: New Pavement Major Rehab	Newly constructed Grade increases by more than 1.5" from overlay or grind/overlay.
3.	Type of pavement?	60% (Asphalt) 1% (Concrete) 39% (Composite)
4.	Lane miles preserved?	1,000–1,200
5.	Method to measure the benefits of PP?	Lane mile years
1.	Method to establish trigger point (e.g., IRI, OPI) to decide frequency and initial year of application?	Decision trees
2.	Method to determine budget for PP vs. RR? Authority charged with decision?	Software: Road care by ARA (Applied Research Associates)
3.	Budget for PP vs RR?	Projected for 2012–2016 at $180M/year Rehab: 65% PP: 35%
4.	Budget allocation: project or network level?	Network
5.	Source of money (federal or state)?	Fed: 80% State: 20%

FHWA's Office of Asset Management began conducting comprehensive technical interviews in 2005 with the help of NCPP and is continually formulating evaluations of individual state DOT pavement preservation programs. These results from NCPP were considered as a base of comparison for the responses collected from various DOTs through the survey conducted for this research. However, not all the questions in the appraisal were similar to the questions that were asked in the questionnaire or interviews. Therefore, only the similar questions were taken as a base of comparison.

4.2.1. Preliminary Information

Following is the data analysis of the data collected from the Survey and each question asked is discussed in detail. First, the participants were asked two basic set of questions which are:

- If State DOTs had pavement preservation in place or not
- If yes to the first question, then how long their State's preservation program has existed.

Use of Pavement Preservation

Twenty-four state DOTs (92%) mentioned that they had pavement preservation in place. Only two state DOTs (8%) mentioned that they did not yet have pavement preservation in place.

TABLE 4.1 shows the DOTs that do or do not have pavement preservation in place. All states from the Midwest, West, Rocky Mountain, and Northeast regions had pavement preservation in place. However, two states from the Southeast region did not have a formal pavement preservation program or a defined policy or direction in place.

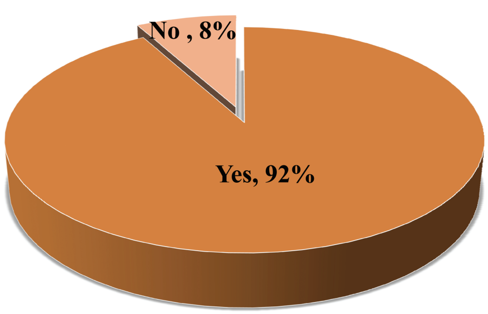

Figure 4.1 DOTs having formal pavement preservation in place

TABLE 4.1
DOTs having formal pavement preservation in place

Regions	DOTs having PP in place	DOTs with no PP in place
Midwest	IN, IL, MN, MI, MO, KS	
West	CA, OR, WA	
Rocky Mountain	AL, CO, NM, TX, UT	
Southeast	FL, MS, VA, LA	WV, AR
Northeast	MD, NJ, NY, ME, PA	

Survey Results from FHWA's Technical Appraisal

According to the results obtained from the FHWA technical appraisal system, all state DOTs from the Western region have pavement preservation programs in place. Around 57% of state DOTs from the Rocky Mountain and Midwest regions have pavement preservation in place. The Southeast and Northeast had the fewest number of states with pavement preservation in place.

In addition, when comparing the above results to the Survey, there were two states that did not have a preservation program in place, both of which fall into the Southeast region. According to the FHWA technical appraisal system, around 56% of DOTs from the Southeast do not have formal pavement preservation in place. Thus, the research team decided not to interview a state from the Southeast region.

Age of Pavement Preservation

Interview candidates were asked how long their pavement preservation programs had existed. As shown in the graph below, 52% of DOTs said that their programs had existed for 1–10 years, 20% for 10–20 years, 24% for more than 20 years, and 4% of the respondents did not know the life of their pavement preservation programs.

State DOTs like those in Kansas, California, Washington, Utah, Florida and Maine become prominent, as they have practiced pavement preservation activities for more than 20 years. Thus, these state DOTs were considered to be the leading players in pavement preservation and were considered for telephone interviews.

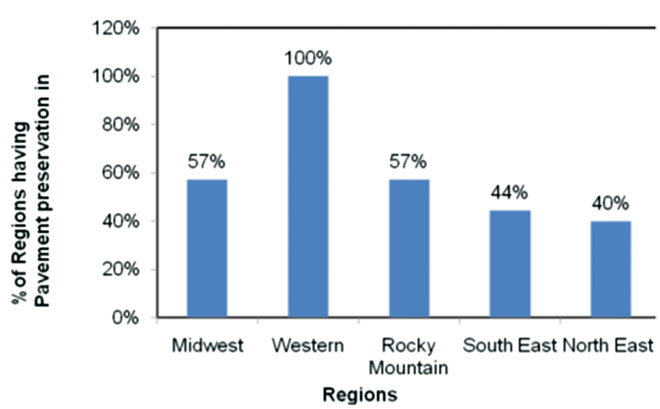

Figure 4.2 Agency having a formal pavement preservation program, or a defined policy in place (FHWA technical appraisal, 2005-present. to date, 42 DOTs have responded and the interview process is still going on.)

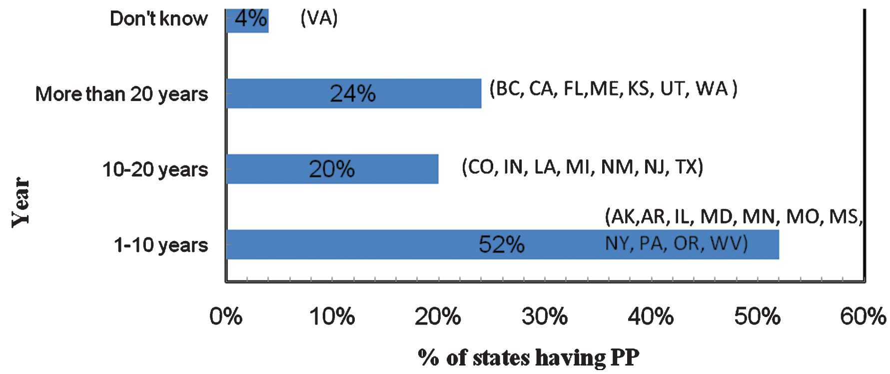

Figure 4.3 Age of pavement preservation programs

TABLE 4.2
Age of pavement preservation programs

Regions	1–10 yrs	10–20years	>20 years	Do not know
Midwest	IL, MO, MN	IN, MI	KS	
West	OR		CA, WA	
Rocky Mountain	AK	CO, NM, TX	UT	
Northeast	MD, PA, NY	NJ	ME	
Southeast	AR, MS, WV	LA	FL	VA
Canadian Provinces			BC	

4.2.2. Budget Allocation

Since most of the states had been practicing pavement preservation for some time, it was important to know whether they had a budget dedicated to these activities and also how they allocated budget for preservation activities and/or what trends they had followed over the years. The next set of questions targeted these questions.

Dedicated Budget

Around 60% of DOTs said that they had a specific budget, and 40% reported that they did not have a specific budget for their pavement preservation program. The results presented in TABLE 4.3 indicate that most of the states from the Midwest, West and Rocky Mountain regions had a set budget for pavement preservation while the majority of states from the Northeast and Southeast did not.

After reviewing the first three basic questions regarding pavement preservation, it was determined that states from the Midwest, West and Rocky Mountain regions had pavement preservation guidelines or directions in place for more than 10 years and also had a dedicated budget for pavement preservation. Considering the status of pavement preservation and their current state of practice, focus was concentrated on states from the Midwest, West and Rocky Mountain regions.

Types of Preventive maintenance Treatments

After focusing on the fundamentals of pavement preservation, questions were asked on the treatments applied. A list of the most commonly used treatments is given in chapter 2 of this report. A question was included in the survey about the treatments used by states for preservation activities. As a part of this analysis, the Indiana DOT was kept as a base and other states' practices were compared to those of Indiana in table 4.5

The graph (Figure 4.5) above shows that asphalt overlay is the most fundamental treatment being used by 21 agencies. Other treatments like crack sealing and filling, chip seal, and partial/full-depth repair were also commonly used treatments. INDOT currently uses

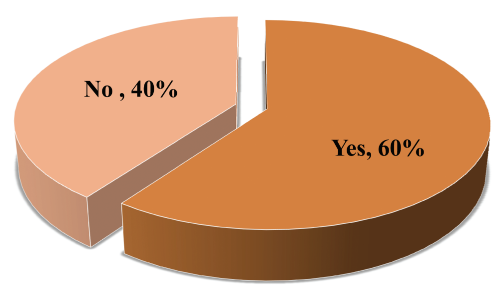

Figure 4.4 Budget allocations for pavement preservation

TABLE 4.3
Budget allocations for State DOTs

Regions	DOTs having dedicated budget	DOTs not having dedicated budget
Midwest	IN, IL, MI, MO, KS	MN
West	CA, OR, WA	
Rocky Mountain	AL, UT, TX	NM, CO
Southeast	Mississippi, Louisiana	AR, FL, VA, WV
Northeast	Maryland, Maine	NY, NJ, PA
Canadian Provinces	British Columbia	

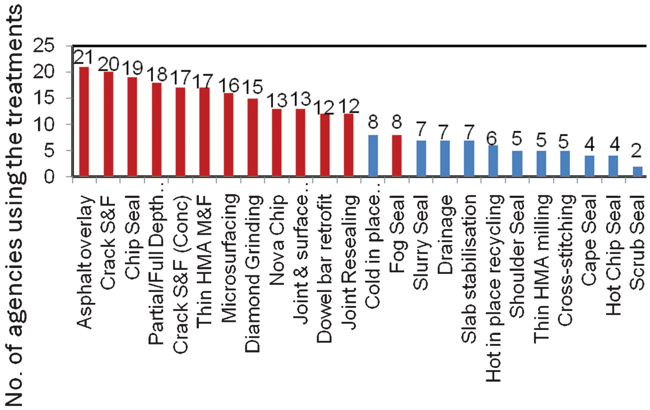

Figure 4.5 Treatments used for pavement preservation

asphalt overlay, chip seal, crack sealing and filling, partial and full-depth patching, thin HMA, microsurfacing, diamond grinding, Ultrathin bonded wearing course, joint and surface spall repar, dowel bar retrofit, joint resealing and fog seal. These treatments were used by most of the other agencies as well.

Budget Allocated for Treatments

Since lane-mile costs are associated with each treatment, interviewees were asked about the budget they allocated to preventive maintenance treatments. The following results were obtained.

As depicted in the table above, responses were quite scattered. States from all regions had a funding spread from less than $10M to more than $100 M.

4.2.3. Life Cycle Cost Analysis (LCCA)

The next question asked of the candidates dealt with Life Cycle Costs Analysis (LCCA). According to the FHWA, "LCCA is an engineering economic analysis tool that allows transportation officials to quantify the differential costs of alternative investment options for a given project" (FHWA Asset Management 2005). LCCA is thus an approach that offers a sophisticated method to determine the economic viability of selected alternatives in an analytical manner. In this particular case, LCCA is not only used to analyze the economic viability of new construction projects but also to examine preservation strategies for current transportation projects. This method can identify the alternative

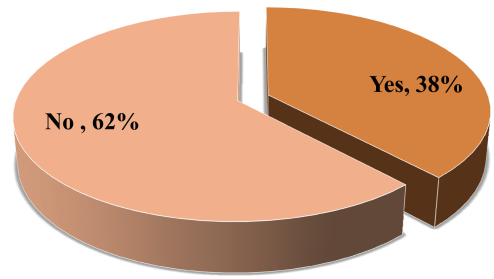

Figure 4.6 Agencies using User Costs for computing Life Cycle Cost Analysis

with the lowest total cost to the highway agency over the entire life of the project. LCCA considers all agency expenses and user costs throughout the life of any alternative, including initial investments. LCCA also helps transportation agencies to study the user cost impacts of different preservation strategies.

Inclusion of User Costs for LCCA

Participants were asked if they considered user costs for Life Cycle Cost Analysis. Around 38%, or 10 DOTs, said that they do employ user costs for LCCA, and 62%, or 16 DOTs, said that they did not employ user costs for LCCA.

This results reveal that there are very few states who employ user costs in LCCA. Not much information was obtained from this question.

User Costs for LCCA

States were asked about the methods by which they calculated user costs. Only four DOTs out of 26 responded to this question. Various methods described are as provided in FIGURE 4.7.

TABLE 4.5
DOTs using User Costs for LCCA calculations

Regions	Yes (Agencies using user costs)	No (Agencies not using user costs)
Midwest	MI, MN	IN, IL, MO, KS
West	WA	CA, OR
Rocky Mountain	CO, NM	AK, TX, UT
North east	MD, PA	ME, NY, NJ
Southeast	FL, VA	AR, LA, MS, WV

TABLE 4.4
DOTs having dedicated budget

Regions	<$10M	$10-$25M	$26-$50M	$51-$75M	$75-$100M	>$100M
Midwest	IL	MN, IN	MO	N.A.	MS, MI	
West	OR					CA, WA
Rocky Mountain	AK		NM, UT, TX			CO
Northeast	NJ		ME		PA	MD, NY
Southeast	WV	AR	LA			FL, VA
Canadian Provinces						BC

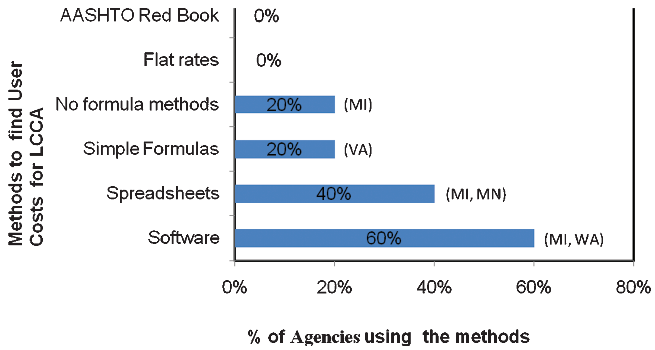

Figure 4.7 Methods and number of Agencies using those methods to calculate LCCA

Most DOTs (60%) used software to calculate user costs and around 40% used spreadsheets. The other 20% used simple formulas or no formula methods to calculate user costs. As shown in Figure 4.7, the Michigan DOT used various methods to calculate user costs. Also, MDOT mentioned that user costs were considered when setting up projects, but that there was no documented Life Cycle Cost Analysis (LCCA) for pavement preservation projects. On larger rehab and reconstruction projects (paving costs over $1 million), MDOT is required by law to perform a LCCA that takes into account pavement preservation cycles.

In addition to this, all State DOTs were also asked what percentage of user costs was included in the LCCA. The following responses were received:

- 0%: MN, VA
- 100%: WA, PA
- Depends on project/ Varies: NM, MA, CO

Very few states participated in this set of questions, and not enough information was gained. Only a few states like Michigan, Minnesota, Washington and Pennsylvania shared their method of calculating user costs for LCCA.

4.2.4. Methods to Quantify Benefits

The candidates were asked how they quantified the benefits of pavement preservation. Only 7 out of 26 responded to this question. Few methods were identified as a result of the analysis of the responses to the Survey. Generally, the benefits were either measured in terms of the increase in the life of the pavement or the reduced costs that an agency invests in preserving the pavement as opposed to rehabilitation activities. A brief description of all the methods is given below.

- Lane-Mile Years: Lane-mile years is a measure of the effect pavement treatment has on the overall network. By taking the overall cost of the treatment and dividing by the lane-mile-years one can compare the relative costs of disparate treatments like resurfacing and preservation. Maryland and Indiana uses lane-mile years as a measure to quantify the benefits of preservation activities.
- Highway Health Index: This is an index that ranges from 0 to 100, with a value of 0 indicating a bridge with all of its elements in the worst defined condition and a value of 100 indicating a bridge with all of its elements in the best defined condition. Louisiana utilizes this index to judge whether preservation activities are improving their highway health index or not.
- Annualized Costs: A term called Uniform Equivalent Annual Costs is often used as a decision making tool in capital budgeting for project life spans and the investments made on them. Put more simply, every project has a different life span and the investment is also different; thus, if all the projects have to be compared over a common scale for the entire life cycle then Annualized Costs are used. Basically, annual costs represent the annual equivalent of all costs converted to either present or future value. This is used to compare investment in pavement preservation versus rehabilitation options. Annualized Costs are calculated for both preservation and rehabilitation activities. Studies and reports show that New Mexico and Florida have been able to quantify the benefits of preservation activities with the help of this method.
- Forecasting System: Michigan uses a Road Quality Forecasting System (RQFS) that helps them to identify the benefits or life gained as a result of pavement preservation activities.
- Software/Models: Maine uses dTIMS software to calculate benefits based on improvement in the overall Pavement Condition Rating (PCR) and AADT (the number of vehicles that experience improved PCR). Indiana also uses dTIMS software for the same purpose. The New York DOT uses extensive modeling that illustrates that preservation is less expensive and provides better conditions than worst-first and other permutations.

4.3. Analysis of Responses from Telephone Interviews

4.3.1. Introduction

As mentioned in the data collection chapter, telephone interviews with state DOTs were conducted to gain a detailed understanding of their current status of pavement preservation, its benefits, methods to evaluate those benefits, budget allocation for preservation activities, the authority charged with making funding decisions, and the amount and method of funds allocated. This data was then analyzed to determine the economic viability of pavement preservation as well as how much budget needs to be allocated to preservation activities, the two main objectives of the research. As mentioned earlier, a total of 26 responses were received from Survey, and after studying those responses thoroughly, seven candidates were chosen for telephone interview. The list of candidates is provided below.

4.3.2. Preliminary Information

According to the FHWA, and as discussed earlier in the literature review, pavement preservation is divided into three main categories: routine maintenance, minor rehab, and preventive maintenance. However, not every state defined these categories in the same manner. Each

TABLE 4.6
Selected DOTs for telephone interview

Midwest	West	Rocky Mountain	Northeast
Indiana Michigan Minnesota	California Washington	New Mexico	Maryland

telephone interview candidate was asked about the activities included in their pavement preservation program. Indiana, New Mexico and Maryland DOTs defined pavement preservation in the same way as the FHWA. In Michigan pavement maintenance can be classified into three groups: preventive, reactive, and routine maintenance. The California DOT includes both base and preventive maintenance under the maintenance heading. In addition, they defined minor rehabilitation as CAPM (Capital Preventive Maintenance) within their capital projects, along with roadway rehabilitation. These separate programs constitute Caltrans' pavement preservation program. The Washington DOT includes both preventive maintenance and rehabilitation in their pavement preservation program. However, routine maintenance is not included in Washington DOT's program.

Just as every DOT had a different way of defining their pavement preservation program, new pavement and major rehabilitation also had a variety of definitions. All DOTs defined new pavement as lanes or entire roadway additions, totally new alignments or routes/roadways. Major rehabilitation referred to structural enhancements that extend the service life of an existing pavement and/or improve its load-carrying capacity. Rehabilitation techniques included restoration treatments and structural overlays. Major rehabilitation was defined by a few other state DOTs as work undertaken to overhaul or renovate an existing roadway, or even as resurfacing the entire pavement. The Maryland DOT defined major rehabilitation as an increase in the grade of more than 1.5" from overlay or grind/overlay.

4.3.3. Total Lane Miles

The next question asked of DOTs was how many lane miles they had and also how many they preserved. The following information was obtained. As seen in FIGURE 4.8, the California DOT had the highest number of lane miles, followed by Minnesota and then Michigan. Also, the highest number of lane miles preserved, apart from Indiana's 7,000, was Michigan's 4,000 lane miles followed by California's 2,700 lane miles.

4.3.4. Methods to Quantify Benefits

The first objective of the research was to determine how DOTs calculate and document the benefits of pavement preservation. According to the FHWA, there are four criteria on the basis of which the benefits of pavement preservation are quantified as shown in TABLE 4.7. These four criteria are:

- Extension in the life of the pavement
- Performance
- Costs involved in applying preventive maintenance treatments
- Cost effectiveness

The average among U.S. DOTs reveals that only about 5% extensively evaluate criteria for tracking the benefits of pavement preservation. More than 60% of DOTs interviewed by the FHWA do not track the benefits gained in terms of life extension and cost effectiveness. However, performance is tracked extensively for about 5% and treatment costs by only about 7%. However, a majority of DOTs do not track or quantify the benefits of pavement preservation.

Generally, the benefits are either measured in terms of an increase in the life of the pavement or in terms of reduced costs that an agency invests in preserving the pavement as opposed to rehabilitating it. The methods used by the DOTs were briefly described in the previous chapter. Those DOTs interviewed over the telephone are discussed in detail below.

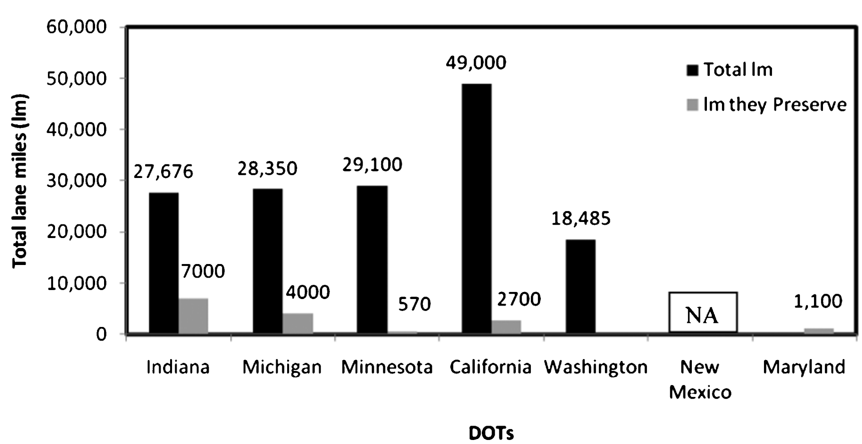

Figure 4.8 Total lane miles preserved by DOTs

TABLE 4.7
Tracking the pavement preservation criteria

National Results	Not Tracked	Little	Somewhat	Moderate	Extensively
Life Extending Benefits	63.4%	17.1%	7.3%	4.9%	
Performance	46.3%	26.8%	12.2%	9.8%	4.9%
Treatment Costs	24.4%	26.8%	24.4%	17.1%	7.3%
Cost Effectiveness	73.2%	14.6%	4.9%	4.9%	2.4%

(FHWA Technical Appraisal System, http://www.pavementpreservation.org/survey)

The Michigan Department of Transportation uses a Road Quality Forecasting System (RQFS). RQFS is a strategy analysis tool used to project the results of pavement rehabilitation policies. However, MDOT uses the same tool to project the conditions of the pavement after applying preservation techniques. In order to calculate the condition of the pavement, MDOT uses a measuring index known as Remaining Service Life (RSL). RSL is basically calculated from the pavement distress data obtained by examining the type and quantity of the cracks in the pavement. Thus, the current pavement condition, age, and repair strategies are entered into the RQFS. Michigan DOT maintains all this information in an inventory of pavement data which is updated on a two-year cycle. This database helps the RQFS to estimate the future condition of a pavement network and can predict the performance of the pavement once the preservation techniques are applied. The standard to which this is done is defined by the Michigan State Transportation Commission (Transportation Asset Management, MDOT). Thus, RQFS helps MDOT identify the benefits/life that the pavement has gained as a result of pavement preservation activities.

The Indiana and Maryland Departments of Transportation quantify the benefits of pavement preservation in terms of lane-mile years. Any present or planned project actions, like reconstruction, rehabilitation and preservation, will produce a net enhancement in the condition of the pavement or network (Galehouse 2009). In order to measure this improvement in the pavement a term known as lane-mile years is used by DOTs like Indiana and Maryland. Mathematically, lane-mile years represent the pavement's design life in years multiplied by the total lane miles of a network. However the way it is perceived is to see whether the pavement had shown a significant improvement after the preservation treatments. Suppose the agency's network consisted of 1,000 lane-miles and for one year no preservation activity was performed. According to the definition, the network would lose 1,000 lane-mile years at the end of first year. However, to avoid this amount of deterioration, if the agency performed preservation equal to or more than the total number of lane-miles, then that number would equal improvement in the network. Thus, the measurable gain of pavement life can be thought of as the network's total lane-miles multiplied by one year; that is, lane-mile years (Galehouse 2009).

The New Mexico and Washington Departments of Transportation use Equivalent Annual Costs as a decision-making tool in capital budgeting for different project life spans and the investments made on them. To compare the costs involved in preservation versus rehabilitation activities, NM and WA DOT use annual costs as a common scale for the entire life cycle of a pavement. They calculate the annual costs by dividing the present value of all costs by the annuity factor for the life of the project. This should then reveal whether the costs of preservation will be less than those for rehabilitation. New Mexico and Washington have been able to accurately quantify the benefits of preservation activities with the help of this method.

4.3.5. Budget Allocation

Each DOT has a different way to allocate the budget for pavement preservation and rehabilitation. Therefore, all the candidates were asked about how the decision for budget allocation for preservation versus rehabilitation was made and who was responsible for making these decisions.

The Minnesota Department of Transportation uses a decentralized funding system that allocates funds to all districts. Districts are further responsible for utilizing the funds for expansion and repair. Due to their decentralized process, they do not have any additional central fund for pavement preservation activities. However, they have funds for bridge repair, which are used for preventive maintenance activities. Each district reports how much they need for preventive activities, documented in the form of a report which first goes to the commissioner and then to the legislature for the final approval.

At the **Indiana Department of Transportation** these decisions are made by the executive staff. Initially, districts submit their needs together. Then the Roadway Asset Committee (RAC) evaluates all the facilities and assigns a ranking to each project, at which point the executive staff decides which projects to approve. The budget is established for the entire INDOT, and once the facilities are selected, the budget is divided among the associated districts.

The Michigan Department of Transportation has separate budgets for rehab and reconstruction and for pavement preservation, just as they have separate budgets for their safety program, bridge program, etc. Pavement engineers work with the districts to evaluate the condition of the roads and to determine the allocation of funds.

The California Department of Transportation establishes each district's share of the statewide pavement rehabilitation and preservation budget according to the needs identified through the pavement condition survey. Allocations are calculated for major rehab and preventive maintenance along with base (corrective) maintenance. This assessment of pavement needs is used to develop the fund estimate for the new State Plan (SHOPP). Districts prepare scoping documents for their respective projects and submit them to Caltrans HQ Programming. Once they know how big the pavement budget is (for both maintenance and SHOPP projects), they allocate the funds according to each district's share of the distress. By evaluating the maintenance project candidates and SHOPP scoping documents, they decide which projects should go forward.

In the **New Mexico Department of Transportation**, districts make decisions regarding rehabilitation, reconstruction, and preservation. NMDOT does not work strictly on triggers; instead, they rehabilitate, reconstruct, and/or preserve as funds become available.

The Maryland Department of Transportation has Chief engineers who present their needs to the districts. The division then runs through the software Road Care by ARA (Applied Research Associates), which will provide a fixed budget to be distributed among the districts, which then decisions where the money should go (i.e., rehab versus pavement preservation).

The Washington Department of Transportation employs pavement preservation engineers who determine the condition of the pavement and decide which pavement needs preservation treatments and which needs rehab or reconstruction. All the needs are then pooled and presented to districts, which then decide how much budget should be allocated to each project.

In sum, each DOT first evaluates the need for pavement preservation with the help of pavement engineers. Districts then identify budget requirements in compliance with pavement engineers and present their needs to the legislature. Finally, funding decisions are made by either the legislature or the executive staff in compliance with the needs portrayed by individual districts and pavement engineers. In addition, several

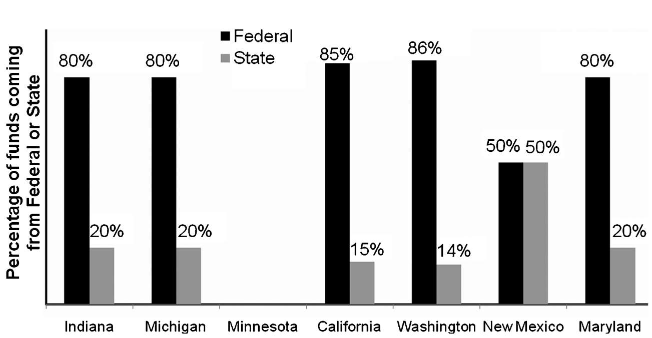

Figure 4.9 Percentage allocation of funds coming from Federal and State sources

DOTs also have customized tools and software to help them make these decisions.

Another question asked of state DOTs involved how much funding they received from federal versus state sources. As shown in FIGURE 4.9, three DOTs (Indiana, Michigan and Maryland) had 80% federal and 20% state funding available. California had 85% federal and 15% state funding, Washington had 86% federal and 14% state funding, and New Mexico had 50% federal and 50% state funding available.

4.3.6. Factors of Initial Year and Frequency of Treatment Application

From the analysis of the Survey, the frequency of treatment, that is, how frequently a treatment was applied after the initial treatment year was determined. However, there were two important facts associated with this:

- How DOTs decided which preventive treatments to apply; and
- How they determined the frequency of application after the initial year of treatment.

For **Indiana DOT**, guidance is given in the Pavement Preservation Initiative Policy Statement. For asphalt pavements, these guidelines are for age (8–12 years) and roughness (IRI $<$ 130). INDOT uses its Pavement Management System (PMS) to screen out candidates meeting these criteria. Districts take this candidate list, and refine it to project specific candidates. These are then field checked to verify they are optimal candidates, and the appropriate treatment to use. Chapter 52 of the Indiana Design Manual contains further information on specific treatments and life.

Michigan DOT has guidelines for pavement preservation. To determine the initial year of application and frequency, they examine the pavement condition and decide whether or not the pavement requires any sort of preservation. They also follow guidelines that would indicate the year a given treatment might be required for the pavement. In order to calculate the condition of a pavement, MDOT uses a measuring index known as Remaining Service Life (RSL). RSL is basically calculated from the pavement distress data obtained by examining the type and quantity of the cracks in the pavement. RSL provides the number of years before a pavement will require reconstruction or rehabilitation. As developed by MDOT, the pavements are categorized based on the RSL as follows:

I. 0–2 years
II. 3–7 years
III. 8–12 years
IV. 13–17 years
V. 18–22 years and
VI. 23–25 years

If the RSL is determined to be 0–2 years, then reconstruction and rehabilitation fixes are applied to the pavement. Capital preventive maintenance treatments are applied to those pavements that fall in categories II, III, IV, and V.

Minnesota DOT uses decision trees that indicate which treatment needs to be applied when. The prescribed process is to measure the roughness distresses and then to convert those distress measurements to a composite value. A PMS helps to project future distresses. Distresses are manually measured by an expert through videos, and all the severities of the distresses are recorded and stored in the PMS. They are then converted to IRI, which is converted into a Ride Quality Index (RQI), which estimates how smooth and satisfying the ride was for the user.

California DOT has special outfitted vans that measure pavement roughness using the International Roughness Index (IRI). This value is entered into the Pavement Condition Survey (PCS), which helps to determine what type of strategy to employ to correct pavement deficiencies. First priority for full rehabilitation/ pavement preservation is given to those pavements that show major distress, that is, cracking, rutting and patching. Together, distress and ride quality determine first priority for preventive maintenance.

Washington DOT examines pavement condition and decides whether or not the pavement requires preservation. They also follow guidelines that indicate the year a treatment might be required for the pavement; this is based on condition of the pavement.

New Mexico DOT's districts make the decision of whether they are going to Rehab/Reconstruct/Preserve by putting it on a matrix which depends on the priority of roads, condition of roads etc. Also, NM doesn't strictly work on triggers as they perform preventive maintenance treatments as and when the funds are available.

Maryland DOT presently considers only ride quality index. They also have a decision matrix, which is currently under the approval of the FHWA.

In sum every state DOT uses either decision trees, guidelines or some other customized tool like PMS to determine which preventive treatments are to be done. They then identify the typical frequency of each treatment and determine the initial year of application.

4.4. Conclusions

This chapter included detailed summaries of the responses received from the Survey and telephone interviews. Information about methods of calculating the benefits of pavement preservation was documented in this chapter in addition to information regarding various preservation practices. Information about budget allocation for pavement preservation activities is described in the next chapter.

5. MODEL FOR BUDGET ALLOCATION

5.1. Introduction

Inevitably, resources are sometimes constrained or limited and available resources for any project, including time, equipment, funding, machines and labor, should be managed effectively. A detailed description of these tools and techniques for resource management is discussed in this chapter. In this research, budget was a primary concern, as demands need to be more leveled in order to overcome variances in budgetary requirements from one year to the next. A model was developed for INDOT to achieve balanced allocation of funds for pavement preservation over a planning period.

A case study from INDOT is presented in Appendix C as an example of resource management. The case study comprises of 196 projects over a three-year period between 2010, 2011 and 2012. Two years of forward float is available for each project. The costs associated with each project are different, and there is a significant discrepancy between the costs of projects in 2010, which required greater resources, versus costs for projects in 2012. In order to avoid this spike in budgetary demands and manage resources in a more leveled manner, resource leveling was adopted. The proposed resource leveling technique, the outcome of the case study and the limitations of the technique are discussed in detail in this chapter.

5.2. Resource Management

As explained earlier in the literature review, there are two main methods for resource management. The first method is resource allocation and the second is resource leveling (Harris 1978). Both methods are used in different scenarios.

- Resource Allocation: best used when resources are limited.
- Resource leveling: best used when project duration is fixed, that is, cannot be altered.

The resource allocation method was not adopted for this research as the objective of the research was to allocate the resources (budget) in a more uniform manner over a fixed period of time. One of the objectives of this research was to determine budget requirements for pavement preservation that do not vary significantly from one year to the next. Therefore, a resource leveling approach was required to determine a more leveled allocation of funds over a planning period.

In construction projects, which are basically large projects, the need for leveling is more prominent than in smaller projects since greater economic gain would result from making such adjustments (Harris 1978). In extensively large projects, the demand for resources is significant. Obtaining and allocating these resources is a difficult task, and a project may fail if resources are not utilized correctly and efficiently. Hence, many attempts have been made to develop methods to level these resources in the most optimum way, including the development of heuristic processes. A traditional approach to research leveling and minimum moment method are discussed below.

5.3. Leveling Methods

5.3.1. Traditional Leveling Approach

The daily resource sum is the algebraic summation of the daily resources allocated for each activity. These daily sums represent the total demands for resources over the duration of a project. An examination is made of all resources, and a possible minimum level is assumed to be the upper limit on daily resource sums (Harris 1978). All daily resource demands are then tested one by one to determine if they are smaller than or greater than the assumed value. If the demand is greater than the assumed limit, an activity is selected from a priority list and shifted by one day. The daily resource sum is again checked and another activity is shifted until the demand has been reduced and falls below the limit of the assumed value. Step by step each day's limit is examined and once a particular day's limit has been checked, the next day is then examined in the same way, and the procedure is continued until the project duration is reached. This is the traditional leveling approach.

5.3.2. Minimum Moment Method

The minimum moment method was developed by Harris (1978) and further illustrated in Harris (1990), Martinez and Ioannou (1992, 1993) and in Hiyassat (2001). A modification of this method is developed in this research for INDOT to determine budget allocation for pavement preservation.

The mathematical calculations shown below are adopted from the work of Hiyassat (2000). Figure 5.1 presents a resource histogram that illustrates the daily sums of resources required over time. Consider a given set, $\{Z\}$, of all elements y_i i.e. y_1, y_2 , y_3, y_4 ….y_n over the fixed set of intervals 1 to n. The above set represents the area of a resource histogram, and the elements y_i (y_1, y_2, y_3, y_4 ….y_n) represent the daily resource sums. Hence,

$$\sum y = \{Z\}_i$$

The moment of an element is $\frac{1}{2}\Sigma y_i^2$ about the axis 0-0. Therefore, the total moment is:

$M = \frac{1}{2}\ \Sigma(y)^2$, which can also be written as $M = \Sigma(y)^2$ (considering ½ as constant and eliminating "½" from the equation).

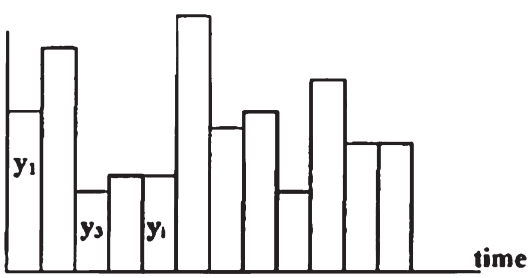

Figure 5.1 Daily resource histogram (Hiyassat 2000)

In the minimum moment approach, a resource Improvement Factor (IF) is computed for each activity. From this, the largest improvement factor is chosen and the associated activity is then shifted by the value of its available free float. This procedure is repeated and the resulting daily resource sums are those that provide the minimum moment and results into leveled resource demands. Improvement in the histogram will only be considered if the new position adopted, has a lower value of the moment than the original one. Thus, the optimal resource allocation exists when the total moment is at a minimum, that is, when the resource histogram is of rectangular shape (i.e., without crests and depressions) (Hiyassat 2000).

To present the mathematical model of this theory, an example was taken from "Modification of Minimum Moment Approach in Resource Leveling" by Hiyassat (2000). A one-day activity "H" having a resource rate of (R) from the set is to be moved S days from one of the elements of Y_1 (having X units of resources) to Y_2 (having W units of resources).

Figure 5.2 shows part of a chart in which activity H is to be shifted from its position having X resources to another position having W resources.

Assume x_1, x_2, ... x_m is the set of daily resource sums

$$\{X\} = \sum_1^m x_i$$

From which m daily resource ratescomma rcomma are to be deducted. Also assume that w_1, W_2, ... w_m is thecr set of daily resource sums

$$\{W\} = \sum_1^m w_i$$

To which m daily resource rates are to be added.

The moment of histogram before shifting an activity can be defined as the sum of the squares of the x_i and w_i. Thus,

$$M_1 = \sum_1^m x_i^2 + \sum_1^m w_i^2$$

Similarly, the moment of the histogram after shifting the same activity can bedefined as the sum of the squares of (x_i $-$r) and (w_i +r). Thus,

$$M_2 = \sum_1^m (x_i - r)^2 + \sum_1^m (w_i + r)^2$$

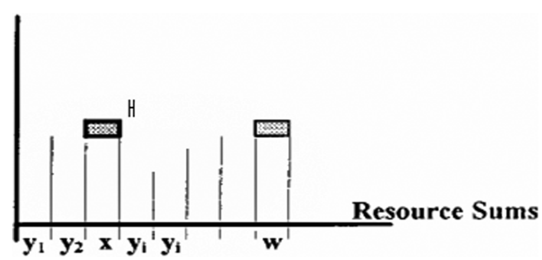

Figure 5.2 Activity H- part of the network (Hiyassat 2000)

Improvement in the histogram that is a lowering of the value of the histogram moment can be said to occur if M2<Ml. Hence,

$$M_2 = \sum_1^m (x_i - r)^2 + \sum_1^m (w_i + r)^2 < \mathrm{M}_1$$

$$= \sum_1^m x_i^2 + \sum_1^m w_i^2$$

Expanding the above expression gives

$$\sum_1^m x_i^2 - 2r\sum_1^m x_i + mr^2 + \sum_1^m w_i^2$$

$$+2r\sum_1^m w_i + mr^2 < \sum_1^m x_i^2 + \sum_1^m w_i^2$$

Collecting terms,

$$-2r\sum_1^m x_i + 2r\sum_1^m w_i + 2mr^2 < 0$$

$$r\left(\sum_1^m x_i - \sum_1^m w_i - mr\right) > 0$$

The left side of the inequality is termed the improvement factor. Thus for any activity H, and the shift, S, the Improvement factor is

$$IF(Act(H), S) = r\left(\sum_1^m x_i - \sum_1^m w_i - mr\right)$$

Where m= min (S, T)

Where,

IF= improvement factor;

S= number of days/ years to be shifted;

m= minimum of either the days that the activity is to be shifted (S) or the activity duration (t); and

R= Resource rate

If the calculated improvement factor for a given activity is either positive or zero, this indicates a positive improvement in the shape of the resource histogram; hence, the activity may be shifted. Otherwise, no shifting is needed. The method requires two cycles of calculations, a forward cycle and a backward cycle. The backward cycle is done in the same way as the forward cycle, taking into consideration the backward float (i.e., the activity can shift back) instead of forward float (i.e., the activity can move forward). From these computations the largest positive improvement factor is determined, and the associated activity is shifted. These two processes are successively repeated for each sequence step until the first step is reached. In the backward cycle, using the back float, activities are examined for possible back shifting in order to make further improvement. For this purpose, the computations are repeated once again, beginning at the first sequence step and ending at the last step. An example is shown below of how to calculate an Improvement Factor (IF) for any given activity.

Days →	1	2	3
Daily Resource Sums	x1	w1	w2
	6	7	3
	10	13	5
	16	20	8

Lets assume that Resource rate R =6 from x1 (Activity H) has to be shifted from x1 to either w1 or w2 depending which option offers a better improvement factor.

Where,

Duration T of activity (H)= 1 year

Days to shift, S= 2 (i.e., it has 2 years of forward float)

$$\mathrm{m} = \min(\mathrm{S,T})$$
$$= \min(2,1)$$
$$= 1$$

Calculating the improvement factor for float =1 year;

$$\text{IF1 (activity H, S)} = \mathrm{R}\left(\sum\mathrm{X}\text{-}\sum\mathrm{W}\text{-mR}\right)$$
$$= 6(16\text{-}20\text{-}1(6))$$
$$= \text{-}60$$

Calculating the improvement factor for float =1 year;

$$\text{IF2 (activity H,S)} = \mathrm{R}\left(\sum\mathrm{X} - \sum\mathrm{W} - \mathrm{mR}\right)$$
$$= 6(16 - 8 - 1(16))$$
$$= 12$$

Thus, as IF2>IF1, the activity H will be shifted by two years i.e., from x1 to w2.

Proposed Method

As mentioned above, a minimum moment algorithm is used for leveling resources. However, some modifications and additions were made to the above algorithm. First, a few assumptions were made in the following model. Assumptions are:

- Each treatment has two years of positive float (i.e., treatments can only move forward).
- The leveling algorithm is run over the entire cycle in batches of three years.
- In a batch of any three years, the 4^{th} and 5^{th} year will be considered float years and their total value is the average value of the summation of the present three years and the previous three years if available.
- Any zero value will not be considered in the average calculations. All the values must be non-zero.

TABLE 5.1
Given projects for first three years

Project	Treatment	Frequency	2010	2011	2012
A1	Crack Seal	3yrs	$ 98,542		
A2	Creack Seal	3yrs	$ 133,848		
A3	Crack Seal	3yrs	$ 162,624		
A4	Crack Seal	3yrs	$ 1,189,232		
A5	Crack Seal	3yrs	$ 2,247,421		
A6	Chip Seal	4yrs	$ 1,157,133		
A7	Chip Seal	4yrs		$ 799,157	
A8	Chip Seal	4yrs		$ 656,304	
A9	Chip Seal	4yrs		$ 528,528	
A10	Chip Seal	4yrs		$ 1,318,912	
A11	Chip Seal	4yrs		$ 220,176	
A12	Chip Seal	4yrs		$ 187,757	
A13	Microsurface	8 yrs			$ 1,189,232
A14	Microsurface	8 yrs			$ 589,232
A15	Microsurface	8 yrs			$ 1,179,520
Total			$ 4,988,800	$ 3,710,834	$ 2,957,984

5.3.3. Framework

When a planning window of three years is considered (e.g., 2010, 2011, and 2012), in the leveling algorithm five years (i.e., 2010, 2011, 2012, 2013 and 2014) are taken. This is because every year has a positive float of two years; therefore, projects from 2012 may shift to 2014. However, one of the assumptions is to consider leveling only in three-year batches, and so years 2013 and 2014 should not be considered in the leveling cycle for that particular batch (i.e., 2010, 2011, and 2012). Thus, to overcome this problem, the values of the daily sums (resources/ budget) have to be pre-fixed, making the years 2013 and 2014 not include in the leveling model. There were four possibilities for this pre-fixed value: no value (empty bins), minimum value, maximum value, and average value. These values must be kept on the basis of the first three years. Now, if the years were kept as empty bins, that is, no value was pre-assigned, then during resource leveling, all projects from 2011 and 2012 (as they have two years of float each) will push projects into years 2013 and 2014. However, this is would not be correct, as a total of five years are being leveled. Secondly, if the values are pre-assigned as minimum values from the first three years, then more and more projects will be pushed into years four and five. Third, if the pre-assigned values are the maximum of the first three years then no projects will shift to 2013 and 2014. However, if the value was kept as an average of the first three years, then only in the worst case scenarios would the projects be shifted to 2013 and 2014. In comparing the averages, there is a possibility that one or more of the previous three years might have a zero resource requirement. In this case, the average over three years would be lowered, creating an artificial push into years four and five. Therefore, the average over the last three years is only taken over years with non-zero resource requirements. Hence, these additions were made to the minimum moment algorithm.

5.3.4. Example

As shown, the above data was used in order to run the leveling algorithm. A total of 15 projects were considered, each having a specific treatment (e.g., crack seal, chip seal, and microsurfacing). Each treatment had a specific frequency in years, as shown in the table above. Initially, all 15 projects were to be completed in a three-year period from 2010 to 2012. Also, the assumption was made that each treatment had a positive two-year float, that is, an activity could only move forward by one or two years from the year initially scheduled.

Initially, the total resources for 2010, 2011 and 2012 years were $ 4.98 M, $3.71 M and $2.95 M, respectively. The leveling algorithm was run for these three years, and the following results were obtained.

Years 2013 and 2014 were kept as average values from years 2010 to 2013. Two projects from 2010 moved to 2012, and one project from 2012 moved to

TABLE 5.2
First leveling cycle for years 2010, 2011 and 2012

Project	2010	2011	2012	2013	2014
A1	$ 98,542				
A2	$ 133,848				
A3	$ -		$ 162,624		
A4	$ -		$1,189,232		
A5	$2,247,421				
A6	$1,157,133				
A7		$ 799,157			
A8		$ 656,304			
A9		$ 528,528			
A10		$ 1,318,912			
A11		$ 220,176			
A12		$ 187,757			
A13			$1,189,232		
A14			$ -		$ 589,232
A15			$ 1,179,520		
Total	$3,636,944	$3,710,834	$3,720,608	$ -	$ 589,232

TABLE 5.3
Second leveling cycle for years 2013, 2014 and 2015

Project	2013	2014	2015	2016	2017
A1	$ -	$ 98,542			
A2	$ -	$ 133,848			
A3			$ -		$ 162,624
A4			$ -		$ 1,189,232
A5	$ 2,247,421				
A6		$1,157,133			
A7			$ 799,157		
A8			$ 656,304		
A9			$ 528,528		
A10			$ 1,318,912		
A11			$ -		$ 220,176
A12			$ 187,757		
Total	$2,247,421	$1,389,523	$3,490,658	$ -	$1,572,032

2014, giving final leveled totals for 2010, 2011 and 2012 of $3.63M, $3.71M and $3.72M, respectively. The resources were more leveled when compared to initial levels.

The next batch of three years, 2013, 2014, and 2015, were taken. According to the frequencies mentioned earlier, all the projects were projected for the years 2013 to 2015, and the following results were obtained.

All these steps were repeated for three-year batches until the year 2026. The results are shown below, with and without leveling. After leveling each year, all those projects that got shifted will be projected automatically in the next batches of years for leveling. According to the frequency mentioned, these projects are projected to take place over the next 16 years, as shown below (without leveling).

After running the leveling algorithm, resources were more consistent over a period of years. Also, TABLE 5.5 shows projections for the projects after resource leveling was done.

5.3.5. Limitations

- Activities are assumed to be continuous. Once an activity is started, no interruptions are expected until that activity is completed.
- Resources applied to each activity are assumed to remain constant throughout the duration of the activity.
- The duration of each activity is assumed to remain constant (i.e., one year) without any reduction or extension.

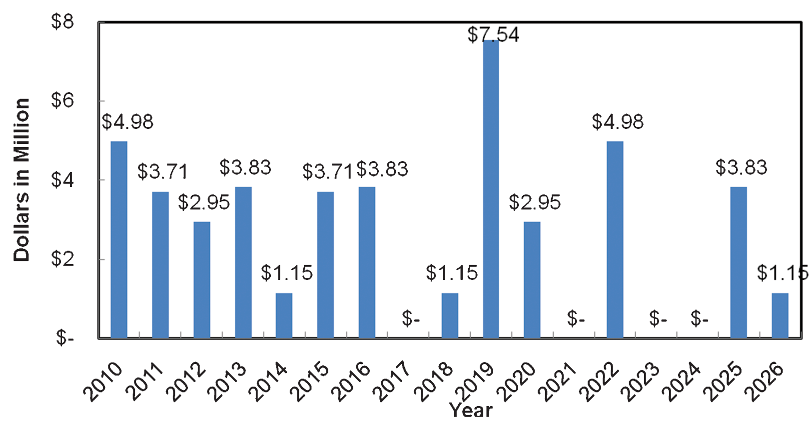

Figure 5.3 Initial results without leveling

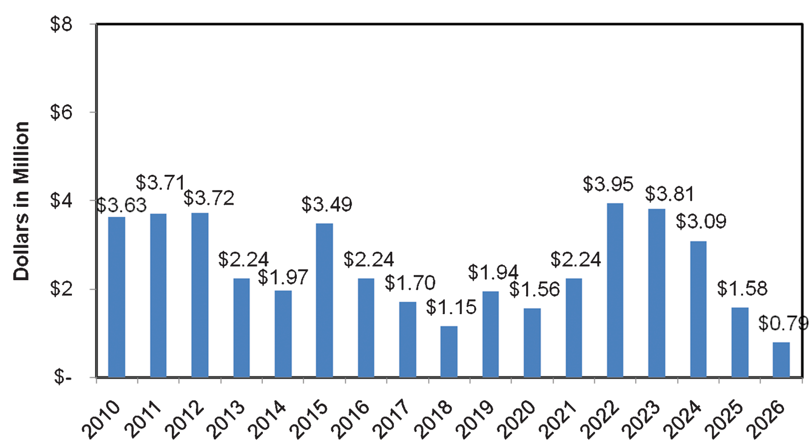

Figure 5.4 Results after leveling

TABLE 5.4
Projects projected over 16 years without leveling

Project	Treatment	Frequency	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
A1	Crack Seal	3yrs	$ 98,542			$ 98,542			$ 98,542			$ 98,542			$ 98,542			$ 98,542	
A2	Crack Seal	3yrs	$ 133,848			$ 133,848			$ 133,848			$ 133,848			$ 133,848			$ 133,848	
A3	Crack Seal	3yrs	$ 162,624			$ 162,624			$ 162,624			$ 162,624			$ 162,624			$ 162,624	
A4	Crack Seal	3yrs	$ 1,189,232			$ 1,189,232			$ 1,189,232			$ 1,189,232			$ 1,189,232			$ 1,189,232	
A5	Crack Seal	3yrs	$ 2,247,421			$ 2,247,421			$ 2,247,421			$ 2,247,421			$ 2,247,421			$ 2,247,421	
A6	Chip Seal	4yrs	$ 1,157,133				$ 1,157,133				$ 1,157,133				$ 1,157,133				$ 1,157,133
A7	Chip Seal	4yrs		$ 799,157				$ 799,157				$ 799,157				$ 799,157			
A8	Chip Seal	4yrs		$ 656,304				$ 656,304				$ 656,304				$ 656,304			
A9	Chip Seal	4yrs		$ 528,528				$ 528,528				$ 538,528				$ 528,528			
A10	Chip Seal	4yrs		$ 1,318,912				$ 1,318,912				$1,318,912				$ 1,318,912			
A11	Chip Seal	4yrs		$ 220,176				$ 220,176				$ 220,176				$ 220,176			
A12	Chip Seal	4yrs		$ 187,757				$ 187,757				$ 187,757				$ 187,757			
A13	Microsurface	8yrs			$ 1,189,232								$1,189,232						
A14	Microsurface	8yrs			$ 589,232								$ 589,232						
A15	Microsurface	8yrs			$1,179,520								$1,179,520						
Total				$ 4,988,800	$3,710,834	$3,831,667	$1,157,133	$3,710,834	$3,831,667	$ -	$1,157,133	$7,542,501	$2,957,984	$ -	$4,988,800	$3,710,834	$ -	$3,831,667	
	$1,157,133																		

TABLE 5.5
Projects projected over 16 years after leveling

Project	Treatment	Frequency	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
A1	Crack Seal	3yrs	$98,542				$98,542					$98,542			$98,542			$98,542	
A2	Crack Seal	3yrs	$133,848				$133,848			$133,848					$133,848			$133,848	
A3	Crack Seal	3yrs			$162,624					$162,624					$162,624			$162,624	
A4	Crack Seal	3yrs			$1,189,232					$1,189,232					$1,189,232			$1,189,232	
A5	Crack Seal	3yrs	$2,247,421			$2,247,421			$2,247,421					$2,247,421			$2,247,421		
A6	Chip Seal	4yrs	$1,157,133				$1,157,133				$1,157,133					$1,157,133			
A7	Chip Seal	4yrs		$799,157				$799,157					$799,157						$799,157
A8	Chip Seal	4yrs		$656,304				$656,304					$656,304				$656,304		
A9	Chip Seal	4yrs		$528,528				$528,528				$528,528				$528,528			
A10	Chip Seal	4yrs		$1,318,912				$1,318,912				$1,318,912				$1,318,912			
A11	Chip Seal	4yrs		$220,176						$220,176						$220,176			
A12	Chip Seal	4yrs		$187,757				$187,757					$187,757				$187,757		
A13	Microsurface	8yrs			$1,189,232										$1,189,232				
A14	Microsurface	8yrs					$589,232									$589,232			
A15	Microsurface	8yrs			$1,179,520										$1,179,520				
Total			$3,636,944	$3,710,834	$3,720,608	$2,247,421	$1,978,755	$3,490,658	$2,247,421	$1,705,880	$1,157,133	$1,945,982	$1,643,218	$2,247,421	$3,952,998	$3,813,981	$3,091,482	$1,584,246	$799,157

5.4. Conclusion

With a few modifications, the minimum moment algorithm was the final model prepared for INDOT to allocate budget for pavement preservation activities. A case study of 196 projects was provided by INDOT, and the results obtained are shown in Appendix C. Results shown in the Appendix C

6. SUMMARY AND CONCLUSION

6.1. Overall Summary and Conclusion

Today, highway users expect smooth and safe mobility on roads in the US. Since the 1990's, the use of highways and the number of automobiles in the US have been increasing rapidly. Many roads are wearing out because of increased traffic, environmental effects, and a lack of proper maintenance (Galehouse 2003). To overcome these obstacles, and also to experience easy mobility, roads and highways have to be well-maintained and well-preserved. It has become increasingly important to take steps that would both meet the nation's needs and satisfy consumers. Allocating more resources or budget to rebuild or rehabilitate more roadways faster is not the solution (NCPP 2010). Thus, most DOTs today are spending a considerable amount of funds on pavement preservation.

The main objectives of this research were to determine methods for calculating the benefits of pavement preservation. Furthermore, to overcome budgetary constraints, a methodology was developed that would assist INDOT in determining more leveled budget requirements that do not vary significantly from one year to the next.

To achieve these goals, the current state of practice of pavement preservation, the age of preservation programs; kinds, frequency, and benefits of preservation treatments; funds allocated for these treatments; constraints in budget allocation; and personnel responsible for making these decisions had to be determined. In order to do this, various pavement engineers or DOT personnel were contacted. Initially, a Survey was sent out to 50 state DOTs in the US and three Canadian provinces. Twenty-six DOTs responded to the survey, and all of the responses were studied thoroughly by the research team and members from the Study Advisory committee (SAC). After this analysis, seven DOTs were selected for telephone interviews. Questions targeted the two objectives of the research.

From the data collected, various aspects of pavement preservation were determined. The main task was to discover methods employed by state DOTs to calculate and document the benefits of pavement preservation. DOTs had different ways to quantify the benefits. Both the Indiana and Maryland DOTs used lane-mile years to quantify the benefits; the Michigan DOT used a Road Quality Forecasting System; and the New Mexico and Washington DOTs used Annualized Costs to determine the benefits of pavement preservation. A description of each method was provided in the report.

Budgetary requirements for pavement preservation activities varied from one year to the next, and a number of discrepancies were observed in allocation of funds from year to year. In order to avoid such discrepancies in budget, a methodology was developed by the research team that would level the budgetary requirements and significantly reduce variability from one year to the next.

Apart from the information pertaining to the two main objectives of the research, significant additional information was found regarding pavement preservation as a whole. Information on pavement preservation practices among different state DOTs, pavement preservation activities, preservation treatments, funds allocated to those treatments, life extended in years by those treatments, and frequency of treatments was obtained from both the Survey and also the telephone interviews.

6.2. Contributions

This research provides significant benefits to INDOT in terms of pavement preservation activities. First, the literature review provides an overall idea of what pavement preservation is versus what it is not. It also documents all the benefits an agency would experience after implementing a pavement preservation program. In addition, it also reveals how the life of a pavement might increase with a minimal use of funds by implementing preservation strategies. Case studies of various state DOTs reinforced these benefits obtained through pavement preservation programs. A detailed analysis was also provided in the literature review about the surveys conducted from 1990 until 2000 by other agencies. This analysis allowed for a strong base of comparison for the responses received from the Survey sent out by the research team. A wealth of information, such as the age of pavement preservation in a particular DOT, various preventive maintenance treatments, their initial application year, frequency of treatment, funds allocated to these treatments, methods to calculate the benefits of pavement preservation, etc., was obtained from the survey.

More detailed information regarding questions asked on the survey was gathered from the telephone interviews. In all, seven DOTs were asked questions pertaining to the objectives of the research. Following information was gathered with respect to the two objectives of the research:

- Objective 1: To document the economic viability of pavement preservation

Through survey and telephone interviews it was found that DOTs use various methods to calculate the benefits of pavement preservation. Currently, INDOT uses lane mile years. It was determined that the Michigan DOT uses a Road Quality Forecasting System (RQFS), Louisiana uses a Highway Health Index, Maine uses DTIMS software, Maryland uses lane mile years, and New Mexico and Washington use an Annualized Costs method to quantify the benefits of pavement preservation. After analysis of these methods, the research team recommended that INDOT use an Annualized Costs method for calculating and quantifying the benefits of pavement preservation. A detailed description of the method is presented in this report.

- Objective 2: To develop a methodology for INDOT to determine the amount of funding that should be dedicated to preservation.

A methodology was developed for INDOT to allocate the budget by developing an algorithm based on the concept of resource leveling. This model developed by the research team would level the budgetary requirements over a project cycle and significantly reduce the variability in demands from one year to the next. This model was run for a case study of 196 projects with different treatments and costs provided by INDOT. The results indicated which projects should be implemented and at what time in order to achieve the optimum results.

In addition, this research also documents the following: how other state DOTs practiced pavement preservation, some of the successful practices adopted by DOTs, how many lane miles every DOT preserved, how DOTs established trigger points for initial application and frequency of a treatment, how decisions regarding allocation of funds were reached, who made such decisions, sources of funding (federal vs. state funds), and whether DOTs preserved pavement on a network or project level.

6.3. Limitations

The project faced a few limitations during the course of the research due to some constraints. The limitations of this research were as follows:

- The timeline of the project was considerably short. It did not allow the research team enough time to conduct extensive field surveys. The researchers had to rely on surveys and telephone interviews to obtain data in a short time.
- Out of 50 state DOTs, only 26 responded to the Survey. Information from all DOTs was not obtained and analysis was thus based on only 26 DOTs from the US.
- Information obtained from the Survey was mostly objective. To obtain more subjective and detailed responses, telephone interviews were conducted. However, due to time constraints, only seven state DOTs were chosen for telephone interviews, which offered a limited set from which to draw concrete conclusions.

BIBLIOGRAPHY

AASHTO Lead States' Work Plan. (1999). "Research Protocols for Pavement Preservation." http://leadstates.transportation.org/pp/transition/pp_transition_plan.pdf (Jan. 25, 2011).

AASHTO. (1999). "Pavement Preservation in the United States: Survey by the Lead States Team on Pavement Preservation." http://leadstates.transportation.org/pp/survey/survey_report.pdf (Jan. 15, 2011).

Ahuja, H. (1976). "Construction performance control by networks." John Wiley & Sons, Inc., New York, NY.

Alfares, H., and Bailey, J. E. (1997). "Integrated project task and manpower scheduling." *IIE Transactions*, 29(9), 711–718.

Bandelloni, M., Tucci, M., and Rinaldi, R. (1994). "Optimal resource leveling using non-serial dynamic programming." *European Journal of Operations Research*, 78(2), 162–178, doi: 10.1016/0377-2217(94)90380-8.

Burgess, A., and Killebrew, J. (1962). "Variation in activity level on a cyclical arrow diagram." *Journal of Industrial Engineering*, 13(2), 76–83.

Connecticut Department of Transportation (n.d.) "Pavement in Connecticut." http://www.pavementpreservation.org/icpp/paper/104_2010.pdf (Jan. 20, 2011).

Davies, R., and Sorenson, J. (2000). "Pavement Preservation: Preserving Our Investment in Highways." *Insights into pavement preservation: a compendium,* Federal Highway Administration (FHWA).

Easa, S. (1989). "Resource leveling in construction by optimization." *Journal of Construction Engineering and Management*, 115(2), 302–316, doi: 10.1061/(ASCE)0733-9364(1989)115:2(302).

Federal Highway Administration (FHWA). (2000). "Insights into pavement preservation: a compendium." http://www.fhwa.dot.gov/infrastructure/asstmgmt/compend.pdf (Jan. 20, 2011).

Federal Highway Administration (FHWA). (2000). FHWA-IF-00-013. (2000). "Optimizing Highway Performance: Pavement Preservation." Report FHWA-IF-00-013.

Federal Highway Administration (FHWA). (2003). "PAVEMENT PRESERVATION COMPENDIUM."

Federal Highway Administration (FHWA). (2005) http://www.fhwa.dot.gov/pavement/preservation/ppc0612.cfm (Jan. 10, 2011).

Federal Highway Administration (FHWA). (2005). http://www.fhwa.dot.gov/pavement/preservation/091205.cfm (Jan. 10, 2011).

Federal Highway Administration Asset Management. (2005). "Life Cycle Cost Analysis." http://www.fhwa.dot.gov/infrastructure/asstmgmt/lcca.cfm (Jan. 11, 2011).

Galehouse, L. (1998). "Innovative Concepts for Preventive Maintenance." Transportation Research Record 1627. Transportation Research Board, Washington, DC.

Galehouse, L. (2009). "Pavement Preservation and Implementation & Best Practices." National Center for Pavement Preservation (NCPP) and American Association of State Highway and Transportation Officials (AASHTO).

Galehouse, L. (2011). "A Quick Check of Your Highway Network Health." http://www.fhwa.dot.gov/pavement/preservation/if07006.cfm (Jan. 10, 2011).

Galehouse, L., and Friend, A. (1996). "Savings from preventive maintenance." National Center for Pavement Preservation (NCPP).

Galehouse, L., Moulthrop, J., and Garyhicks, R. (2003). "Principles of Pavement Preservation Definitions, Benefits, Issues, and Barriers." Federal Highway Administration (FHWA).

Gather, T., Zimmermann, J., and Bartels, J., H., (2010). "Exact methods for the resource levelling problem." *Journal of Scheduling*, 1–13.

Geiger, D.R. (2005). "Pavement Preservation Definitions." Federal Highway Administration Memorandum, September 12, 2005, Washington, D.C. 5th Symposium on Pavement Surface Characteristics, 2005, Toronto, Canada. http://www.fhwa.dot.gov/pavement/preservation/091205.cfm (Jan. 25, 2011).

Harris, R. (1978). "Precedence and arrow networks for construction." New York: John Wiley & Sons, Inc., New York, NY, 254–313.

Harris, R. (1990). "Packing method for resource leveling (pack)." *Journal of Construction Engineering and Management*, 116, 39–43, doi: 10.1061/(ASCE)0733-9364(1990)116:2(331).

Hinze, J. (2004). "Construction planning and scheduling." Pearson Prentice Hall, ISBN: 013092861-5.

Illinois Department of Transportation (2010). "Bureau of Design and Environment Manual."

Illinois Department of Transportation. (2010). "Pavement preservation benefits." http://www.dot.state.il.us/desenv/BDE%20Manual/BDE/pdf/Chapter%2052%20Pavement%20Preservation.pdf (Jan. 20, 2011).

Kercher, A. S. (2004). "Preventive Maintenance – Part 3: Successful Implementation of a Pavement Preservation Program." Delaware T^2 Center, University of Delaware, Newark, DE.

Kercher, A.S. (n.d.). "Best-First Policy is the Best Policy." http://www.kercherei.com/pw_institute/prev_maint/best.html (Jan. 10, 2011).

Larson, R. M. (1999). "Justification for Evaluation of Tire/Pavement Friction/Texture Effects on Total and Wet Weather Crash Rates."

Lee, J., and Shields, T. (2010). "Treatment Guidelines for Pavement Preservation." Joint Transportation Research Program, FHWA/INDOT/SPR-3114. http://www.in.gov/indot/files/INDOT_Treatment_Guidelines_for_Pavement_Preservation.pdf (Feb. 3, 2011).

Leu, S. S., Yang, C., and Huang J.C. (1999). "Resource leveling in construction by genetic algorithm-based optimization and its decision support system application." *Automation in Construction*, 10(2000), 27–41.

Michigan Department of Transportation. (n.d.). "Road quality forecasting system." *Transportation Asset Management* http://www.michigan.gov/documents/roadquality_19998_7.pdf (Jan. 25, 2011).

National Center for Pavement Preservation (n.d.) "Technical Appraisal System." Michigan State University, East Lansing, MI. http://www.pavementpreservation.org/survey/ (January 28, 2011).

New Mexico Department of Transportation. (2007) "Pavement Maintenance Manual."

Neumann, K., and Zimmermann, J. (2000). "Procedures for resource leveling and net present value problems in project scheduling with general temporal and resource constraints." *European Journal of Operations Research*, 127, 425–443, doi: 10.1016/S0377-2217(99)00498-1.

Pennsylvania State University. (2005). Management 520: Planning and Resource Management, https://courses.worldcampus.psu.edu/welcome/pmangt/samplecontent/520lesson08/lesson08_02.html (Jan 10th 2011).

Peshkin, D.G., and Hoerner, T.E. (2005). "Pavement preservation: practices, research plans, and initiatives." National Cooperative Highway Research Program, Project No. 20-07, Task 184.

Petrovic, R. (1969). "On optimization of resource leveling in project plans." H. J. Lombaers, ed., *Project planning by network analysis: proceedings of the 2nd international congress* (pp. 268– 273). Amsterdam: North-Holland.

SHRP Lead State Team for Preventive Maintenance. (1997). "Survey of States' Preventive Maintenance Needs." http://www.google.com/search?hl=en&biw=1260&bih=864&q=Leads+States+team+survey&oq=Leads+States+team+survey&aq=f&aqi=&aql=&gs_sm=e&gs_upl=3969l6219l0l6500l19l19l1l17l0l0l219l2191l2-111 (Jan. 2011).

Sims, T.B. (2005). "TEXAS PAVEMENT PRESERVATION PROGRAM" http://www.utexas.edu/research/tppc/pubs/sims.pdf (Jan. 25, 2011).

Smith, K. D., Hoerner, T. E., and Peshkin, D.G., (2008). "Concrete Pavement Reference Manual." National Concrete Pavement Technology Center, Iowa State University, Ames, IA.

Sorenson, J. (2006). "Resources for a Better Future" *Pavement preservation compendium*. Federal Highway Administration, 57–59.

Yildirim, Y. (2009). "Texas pavement preservation center four-year summary report." Texas Department of Transportation, Center for Transportation Research, Bureau of Engineering Research at the University of Texas at Austin, Austin, TX.

APPENDIX A: SURVEY

QUANTIFY THE BENEFITS OF PAVEMENT PRESERVATION

The purpose of this questionnaire is to obtain current pavement preservation-related information from all the State DOTs.This information will be used to prepare a summary/ report on the current status of pavement preservation activities (i.e., implementation status, ongoing preventive maintenance practices, treatment selection and frequency of all practices, level of funding, future research, and so on).

DEFINITIONS USED IN THE SURVEY:

Several terms are used throughout this questionnaire. The following definitions are provided for the sake of consistency only. (Reference: FHWA)

Pavement Preservation— A program employing a network level, long-term strategy that enhances functional pavement performance by using an integrated, cost-effective set of practices that extend pavement life, improve safety, and meet motorist expectations.
Pavement Preventive Maintenance— A planned strategy of cost-effective treatments applied 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).
Preventive Maintenance Treatment— Any individual maintenance activity that is used in a preventive manner (i.e., applied to a pavement in relatively good condition), while not adding any structural capacity to the pavement. Examples, of preventive maintenance treatments include crack sealing and joint resealing, fog seals, chip seals, slurry seals, microsurfacing, dowel bar retrofitting, diamond grinding, and so on.
New Pavement—New construction or asphalt resurface >=1.5”.
Please return this questionnaire by June 27, 2010, and thank you for your assistance.
Q1. Does your state currently have a Pavement Preservation Program?
( ) Yes
( ) No
Note:If Yes please continue;No then exit the questionnaire.
Q2. Approximately how long has your state’s Pavement Preservation Program existed?
( ) 1–10 years
( ) 10–20 years
( ) More than 20 years
( ) Don’t know
Q3. Does your state assign a dedicated budget for Pavement Preservation Program?
( ) Yes
( ) No
Q4. Check all the Pavement Preservation treatments, their initial year of application and the typical frequency that your state prescribes?

Treatments	Treatments used by your agency (check all that apply)	Initial year of application (after construction/reconstruction)	Typical treatment frequency (in years)
Asphalt Overlay			
Chip Seal			
Cape Seal			
Crack Sealing and Filling			
Cold in place bituminous recycling			
Hot in place bituminous recycling			
Hot Chip Seal			
Flush Seal			
Fog Seal			
Microsurfacing			
Ultrathin bonded wearing course			
Sand seal			
Slurry Seal			
Scrub Seal			
Shoulder Seal			
Thin HMA milling			
Thin HMA milling & filling			
Crack Sealing /Filling			
Cross-stitching			
Diamond Grinding			
Drainage			
Dowel Bar retrofit			
Joint & surface spall repair			
Partial/Full Depth Patching			
Joint Resealing			
Slab stabilisation			

If other, please specify here:

Q5. What level of annual funding is dedicated for the treatments selected in Question 4?

( ) Less than $10 million
( ) $10-$25 million
( ) $26-$50 million
( ) $51-$75 million
( ) $75-$100 million
( ) More than $100 million

Q6. Does your state consider User Costs for Life Cycle Cost Analysis (LCCA)?

( ) Yes
( ) No

Note: If Yes, please continue, No then proceed to Q8.

Q7. How does your state determine User Costs for LCCA?

( ) Simple Formulas
( ) Spread Sheets
( ) Softwares
( ) AASHTO Red Book
( ) Flat Rates
( ) No Formula methods
( ) Other, specify

Q8. What percentage of User Costs is included in the LCCA?

____

Q9. Does your state measure or quantify the benefits of Pavement Preservation?

( ) Yes
( ) No

If yes, please describe how you measure /quantify the benefits:

Q10. Contact information

Name:
Position Title:
Agency:
Phone Number:
Email Address:

APPENDIX B: INTERVIEW QUESTIONS

QUANTIFY THE BENEFITS OF PAVEMENT PRESERVATION

General Information:

1. What is included in Pavement Preservation Program? Minor Rehab, Routine Maintenance, Preventive Maintenance?
2. What definition does your State use for New Pavement and Major Rehabilitation?
3. What is the type of your pavement: Asphalt/ Concrete?
4. How many lane –miles do you preserve?
5. How do you measure the benefits to justify the continuous budget allocation to Pavement Preservation activities?

Methodology for allocation of funds:

1. How is the budget for Pavement Preservation vs. Rehabilitation decided? How much budget is allocated for each one? Who makes this decision?
2. How do you establish the trigger point (like IRI, OPI etc.) to decide the frequency and the initial year of application of the treatments?(Guidelines)
3. What is the budget allocation method? Project Level / Network Level? (Discount factor)
4. Where does the money come from? Federal/State?

Below are the contacts of the interviewees from all 7 State DOTs:

California DOT:	**Rob Marsh: rob.marsh@dot.ca.gov**
Maryland DOT:	**Geoff Hall: ghall1@sha.state.md.us**
Indiana DOT:	**Bill Tompkins: btompkins@indot.in.gov**
Michigan DOT:	**Kevin Kennedy: kennedyk@michigan.gov**
Minnesota DOT:	**Erland Lukanen: erland.likanen@state.mn.us**
New Mexico DOT:	**Robert.young@state.nm.us**
Washington DOT:	**Jeff Uhlmeyj@wsdot.wa.gov**

APPENDIX C: INDOT CASE STUDY

Results before leveling

No.	Project	Treatment Type	Frequencey (years)	2010	2011	2012
1	**SR 159**	**Chip Seal**	**4**	$98,542.40		
2	**SR 234**	**Chip Seal**	**4**	$93,121.60		
3	**SR 234**	**Chip Seal**	**4**	$182,828.80		
4	**SR 246**	**Chip Seal**	**4**	$133,848.80		
5	**SR 71**	**Chip Seal**	**4**	$228,800.00		
6	**SR 71**	**Chip Seal**	**4**	$207,900.00		
7	**SR 75**	**Chip Seal**	**4**	$121,792.00		
8	**SR 75**	**Chip Seal**	**4**	$117,700.00		
9	**SR 19**	**Chip Seal**	**4**	$140,800.00		
10	**SR 119**	**Chip Seal**	**4**	$162,624.00		
11	**SR 101**	**Chip Seal**	**4**	$178,464.00		
12	**SR 9**	**Chip Seal**	**4**	$344,608.00		
13	**SR 327**	**Chip Seal**	**4**	$121,968.00		
14	**SR 14**	**Chip Seal**	**4**	$164,736.00		
15	**SR 13**	**Chip Seal**	**4**	$227,040.00		
16	**SR 9**	**Chip Seal**	**4**	$190,080.00		
17	**SR 37**	**Chip Seal**	**4**	$179,520.00		
18	**SR 18**	**Chip Seal**	**4**	$184,800.00		
19	**SR 9**	**Chip Seal**	**4**	$168,960.00		
20	**SR 28**	**Chip Seal**	**4**	$334,065.00		
21	**US 40**	**Chip Seal**	**4**	$392,832.00		
22	**SR 140**	**Chip Seal**	**4**	$45,619.50		
23	**US 52**	**Chip Seal**	**4**	$228,799.50		
24	**SR 213**	**Chip Seal**	**4**	$351,120.00		
25	**US 41**	**Chip Seal**	**4**	$432,432.00		
26	**SR 114**	**Chip Seal**	**4**	$177,408.00		
27	**SR 4**	**Chip Seal**	**4**	$201,432.00		
28	**SR 23**	**Chip Seal**	**4**	$112,200.00		
29	**US 421**	**Chip Seal**	**4**	$234,080.00		
30	**US 24**	**Chip Seal**	**4**	$456,086.40		
31	**SR 10**	**Chip Seal**	**4**	$141,680.00		
32	**US 421**	**Chip Seal**	**4**	$264,000.00		
33	**US 20**	**Chip Seal**	**4**	$183,744.00		
34	**US 20**	**Chip Seal**	**4**	$264,000.00		
35	**SR 17**	**Chip Seal**	**4**	$94,600.00		
36	**SR 135**	**Chip Seal**	**4**	$221,760.00		
37	**US 52**	**Chip Seal**	**4**	$214,368.00		
38	**SR 62**	**Chip Seal**	**4**	$266,112.00		
39	**SR 250**	**Chip Seal**	**4**	$86,240.00		
40	**SR 11**	**Chip Seal**	**4**	$184,800.00		
41	**SR 11**	**Chip Seal**	**4**	$146,731.20		
42	**SR 356**	**Chip Seal**	**4**	$191,065.60		
43	**SR 558**	**Chip Seal**	**4**	$24,200.00		
44	**SR 545**	**Micro**	**8**	$985,600.00		
45	**SR 545**	**Chip Seal**	**4**	$219,859.20		
46	**SR 337**	**Chip Seal**	**4**	$253,660.00		
47	**SR 645**	**Chip Seal**	**4**	$41,580.00		
48	**SR 29**	**4.75 HMA**	**10**	$1,189,232.00		
49	**SR 39**	**Micro**	**8**	$700.098.67		
50	**SR 46**	**Micro**	**8**	$466,048.00		
51	**US 231**	**UBWC**	**10**	$1,095,600.00		
52	**US 40**	**Micro**	**8**	$692,384.00		
53	**I 69**	**Micro**	**8**	$1,350,272.00		
54	**US 20**	**Micro**	**8**	$555,456.00		
55	**US 30**	**Micro**	**8**	$1,143,296.00		
56	**US 30**	**Micro**	**8**	$1,063,040.00		
57	**US 20**	**Micro**	**8**	$797,632.00		
58	**SR120**	**UBWC**	**10**	$272,682.67		
59	**SR 101**	**UBWC**	**10**	$109,073.07		
60	**US35**	**UBWC**	**10**	$311,637.33		

(Continued)

No.	Project	Treatment Type	Frequencey (years)	2010	2011	2012
61	**SR 32**	**Micro**	**8**	$325,000.00		
62	**SR 227**	**Micro**	**8**	$630.960.00		
63	**SR 227**	**4.75mm**	**10**	$303,072.00		
64	**US 35**	**Micro**	**8**	$225,280.00		
65	**SR 11**	**UBWC**	**10**	$998.697.50		
66	**US 421**	**Microsurface**	**8**	$885,632.00		
67	**SR 62**	**Microsurface**	**8**	$590,216.00		
68	**SR 54**	**Microsurface**	**8**	$320,320.00		
69	**SR 66**	**UBWC**	**10**	$128,550.40		
70	**SR 545**	**Micro**	**8**	$811,829.33		
71	**SR 145**	**UBWC**	**10**	$1,863,786.03		
72	**SR 157**	**Chip Seal**	**4**		$ 220.176.00	
73	**SR 234**	**Chip Seal**	**4**		$ 220,096.80	
74	**SR 234**	**Chip Seal**	**4**		$ 158,188.80	
75	**SR 234**	**Chip Seal**	**4**		$ 192,192.00	
76	**SR 236**	**Chip Seal**	**4**		$ 157,977.60	
77	**SR 26**	**Chip Seal**	**4**		$ 165,580.80	
78	**SR 18**	**Chip Seal**	**4**		$ 230,841.60	
79	**SR 39**	**Chip Seal**	**4**		$ 253,158.40	
80	**SR 38**	**Chip Seal**	**4**		$ 187.756.80	
81	**SR 76**	**Chip Seal**	**4**		$ 249,480.00	
82	**SR 32**	**Mciro**	**8**		$ 799,157.33	
83	**SR 39**	**Mciro**	**8**		$ 458,304.00	
84	**SR 39**	**Mciro**	**8**		$ 221,760.00	
85	**SR 46**	**Micro**	**8**		$ 446,629.33	
86	**US 231**	**UBWC**	**10**		$ 1,095,600.00	
87	**US 231**	**Thin HMA**	**10**		$ 528,528.00	
88	**SR 14**	**Chip Seal**	**4**		$ 184,272.00	
89	**SR 109**	**Chip Seal**	**4**		$ 325,776.00	
90	**SR 25**	**Chip Seal**	**4**		$ 159,808.00	
91	**SR 14**	**Chip Seal**	**4**		$ 118.826.40	
92	**SR 13**	**Chip Seal**	**4**		$ 148.579.20	
93	**SR 3**	**Chip Seal**	**4**		$ 158,928.00	
94	**SR 3**	**Chip Seal**	**4**		$ 312,312.00	
95	**SR 218**	**Chip Seal**	**4**		$ 94,776.00	
96	**SR 124**	**Chip Seal**	**4**		$ 182,353.60	
97	**SR 8**	**Chip Seal**	**4**		$ 228,412.80	
98	**US 33**	**Chip Seal**	**4**		$ 79,569.60	
99	**SR 19**	**Chip Seal**	**4**		$ 111,980.00	
100	**SR 5**	**Chip Seal**	**4**		$ 109,014.40	
101	**SR 120**	**Chip Seal**	**4**		$ 106.480.00	
102	**SR 1**	**Chip Seal**	**4**		$ 145,587.20	
103	**SR 1**	**Chip Seal**	**4**		$ 114,083.20	
104	**SR 8**	**Chip Seal**	**4**		$ 87,533.60	
105	**SR 101**	**Chip Seal**	**4**		$ 19,588.80	
106	**SR 101**	**Chip Seal**	**4**		$ 22,083.60	
107	**I 69**	**Micro**	**8**		$ 1,371,274.67	
108	**SR 120**	**Micro**	**8**		$ 1,022,560.00	
109	**SR 120**	**Micro**	**8**		$ 822,800.00	
110	**US 27**	**Micro**	**8**		$ 1,590,922.67	
111	**US 27**	**Micro**	**8**		$ 788,597.33	
112	**US 27**	**CPR**	**10**		$ 9,999.00	
113	**SR 218**	**Chip Seal**	**4**		$ 144,144.00	
114	**SR 26**	**Chip Seal**	**4**		$ 217,817.60	
115	**SR 1**	**Chip Seal**	**4**		$ 76,648.00	
116	**SR 227**	**Chip Seal**	**4**		$ 159,984.00	
117	**US 36**	**Chip Seal**	**4**		$ 143,616.00	
118	**SR 121**	**Chip Seal**	**4**		$ 223,872.00	
119	**SR 44**	**Chip Seal**	**4**		$ 104,192.00	
120	**SR 1**	**Chip Seal**	**4**		$ 215,705.60	
121	**US 52**	**Chip Seal**	**4**		$ 256,256.00	
122	**SR 44**	**Chip Seal**	**4**		$ 189,024.00	
123	**SR 38**	**Chip Seal**	**4**		$ 146,520.00	

(Continued)

No.	Project	Treatment Type	Frequencey (years)	2010	2011	2012
124	**SR 109**	**Chip Seal**	**4**		$ 148,632.00	
125	**SR 44**	**Chip Seal**	**4**		$ 194,304.00	
126	**SR 109**	**Chip Seal**	**4**		$ 234,960.00	
127	**SR 13**	**Chip Seal**	**4**		$ 246,576.00	
128	**SR 28**	**Chip Seal**	**4**		$ 254.038.40	
129	**SR 13**	**Chip Seal**	**4**		$ 147,804.80	
130	**SR 19**	**Chip Seal**	**4**		$ 238,920.00	
131	**SR 19**	**Chip Seal**	**4**		$ 119,081.60	
132	**SR 213**	**Chip Seal**	**4**		$ 292,248.00	
133	**US 6**	**Chip Seal**	**4**		$ 264.000.00	
134	**SR 4**	**Chip Seal**	**4**		$ 76.560.00	
135	**SR 16**	**Chip Seal**	**4**		$ 52,800.00	
136	**SR 16**	**Chip Seal**	**4**		$ 110,880.00	
137	**SR 218**	**Chip Seal**	**4**		$ 135,520.00	
138	**SR 18**	**Chip Seal**	**4**		$ 369,600.00	
139	**SR 23**	**Chip Seal**	**4**		$ 73,920.00	
140	**R Old US:**	**Chip Seal**	**4**		$ 63,360.00	
141	**US 41**	**Chip Seal**	**4**		$ 985,600.00	
142	**SR 39**	**Chip Seal**	**4**		$ 232,320.00	
143	**SR 10**	**Chip Seal**	**4**		$ 96,800.00	
144	**SR 10**	**Chip Seal**	**4**		$ 161,920.00	
145	**US 421**	**Micro**	**8**		$ 616,000.00	
146	**US 24**	**Thin HMA**	**10**		$ 1,108.800.00	
147	**US 24**	**Micro**	**8**		$ 469,333.33	
148	**US 24**	**Micro**	**8**		$ 563,200.00	
149	**SR 229**	**Thin HMA**	**10**		$ 1,302,048.00	
150	**US 52**	**Thin HMA**	**10**		$ 1,048,432.00	
151	**SR 43**	**Chip Seal**	**4**		$ 208,313.60	
152	**SR 135**	**Chip Seal**	**4**		$ 275,264.00	
153	**SR 3**	**Chip Seal**	**4**		$ 238,022.40	
154	**SR 3**	**Chip Seal**	**4**		$ 467,940.00	
155	**SR 252**	**Chip Seal**	**4**		$ 376,499.20	
156	**SR 43**	**Chip Seal**	**4**		$ 265,126.40	
157	**SR 37**	**Micro**	**8**		$ 323,605.33	
158	**SR 64**	**Micro**	**8**		$ 731,808.00	
159	**SR 62**	**Chip Seal**	**4**		$ 119,451.20	
160	**SR 59**	**Chip Seal**	**4**		$ 214,830.00	
161	**SR 157**	**Chip Seal**	**4**		$ 234,080.00	
162	**SR 63**	**Chip Seal**	**4**		$ 83,635.20	
163	**SR 241**	**Chip Seal**	**4**		$ 289,766.40	
164	**SR 37**	**Micro**	**8**		$ 1,043,914.67	
165	**SR 545**	**Chip Seal**	**4**		$ 237,952.00	
166	**SR 550**	**Chip Seal**	**4**		$ 183,532.80	
167	**SR 69**	**Chip Seal**	**4**		$ 91,185.60	
168	**SR 165**	**Chip Seal**	**4**		$ 378,180.00	
169	**SR 1**	**UBWC**	**10**		$ 424,118.93	
170	**SR 1**	**Micro**	**8**		$ 719,018.67	
171	**SR 38**	**Micro**	**8**		$ 488,400.00	
172	**SR 9**	**Chip Seal**	**4**			$ 1,318,912.00
173	**SR 1**	**Chip Seal**	**4**			$ 1,157,132.80
174	**SR 128**	**Chip Seal**	**4**			$ 95,515.20
175	**SR 9**	**Chip Seal**	**4**			$ 1,262,680.00
176	**US 36**	**Chip Seal**	**4**			$ 1,179,520.00
177	**SR 1**	**Chip Seal**	**4**			$ 11,719.116.80
178	**SR 121**	**Chip Seal**	**4**			$ 196,782.40
179	**SR 227**	**Chip Seal**	**4**			$ 252,032.00
180	**SR 109**	**Chip Seal**	**4**			$ 1,247,420.80
181	**SR 234**	**Chip Seal**	**4**			$ 188,249.60
182	**SR 3**	**Chip Seal**	**4**			$ 182,723.20
183	**SR 3**	**Chip Seal**	**4**			$ 58,080.00
184	**US 40**	**Chip Seal**	**4**			$ 758,419.20
185	**SR 13**	**Chip Seal**	**4**			$ 151,536.00
186	**SR 19**	**Chip Seal**	**4**			$ 133,980.00

(Continued)

No.	Project	Treatment Type	Frequencey (years)	2010	2011	2012
187	**SR 213**	**Chip Seal**	**4**			$ 308,880.00
188	**SR 28**	**Chip Seal**	**4**			$ 99,792.00
189	**US 27**	**Microsurface**	**8**			$ 302,544.00
190	**SR 109**	**4.75 HMA**	**10**			$ 618,420.00
191	**US 35**	**Microsurface**	**8**			$ 178,200.00
192	**US 421**	**Microsurface**	**8**			$ 194,245.33
193	**SR 67**	**Microsurface**	**8**			$ 722,216.00
194	**SR 7**	**Microsurface**	**8**			$ 641,828.00
	Total			**$26,830.012.20**	**$32,783,638.27**	**$22,970,237.33**

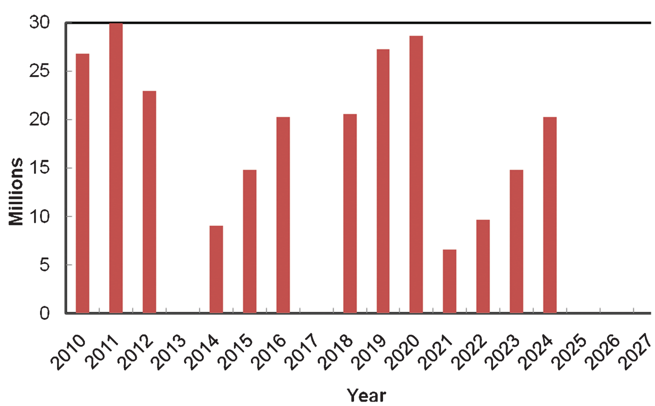

Figure: Before leveling

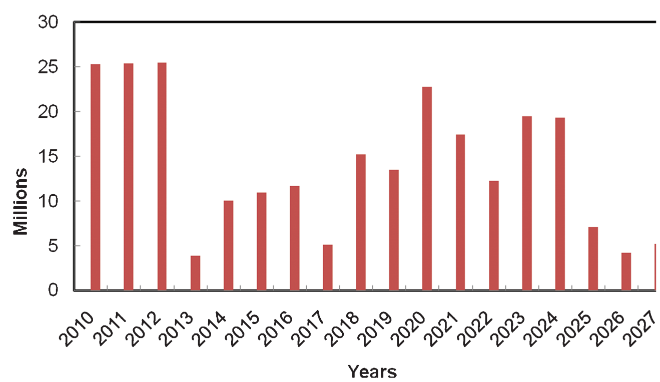

Figure: After Leveling

TABLE:
Results of before and after leveling

Before Leveling																	
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
$25,325,314.20	$25,389,326.60					$25,433,416.27	$-				$7,509,919.20	$10,944,494.00	$11,719,116.80	$9,396,469.20	$23,593,179.20		
$12,829,987.87	$22,896,758.46					$22,100,982.27					$10,938,402.10	$11,698,302.30	$13,314,292.80	$10,842,018.80	$3,794,792.00	$305, 131.20	
2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
After Leveling																	
$25,329,33420	$25,393,34860					$25,437,4027					$3,890201,33	$10,067,56960	$10.948,52400	$11,723,14890	$5,15467400	$15,257,414.	$13,49052227
$22,77902267	$17,46897896					$12,284,31244					$19,506,70673	$19,33287600	$7,115,79400	$4239,11690	$5,194,36320		