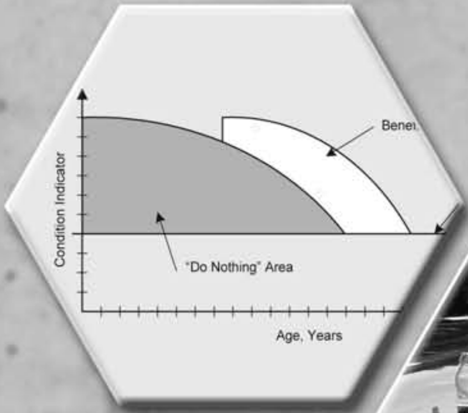
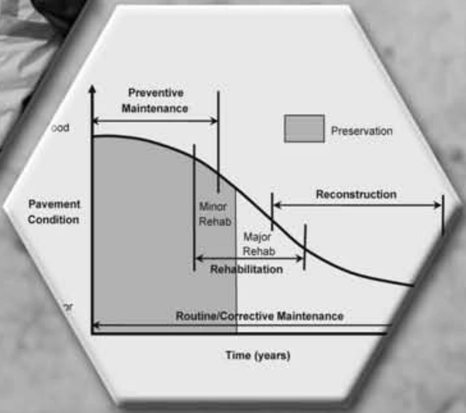
SECOND EDITION 2012

# PAVEMENT MANAGEMENT GUIDE




AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS

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THE VOICE OF TRANSPORTATION

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# LIST OF FIGURES

# LIST OF TABLES

# TABLE OF CONTENTS

CHAPTER ONE

# Introduction to the Guide

## 1.1 BACKGROUND

Pavement management provides a systematic approach to managing a pavement network that enables agencies to evaluate the consequences associated with various investment decisions and to determine the most cost-effective use of available funds for maintaining their roads, streets, and highways. Although pavement management concepts have been widely promoted since the late 1970s, the use of pavement management information to guide agency decisions is not widely employed. Technical factors, such as data quality and data integration issues, and institutional issues, such as the practice of repairing the worst roads first, have impacted the degree by which pavement management concepts have been applied in some agencies. However, pavement management is working well in a number of agencies where the recommendations from pavement management are part of an overall asset management program. In these agencies, pavement management is used to assess and justify funding needs for pavement preservation and rehabilitation, and to help set attainable pavement-related performance goals. These successes illustrate that when reliable technical information is presented effectively, it can go a long way towards overcoming the institutional issues that threaten the use of innovative and cost-effective strategies.

The American Association of State Highway and Transportation Officials (AASHTO) has supported the development and use of pavement management since the early 1980s. In 1990, AASHTO published the *AASHTO Guidelines for Pavement Management Systems* (AASHTO 1990), which introduced the concepts of pavement management, explained the differences between network- and project-level analyses, outlined the components of a pavement management system, and documented the steps to implement a computerized system. In 2001, AASHTO published the *Pavement Management Guide* (AASHTO 2001), which covered pavement management in much more detail. The following topics were included as chapter headings in the 2001 guide:

- Overview of How to Use This Guide
- Pavement Management Overview
- Selecting Pavement Management Systems Procedures
- Data Collection
- Data Management

- Data Reporting
- Predicting Deterioration
- Needs Analysis
- Selection of Candidate Sections When Funds Are Constrained
- Impact Analysis and Presenting Results to Decision Makers
- How to Implement a Pavement Management System

While many of the topics included in the guide are still relevant today, there are several significant advancements that have taken place since the guide was published. For instance, today there is more of a focus on managing pavements rather than on pavement management software. In addition, there is an increased emphasis on the use of preventive maintenance treatments as part of a pavement preservation program and there are advancements that have taken place in terms of data quality and integration issues. There are also recent initiatives that are impacting the types of data required by pavement management, including the changes to the Highway Performance Monitoring System (HPMS) and the calibration and verification activities associated with implementing the new Mechanistic Empirical Pavement Design Guide (MEPDG) (AASHTO, 2008). Other initiatives, such as the increased importance of performance measurement and asset management principles, will further influence the practice and future of pavement management. These changes also influence the need for training so practitioners can adapt.

## 1.2 DESCRIPTION OF THE CONTENTS

The updated *Pavement Management Guide* contains the nine chapters listed below:

- Chapter 1: Introduction to the Guide
- Chapter 2: Managing Transportation Assets Effectively
- Chapter 3: Inventory Data Collection and Data Integration
- Chapter 4: Pavement Condition Assessment
- Chapter 5: Pavement Performance Modeling
- Chapter 6: Project and Treatment Selection
- Chapter 7: Using and Presenting Pavement Management Results
- Chapter 8: Implementation Activities
- Chapter 9: Future Directions

Chapters 2 through 5 provide the foundation for understanding pavement management. Chapter 2 begins with the premise that pavements are an important asset that have a significant value and represent a major investment. For that reason, it is important that pavements are managed effectively so they provide the public with a safe and smooth method of travel as long as possible. Chapter 2 also establishes a link to asset management by introducing the five core questions that every agency should be able to answer about its pavements, bridges, and other roadway appurtenances to manage them cost-effectively. In addition, this chapter introduces the components of a pavement management system; the use of pavement management at the project, network, and strategic levels; and the differences between the types of information used at each of the three decision levels. Finally, Chapter 2 introduces the benefits of using pavement management to support agency decisions.

Once the fundamental principles of managing assets have been established, the guide then addresses several basic pavement management components, including the establishment of an inventory and the types of data integration issues that arise when sharing data (in Chapter 3), the assessment of pavement condition (in Chapter 4), and pavement performance modeling (in Chapter 5).

Pavement management functions and uses are addressed in Chapters 6 and 7, which describe the project and treatment selection process (in Chapter 6) and the use and presentation of pavement management results to support agency decisions (in Chapter 7). Chapter 6 introduces the development of treatment rules for project and treatment selection, and also addresses the increased use of preventive maintenance treatments as part of a pavement preservation program. Typical uses of pavement management information are presented in Chapter 7, including its application for determining pavement maintenance and rehabilitation needs, for demonstrating the consequences of different funding strategies (e.g., *what if* scenarios), and for establishing performance targets. Chapter 7 also explores the use of pavement management information to support alternate delivery contracts and the trend towards web-based accessibility to pavement management data.

The steps involved in the implementation of pavement management are introduced in Chapter 8. This chapter addresses the needs of all types of pavement management users, from the novice agency that might need assistance with getting started or acquiring a computerized tool, to existing users who are seeking help with enhancing their existing capabilities or who are addressing critical institutional issues (e.g., resistance to change or institutional barriers) that can hinder the effective use of pavement management strategies.

The guide concludes with a summary of some of the evolving issues that should be addressed to keep pavement management viable into the future. National initiatives in sustainability and livability are already influencing the types of factors that must be considered in making pavement preservation and rehabilitation recommendations. These and other considerations that are expected to influence the way pavements are managed in the future are explored.

The guide's Appendices include a glossary of common terms and acronyms and a useful list of references sorted by topic area.

## 1.3 SUGGESTIONS FOR USING THE GUIDE SUCCESSFULLY

The anticipated primary audience for this guide is pavement management staff in the highway agencies. It is anticipated that most of the guide's users will view it as a resource to address particular issues or concerns that arise as agencies face the challenges associated with managing pavements effectively. The guide's organization by pavement management components and functions should help support this use.

However, the guide may also be used to assist those seeking general knowledge of pavement management concepts. Since pavement management is not a subject normally included in a civil engineering college curriculum, it is hoped that the structure of the guide will support this use as well.

The authors acknowledge that the guide was primarily developed for use by state DOTs or provincial government agencies. Even so, pavement management's fundamental concepts and principles are applicable to other types of organizations, including local agencies; regional planning agencies, such as metropolitan planning organizations (MPOs); airport authorities; and others responsible for the management of pavement networks (e.g., toll authorities, community associations, park and forest land management agencies, and corporations). The concepts are equally applicable to private and quasi-government agencies that may be managing pavements under contractual arrangements, such as public-private partnerships (PPP). Therefore, this guide could serve as a useful resource for both state DOTs and other organizations.

CHAPTER TWO

# Managing Transportation Assets Effectively

## 2.1 IMPORTANCE OF MANAGING A PAVEMENT NETWORK EFFECTIVELY

A 2011 report estimates that the United States needs $2 trillion dollars to repair and rebuild the nation's deteriorated roads, bridges, and other infrastructure components (ULI & Ernst & Young 2011). The magnitude of this outlay places a tremendous responsibility on asset managers to identify strategies and tools that support wise investment choices and preserve the value of their infrastructure investments as long as possible. Today, transportation agencies are looking for ways to make even more prudent decisions than in the past, using available technology as well as sound engineering and economic principles. In simple terms, agencies are seeking strategies that allow them to *get the most bang for their buck*.

As agencies seek ways to preserve their transportation investments, they are doing so in an environment that offers tremendous challenges from both internal and external forces. These challenges can often have long-lasting impacts on the manner in which an agency manages its transportation assets. For instance, agencies are facing severe funding reductions and pressure from elected officials and the traveling public to improve efficiency and to demonstrate that funds are being used wisely. There is increased pressure to streamline organizations and, as a result, institutional knowledge, which has been the backbone of transportation agencies for many years, is diminishing as experienced workers retire or leave government employment. There is also more competition for available funding and some agencies are responding by outsourcing or privatizing the maintenance of a portion of their network. Additionally, increased pressure for improved accountability in the use of public funds is causing agencies to establish performance-based metrics that allows agencies to defend funding requests and to document how funds have been used and what benefits have been gained.

The idea of managing transportation assets effectively is not new. In fact, state DOTs have been managing roads, bridges, and other highway assets since public road departments were first established in this country. Today's agencies understand the typical life cycle of a pavement and recognize the need for periodic maintenance, rehabilitation, and reconstruction activities. However, in the past, funding for maintenance and rehabilitation projects to preserve the condition of existing assets often competed with funds for more politically and publicly-driven projects that expanded the network to address capacity and mobility issues. What has changed in recent years is the inadequacy of funding to address all of the needs identified by transportation agencies. As a result, stewards of transportation agencies have placed more of an emphasis on preserving their existing assets and better linking investment decisions to agency priorities.

This has led to a shift in the way agencies think about asset investments, with more consideration for the interrelationship between funding decisions. This shift has fueled the development and acceptance of asset management principles as a way of managing transportation assets.

In most state DOTs, the pavement and bridge networks easily represent the largest single investment in transportation assets. In recognition of the tremendous value of these assets, the Government Accounting Standards Board (GASB) issued Statement 34, which recommends including the value of transportation assets in the financial statements for government agencies (FHWA 2000). As a result, since 2001, state, local, and municipal government agencies have been reporting the replacement value of transportation assets and either depreciating the asset over time, or maintaining the value through their asset management efforts. This change in reporting the value of transportation assets to preserve an agency's bonding capacity was an early factor contributing to the increased use of more effective asset management principles.

The potential impact of improving the effectiveness of investment decisions can be significant. For example, Cowe Falls et al. (1994) estimated the impact that pavement management has had on user cost savings in the Province of Alberta. Using a conservative analysis that evaluated changes in the paved network condition over a 5-year period, the authors reported that the use of pavement management software resulted in improved conditions that were converted to an increase in asset value. The study found that every dollar (Cdn) spent on pavement management in Alberta resulted in a nearly $100 (Cdn) improvement in terms of user cost savings or savings in asset value.

The importance of adopting strategies that improve the overall effectiveness of the way in which assets are managed cannot be ignored. Whether an agency is looking for strategies to manage a single asset (e.g., pavement) or an entire network of assets, improvements that lead to wiser investment decisions can result in improved network conditions, a higher level of service for the public, a better understanding of the impact that spending in one area has in another area, and a more streamlined decision process. Coupled with the resulting improvements in accountability, the use of asset management principles (such as those described in the next section) is finding increased acceptance within state DOTs and other agencies with a significant investment in transportation assets.

## 2.2 INTRODUCTION TO AN ASSET MANAGEMENT APPROACH

AASHTO currently defines asset management as follows (AASHTO 2006b):

> *Transportation asset management (TAM) is a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision-making based upon quality information and well defined objectives.*

Asset management is based on several fundamental principles, which are listed below (INGENIUM 2006; NCHRP 2009).

- **Investment decisions are driven by policy**. As a result, resources are allocated based on clearly defined goals that reflect agency priorities.
- **Decisions are based on performance metrics**. Asset management includes methods for assessing agency and asset performance and for monitoring performance with time. Measures of performance should be tied to the agency strategic objectives and linked to the resource allocation process.
- **Options and trade-offs are considered in the decision process**. Investment decisions consider both the long- and short-term impacts that each option has on overall asset performance. In addition to evaluating different investment strategies within a single asset class (e.g., pavements), asset management considers investment options across asset type (e.g., more in pavements and less in bridges) and across agency objectives (e.g., asset preservation versus system expansion). The evaluation of trade-offs considers the risk associated with asset failures as well as the impact on other agency initiatives, such as sustainability or livability.
- **Decisions are based on quality information**. The type of data used to support asset management depends on the types of questions each agency needs to address and the information needed to answer the questions. The data must be credible, reliable, and maintainable over time.
- **Performance is monitored with time**. Monitoring performance provides an opportunity for agencies to track conditions and to institute processes to continue to improve performance with time.

In organizations where these principles are applied, there is a clear connection between the strategic objectives identified during the short- and long-term planning processes and the construction and maintenance programs delivered in the field. On-going monitoring activities, such as pavement condition surveys and roadside feature surveys, provide feedback to the planning process on progress towards achieving agency goals so that any necessary adjustments and corrections can be made. The relationships and connections between these activities are depicted in Figure 2-1.

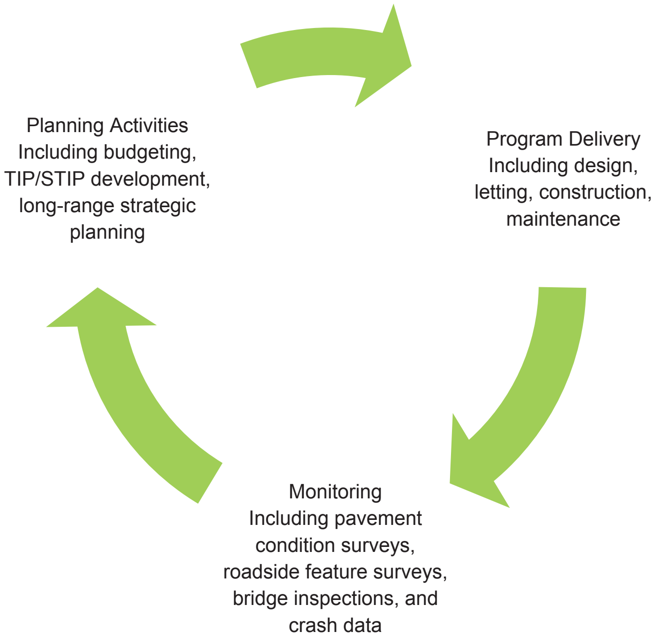



**Figure 2-1. Asset Management Activity Cycle (Adapted from AASHTO 2011)**

Within an asset management environment, many of the activities shown in Figure 2-1 continue to be conducted independently. However, these activities should be conducted in an environment in which there is a clear understanding of the agency's goals and objectives, and related performance measures are used at each level to guide decisions and to allocate resources. As a result, there is greater sharing of information at each level and communication across organizational functional units typically improves. Since performance expectations are well understood and accepted in an asset management environment, an agency can operate more efficiently and decisions are more streamlined.

Figure 2-2 illustrates the more streamlined decision process that exists in an asset management environment and the integration between decisions at various levels within the organization. At the strategic level, performance targets and agency goals are developed to guide the resource allocation process. Information from the network (or tactical) level supports the resource allocation decisions, as shown by the double arrows linking these activities. At the network level, decisions are made regarding funding for maintenance and operations, system preservation and renewal, and system expansion and enhancement. The impacts of different investments in each of these options are based on an analysis of each asset, using management systems (e.g., pavement management and maintenance management systems) whenever possible. At the project (or operational) level, the selected program is delivered in the field. At each level, performance measures are used to align decisions with the strategic goals.

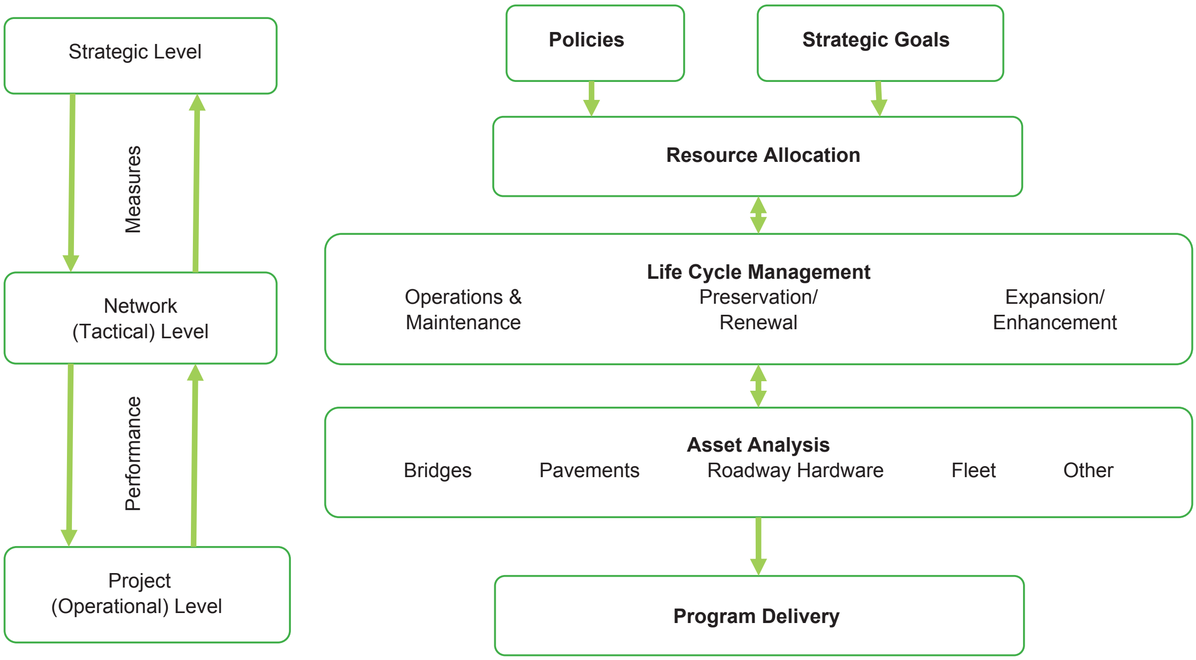



**Figure 2-2. Integrated Decisions Within an Asset Management Environment**

The importance of these relationships was reinforced during a recent scan tour in which representatives from the United States visited six transportation agencies in Sweden, Canada, the United Kingdom, Australia, and New Zealand. Although these agencies represented a diverse set of conditions and population densities, they agreed on the following five recommendations that will help an agency shift to an environment in which an asset management philosophy can thrive (FHWA 2010a):

1. Articulate a limited number of high-level national transportation policy goals that are linked to a clear set of measures and targets.
2. Negotiate intergovernmental agreements on how state, regional, and local agencies will achieve the national goals while translating them into local context and priorities.
3. Evaluate performance by tracking the measures and reporting them in clear language appropriate for the audience.
4. Collaborate with state, regional, and local agencies to achieve the targets by emphasizing incentives, training, and support—instead of penalties—as the preferred way to advance performance.
5. Perpetuate long-term improvements by understanding that the real value of performance management is an improved decision-making and investment process, not the achievement of many arbitrary, short-term targets.

These findings emphasize the important relationships between all levels of government to achieve national policy goals. From a state perspective, the findings support the establishment of clear goals that are linked to performance metrics and the promotion of collaborative efforts between all parties to accomplish those goals. The study also emphasized the importance of focusing on long-term improvements to reach these goals, rather than the short-term, politically influenced decisions that are often more typical in transportation agencies within the United States.

As agencies move forward to advance their adoption and implementation of an asset management framework, it is recommended that processes be adopted that enable the agency to answer the following five core questions about its assets (EPA/FHWA 2009):

1. **What is the current state of our assets?** Answering this question requires agencies to have a good understanding of the assets they own, where they are located, and what condition they are in. The agency should also have some idea of the remaining life of each asset, and its economic value.
2. **What is the required level of service?** Targeted levels of service for each asset are based on a number of factors, including stakeholder needs, current conditions, and anticipated funding levels. Other considerations, such as regulations (e.g., standards for retroreflectivity on signs), must also be taken into account when setting performance targets.
3. **Which assets are critical to sustained performance?** In an asset management environment, agencies understand asset life cycles and the methods by which assets fail. This allows them to incorporate risk into the analysis by considering both the likelihood of and the potential consequences associated with failure.
4. **What are the best investment options available?** Organizations have many options for managing their transportation assets. Within an asset management framework, agencies have the tools available to allow them to identify the investment options available and to understand the potential consequences associated with each option. Since agency goals are known, options that are not aligned with these objectives can be quickly eliminated from consideration.
5. **From a long-term point of view, what is the best funding strategy for the agency?** Consideration of the information obtained in response to the previous questions allows an agency to make an informed decision regarding the best long-term funding strategy. Resources are allocated in alignment with this strategy and operational plans are put in place to ensure that the programs delivered support the agency's goals.

Many state DOTs have management systems in place to help answer many of the five core questions for a single asset (e.g., pavements or bridges) or an asset class (e.g., roadway hardware). These systems supply much of the information used to monitor asset performance and to evaluate the consequences of different investment strategies. These systems are critical to supporting asset management decisions. This guide focuses on one of the more commonly used management systems: pavement management.

## 2.3 INTRODUCTION TO PAVEMENT MANAGEMENT

AASHTO defines pavement management as "…a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time (AASHTO 1993)." It provides a systematic approach that enables agencies to perform the following functions:

- Assess both current and future pavement conditions.
- Estimate funding needs to achieve targeted condition levels.
- Identify pavement preservation and rehabilitation recommendations that optimize the use of available funding.
- Illustrate the consequences of different investment levels and treatment strategies on both short- and long-term pavement conditions.
- Justify and secure increased funding for pavement maintenance and rehabilitation.
- Evaluate the long-term impacts of changes in material properties, construction practices, or design procedures, or some combination thereof, on pavement performance.
- Agencies that have used pavement management tools have reported improvements in the efficiency with which resources are used and better transparency when communicating with elected officials and the public (AASHTO 2001). A **pavement management system** (PMS) is the analysis tool, or software program, that is used to generate and analyze pavement management strategies.

Pavement management has evolved since the concepts were first introduced to the transportation industry in the late 1960s and early 1970s. Early pavement management activities involved the development of mathematical equations to estimate the pavement performance measurements recorded at the AASHO Road Test in Illinois. From there, researchers expanded the use of pavement management concepts by developing a "systems" approach to managing pavement performance. Most of the early pavement management systems operated on mainframe computers, which limited their application by smaller agencies.

The use of pavement management tools changed dramatically in the 1980s with the availability of personal computers. As technology has continued to evolve, pavement management practitioners have experienced dramatic changes in the way pavement condition data are collected, in the types of analyses that can be conducted, and in the methods used for sharing and reporting pavement inventory and condition information. Today, many agencies use Geographic Information Systems (GIS) as a platform for presenting pavement management results. Greater accessibility of pavement-related data through system integration has also expanded the use of pavement management information. For instance, some agencies are using their pavement condition data to correlate and calibrate sophisticated pavement design models.

In addition to changes in technology, the role of pavement management within a transportation agency has also had to evolve due to organizational, political, and societal changes that have taken place in the past 30 years. While many transportation agencies primarily focused on construction activities and system expansion when the interstate highway system was being built, today many agencies are placing a higher priority on preserving the existing system because funding levels are not adequate to address system needs. At the same time, pavement conditions are declining and agencies are having to develop more economically efficient means of maintaining their pavement network, such as the use of preventive maintenance treatments early in the life of a pavement. Additionally, agencies are developing strategies for capturing institutional knowledge before experienced personnel retire or are displaced as part of organizational restructuring. These strategies may include job shadowing, cross-training, or the development of databases, or some combination thereof, to store the historical information that will be lost. In addition, many transportation agencies are investing significant resources into integrated databases for storing and using data more effectively. Improvements in data integration have led to the availability of information to assist in making investment decisions that consider the impacts on multiple assets and the increased use of the asset management principles discussed earlier.

### 2.3.1 Basic Pavement Management Framework

Pavement management supports agency decisions at three different levels: strategic, network (tactical), and project (operational). Each of the three levels and the types of decisions that are made are illustrated in Table 2-1. The table also indicates the level of detail in the data used to make decisions.

#### 2.3.1.1 Strategic Level

**Strategic** decisions are made at the highest level within an organization by individuals responsible for making policy and investment decisions, such as elected officials, transportation boards and commissions, city councils, and agency upper management. At this level, individuals are charged with making long-term strategic decisions that reflect agency and stakeholder priorities and establishing targeted performance levels. Traditionally, strategic decisions have been less structured than decisions made at other levels and the information on which the decisions are based is more speculative, requiring the ability to predict future conditions under a variety of scenarios. In the absence of reliable information to serve as the basis for sound business decisions, political priorities may prevail.

#### 2.3.1.2 Network (Tactical) Level

At the **network (tactical)** level, strategies are identified to achieve the agency's goals. At this level, the overall needs of the entire road network are considered and multi-year improvement programs are developed. For pavements, several different strategies might be considered, such as a worst-first strategy in which the roads in the worst condition are the agency's highest priority and an alternate strategy in which a mix of preventive maintenance, rehabilitation, and reconstruction projects are included. The results of the network-level analysis are presented to the decision makers at the strategic level to assist them in setting realistic performance targets and to evaluate investment options. Since network-level analyses require information on the entire network, agencies strive for a balance between the level of detail that can be provided and the resources available to collect the information. Therefore, information at the network level is generally considered to be moderate in terms of sophistication. For example, predicted condition on each individual road or street may not be exact, but overall the average rate of pavement deterioration is considered reasonable and representative. Traditionally, pavement management activities have focused primarily on network-level decisions. This guide is primarily focused on pavement management activities at the network level, but the relationship and use of pavement management information at other levels is also discussed.

**Table 2-1.** Differences in Strategic-, Network-, and Project-Level Decisions

| Decision Level | Examples of Job Titles at this Level | Types of Decisions/Activities | Range of Assets Considered | Level of Detail | Breadth of Decisions |
|---|---|---|---|---|---|
| Strategic | • Legislator<br>• Commissioner<br>• Chief Engineer<br>• Council Member | • Performance targets<br>• Funding allocations<br>• Pavement preservation strategy | All assets statewide | Low | Broad |
| Network (Tactical) | • Asset Manager<br>• Pavement Management Engineer<br>• District Engineer | • Project and treatment recommendations for a multi-year plan<br>• Funding needed to achieve performance targets<br>• Consequences of different investment strategies | A single type of asset or a range of assets in a geographic area | Moderate | Moderate |
| Project (Operational) | • Design Engineer<br>• Construction Engineer<br>• Materials Engineer<br>• Operations Engineer | • Maintenance activities for current funding year<br>• Pavement rehabilitation thickness design<br>• Material type selection<br>• Life cycle costing | Specific assets in a specific area | High | Focused |

#### 2.3.1.3 Project (Operational) Level

The third decision level is the **project (operational)** level. At this level, decisions are very specific and are usually concentrated on a particular portion of the network. For example, once a road is identified as a candidate for repair at the network level, a more detailed project-level evaluation is used to design the improvement based on in situ conditions. Project-level decisions are typically focused over a fairly short timeframe, such as the first two to three years of a five-year improvement program developed at the network level. Because a project-level analysis is concentrated on such a small portion of the network, agencies can typically afford to collect more detailed information about a pavement at this level. For instance, cores and material testing may be conducted to determine in situ conditions at the project level, but it is impractical to consider this level of detail at the network level. Individually, the impact of project-level decisions is not as far-reaching as decisions that are made at the network or strategic levels. However, over time a series of poor project-level decisions (e.g., poor design decisions) can have a cumulative negative effect on an agency's ability to meet its needs.

### 2.3.2 Components

Although pavement management features can vary dramatically depending on the types of information the agency needs to support decisions and the resources available, there are a few basic components that are common to most systems, as shown in Figure 2-3. The key features shown in this figure are described in the following sections.

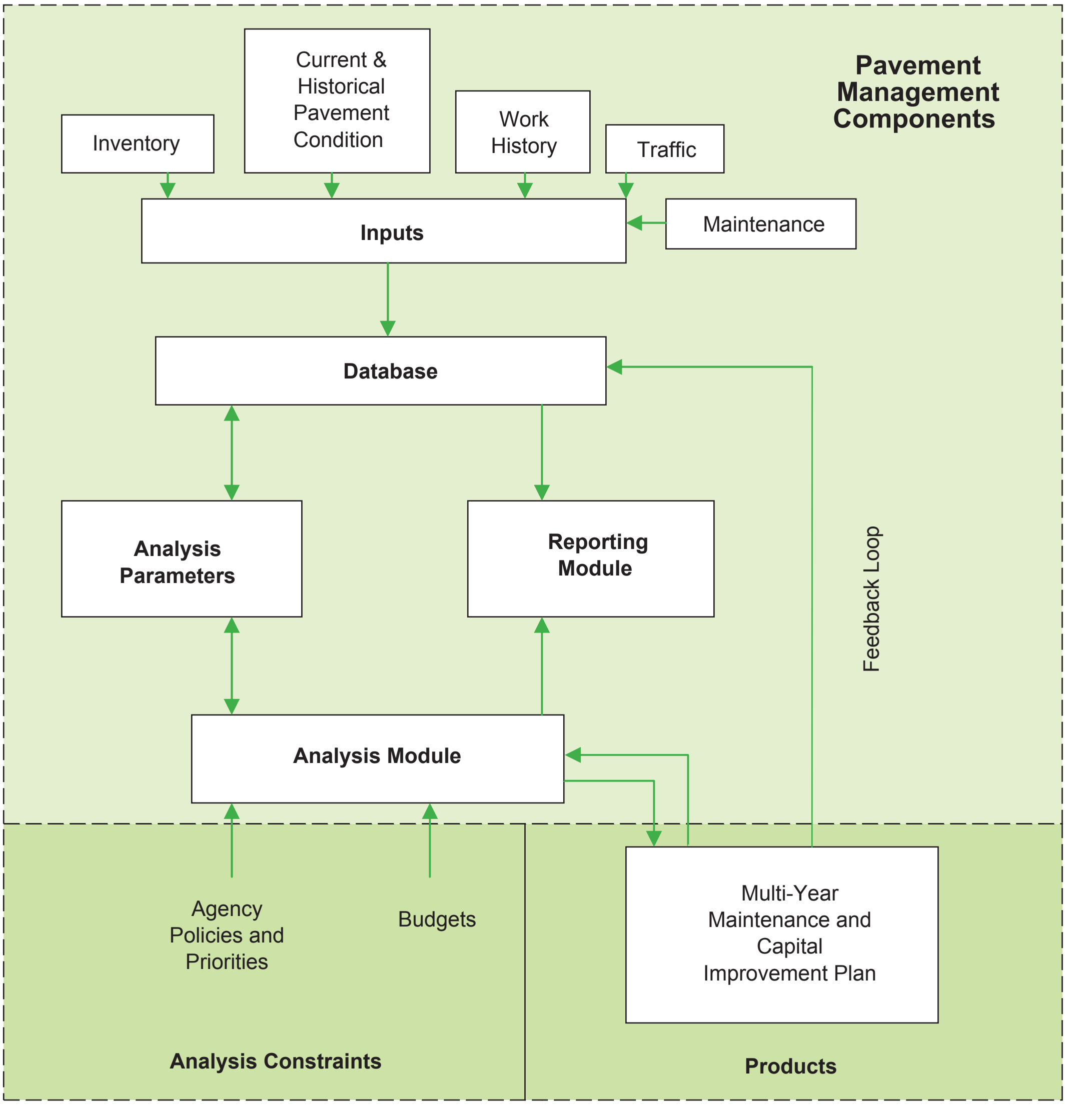



**Figure 2-3. Pavement Management Components**

#### 2.3.2.1 Inputs

The foundation of any pavement management system is the data upon which all decisions are based. In the most basic pavement management systems, the inputs include general inventory information (e.g., road identifier, road location, number of lanes, lane width, pavement type) and pavement condition information (both current and historical data). In addition, a pavement management system requires an estimate of pavement age to predict future conditions. Traffic counts may be used to estimate pavement age, but it is far more common for agencies to base pavement age on the year in which the last major construction activity was performed, whether that was the original construction of the road, the date of the last resurfacing, or some other type of global treatment.

Although a pavement management system can operate with the basic information listed above, a more sophisticated analysis is possible with the inclusion of additional detailed information. For instance, if detailed construction history information is available, an agency could link differences in pavement performance to pavement structure characteristics. In the absence of detailed construction history information, more general rates of deterioration might have to be developed. The types of inventory and condition information used in pavement management are discussed in Chapters 3 and 4, respectively.

#### 2.3.2.2 Database

Even though pavement management activities can be performed without a formal computerized system, it helps to make use of technology for storing, sorting, and retrieving the inventory and condition information. The type of data storage can range from a simple spreadsheet to a relational, self-contained database, to a data warehouse in which all of the agency's data are stored. Other state DOTs have used their Geographic Information Systems (GIS) as a way to facilitate the shared use of data. Additional information on data storage and integration can be found in Chapter 3.

#### 2.3.2.3 Analysis Parameters

To generate pavement project and treatment recommendations, certain analysis parameters must be created. There are at least four types of analysis parameters commonly used in pavement management: pavement deterioration models, treatment rules, impact rules, and cost models. Pavement deterioration models provide the basis for predicting future changes in network conditions. They are critical for estimating future funding needs and for determining when maintenance and rehabilitation activities will be required. The models also serve as the basis for demonstrating the consequences of different investment levels or treatment strategies so an agency can decide which option best addresses agency goals. Once models of pavement performance have been established, they can assist an agency in a number of ways. For instance, the models can be used to compare the performance of different pavement design features, to demonstrate the cost-effectiveness of different treatment strategies, or to establish treatment cycles for use in life cycle costing. The development and use of pavement performance models is described in more detail in Chapter 5.

Pavement management also relies on treatment rules to define the conditions under which pavement maintenance, rehabilitation, and reconstruction activities are considered to be feasible. Treatment rules can range in sophistication from simple rules that recommend the level of repair needed (e.g., preventive maintenance, minor rehabilitation, major rehabilitation) to very complex rules that consider many factors, such as the type of treatment last applied, the geographic location of the project, and type of traffic using the facility. The degree of sophistication for defining treatment rules depends on the needs of the agency and the availability of the data required to support treatment selection. Agencies just beginning in pavement management are cautioned to start with fairly simple decision trees and to increase the degree of sophistication over time.

In addition to developing rules for treatment selection, a pavement management system also requires that the impacts of different treatments be defined. In addition to developing rules for treatment selection, a pavement management system also requires that the impacts of different treatments be defined. These definitions are commonly referred to as impact rules, which dictate how much of an increase in pavement condition can be expected from the application of a treatment and how that treatment will perform with time. Impact rules are used in a pavement management analysis to predict consequences of various scenarios on pavement conditions. The type of software used for pavement management often determines the degree of sophistication with which impact rules can be created. For example, some systems may assume that all treatments return a pavement to excellent condition immediately after construction and that it deteriorates at the same rate as it did prior to the construction of the treatment. However, other systems have more sophisticated capabilities that enable the user to define different impacts (e.g., one treatment may return a pavement to excellent condition while another treatment may only change crack severity from medium to low) and unique rates of deterioration for each treatment. Again, the type of computerized tool used to support pavement management frequently dictates the type of impact rules that need to be defined for each treatment.

The final component to the analysis parameters includes cost information. At a minimum, a pavement management system requires costs for each of the treatments or treatment categories considered in the analysis and anticipated budget levels for each year in the analysis.

The development and use of treatment and impact rules are discussed in Chapter 6.

#### 2.3.2.4 Analysis Module

One of the most powerful functions of a pavement management system is its ability to quickly process and analyze pavement data to provide information that supports agency decisions regarding which projects to fund and what types of treatments to use. The pavement management analysis module is the feature that provides this type of information. As with the other features in pavement management, the degree of sophistication for the analysis can vary dramatically depending on an agency's needs. For instance, some agencies find it suitable to perform the analysis using a spreadsheet to rank different priorities. However, other agencies optimize the use of available funding over a multi-year period by using more sophisticated mathematical programming techniques such as linear programming or an incremental benefit-cost analysis. Regardless of the approach used, the primary objective of the analysis module is to assist agencies in evaluating the consequences of applying different investment levels and treatment strategies. The most common outputs from the analysis module include the following:

- An assessment of the funding level needed to reach a targeted performance level.
- Recommendations for the optimal use of available funding.
- Estimated future pavement conditions for different treatment and investment scenarios.

However, the results of an analysis can be used for many other purposes. For instance, the information can be very useful for establishing criteria for performance-based specifications or for setting performance targets under warranty contracts. More information on the techniques used to perform these activities can be found in Chapters 6 and 7. Chapter 6 presents the techniques used for project and treatment selection and Chapter 7 presents the uses of pavement management results.

#### 2.3.2.5 Reporting Module

As the central repository for pavement-related information, a pavement management system is often the source of many different types of reports about a pavement network. Therefore, most pavement management systems have a reporting function that provides users with the ability to generate standard and ad hoc reports in many different formats. In recent years, accessibility to pavement management information has increased dramatically through the use of GIS and web programs to obtain pavement management information. Techniques for reporting and accessing pavement management results are included in Chapter 7.

#### 2.3.2.6 Feedback Loop

The reasonableness of the outputs from a pavement management system is largely dependent on the reliability of the inputs and the similarity between the analysis parameters and the practices in the field. Therefore, a pavement management system relies on a feedback loop that updates the pavement management records with pavement performance and construction information from the field. Ideally, the feedback loop is accomplished using automated systems that link relevant information together. In real life, the feedback loop typically relies on the relationships between agency personnel who understand the value of the information and have developed business processes to make sure the necessary information is provided on a timely basis. Examples of the types of information normally provided to pavement management through a feedback loop include maintenance and rehabilitation completion dates, changes in the conditions under which treatments are used, or changes in material properties, or some combination thereof. Pavement management can also provide feedback to other agency functions by providing information relative to the performance of different treatments under a range of conditions, the primary mechanisms causing pavement deterioration, and the average performance of various pavement designs and treatments.

## 2.4 TYPES OF PAVEMENT MANAGEMENT SOFTWARE

Pavement management systems can vary greatly in their complexity, flexibility, and cost. The simplest pavement management systems are public agency programs that have been developed through government funding. These types of programs typically have a standard analysis structure that is followed by all users and they are relatively low in cost. Many of the public agency developers have organized user groups and training programs to facilitate the use of their programs.

There are several very successful public agency-developed pavement management software programs. For example, the MicroPAVER pavement management system developed by the U.S. Army Corps of Engineers and distributed through the American Public Works Association (APWA) is an example of this type of software (FHWA 2008a). Another example is StreetSaver, which was developed by the Metropolitan Transportation Commission in the San Francisco Bay area (FHWA 2008a). There are also examples developed by FHWA Local Technical Assistance Programs in Utah and Michigan (FHWA 2008a). These programs are relatively inexpensive to implement and there are many private corporations that are trained to assist agencies with the implementation of these programs. Therefore, they make an excellent way for small- and medium-sized agencies to begin using pavement management tools. However, the limited ability to customize these programs to the specific needs of its users can keep some agencies from implementing these types of programs. For instance, the StreetSaver software dictates the type of pavement condition survey that is used to assess pavement condition. Consequently, an agency that collects pavement condition data using a different methodology must either change its data collection approach or select a different pavement management software program.

At the other extreme are proprietary pavement management systems developed and licensed by private corporations. These programs are typically more expensive than public domain programs, but they provide a much greater degree of flexibility in the amount of customizing that can be done for each user. For instance, while the StreetSaver program utilizes a particular pavement condition survey technique, some of the more sophisticated proprietary pavement management systems allow the user to input any type of pavement performance measure into the system. Proprietary systems typically allow users to define the types of treatments that can be analyzed, the number of budget sources that can be considered, and the way data are stored. The programs are also updated regularly by the developers so the program remains competitive with other available options. The disadvantage to the use of proprietary systems is that they are more expensive than public domain options and the number of licensed vendors who can implement and update the software is limited.

Some pavement management software vendors offer integrated packages that allow an agency to assess needs for other transportation assets (e.g., signs and sidewalks). These systems address a specific need for incorporating a broader spectrum of transportation assets in determining agency needs.

In 2008, the FHWA published a *Pavement Management Catalog* listing 12 different proprietary systems and four public agency systems from vendors who elected to participate in its development (FHWA 2008a). Information provided by the distributors of both proprietary and public domain systems is included in the *Catalog*. Although some of the information contained in the *Catalog* may be dated, the list of pavement management vendors and their contact information can be an excellent starting point for agencies interested in learning more about pavement management software. The *Catalog* also lists vendors of data collection equipment.

## 2.5 ROLE OF PAVEMENT MANAGEMENT IN SUPPORTING ASSET MANAGEMENT

The *Transportation Asset Management Guide: A Focus on Implementation* describes an asset management maturity scale that agencies can use to assess their current practices and to identify steps that might be taken to better adopt asset management principles (AASHTO 2011). In the early stages of the maturity scale, agencies may be collecting required data, but the use of the information in making decisions is limited. If management systems such as pavement management or bridge management are in place, the information may be used to support decisions for that class of assets only. This is commonly referred to as an "organizational silo" operation in which decisions about individual assets are made independently of other assets.

As agencies progress through the maturity scale, more structured business processes are created to support the decisions within each organizational silo to reach the performance targets established by the agency. At these levels, decisions continue to be made vertically within an organizational silo. It is not until the final stages of the maturity cycle that agencies begin to evaluate trade-offs across organizational silos so the impact of different investment levels in one asset can be evaluated in terms of the impact on other asset classes. In organizations at these levels, both vertical and horizontal decisions are being made to achieve agency performance targets. A graphical representation of the horizontal and vertical flow of information is illustrated in Figure 2-4.

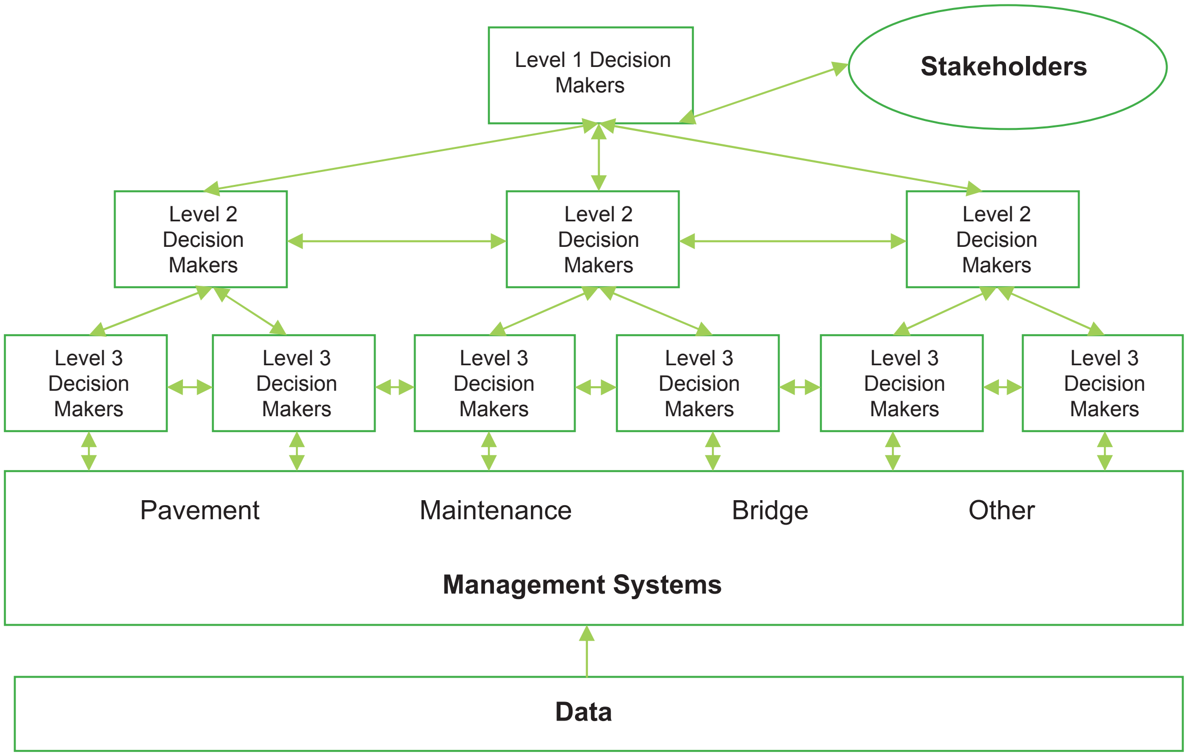



**Figure 2-4. Horizontal and Vertical Flow of Information Within a Transportation Agency (Adapted from AASHTO 2011)**

As shown in the figure, management systems serve as the basis for the information used to make decisions at each level. For pavements, a pavement management system provides the information needed to assess funding needs, to determine the impacts of different funding levels on pavement conditions, and to determine reasonable performance targets. Other management systems, such as bridge management or maintenance management systems, perform similar functions for other transportation assets including bridges and roadside hardware (e.g., guardrail, pavement striping), respectively. One of the responsibilities of upper-level management is to consider the information from these management systems to establish agency priorities and to allocate funds accordingly. In highly performing agencies, agency priorities and performance targets are aligned with investment decisions, and the project and treatment recommendations from the management systems are also aligned. This concept is presented graphically in Figure 2-5.

In this environment, a pavement management system has an important role in providing the answers to the five core questions introduced earlier in Section 2.2, as shown in Table 2-2. For instance, the pavement management inputs help address the first question of what the agency owns and what condition it is in. The analysis capabilities help agencies evaluate a reasonable performance target, taking into account the current network conditions and the anticipated budget levels. The performance modeling component of a pavement management system helps address the third question by simulating the various conditions under which pavements deteriorate. This helps address at least one aspect of the risk factor: the likelihood of failure. The fourth of the core questions asks what investment options are available and pavement management has a long history of providing information to address this question. The results of the analysis can be used to illustrate the consequences of different investment strategies on long-term network conditions. This information is invaluable as agencies seek to answer the fifth core question about which funding strategy is best for the agency from a long-term point of view. Clearly, pavement management plays a critical role in asset management.

**Table 2-2.** Use of Pavement Management to Answer the Five Core Questions

| Core Question | Pavement Management Information to Answer the Core Questions |
|---|---|
| 1. What is the current state of our assets? | • Inventory<br>• Location<br>• Condition<br>• Remaining service life |
| 2. What is the required level of service? | • Forecast conditions under different financial scenarios |
| 3. Which assets are critical to sustained performance? | • Rate of deterioration<br>• Likelihood of failure under different financial scenarios |
| 4. What are the best investment options available? | • Forecast conditions under different financial scenarios<br>• Forecast conditions using different treatment strategies (e.g., fixing the worst roads first) |
| 5. From a long-term point of view, what is the best funding strategy for the agency? | • Recommendations for funding levels and corresponding project and treatments to achieve agency goals |

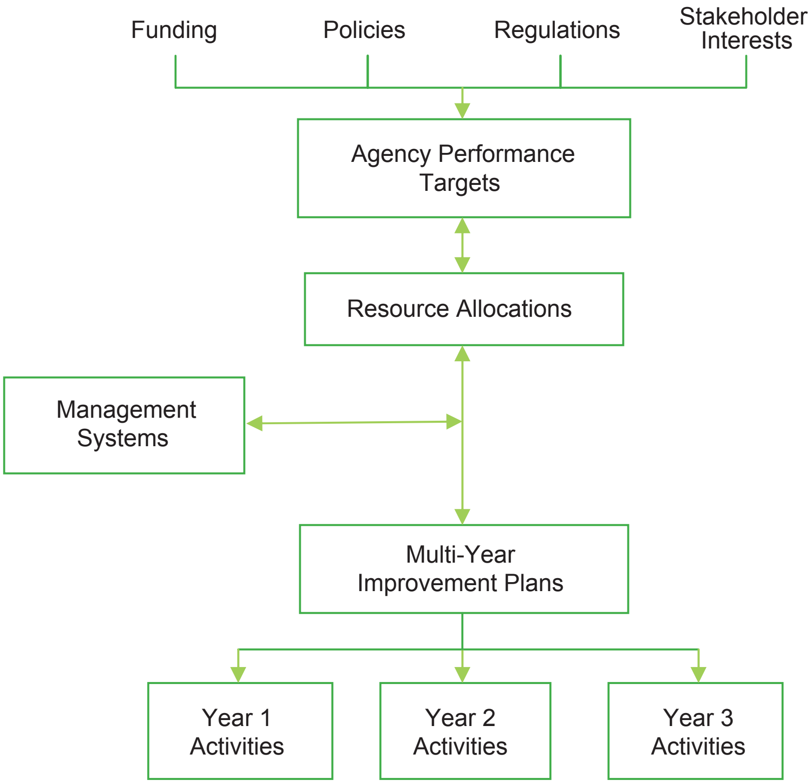



**Figure 2-5. Alignment of Agency Decisions in an Asset Management Environment**

## 2.6 BENEFITS OF USING PAVEMENT MANAGEMENT

Agencies that regularly employ pavement management concepts for managing their road network have recognized the following benefits (AASHTO 2001; FHWA 2010b):

- The identification of strategies for using available resources more effectively to improve pavement performance.
- The ability to justify and secure increased funding for pavement maintenance and rehabilitation activities.
- The ability to defend needs for pavement maintenance and rehabilitation.
- Improved access to information about the road network.
- A better sense of current and future road conditions and needs.
- The ability to identify and communicate the consequences of agency decisions on current and future pavement conditions.
- The ability to better respond to queries from both internal and external stakeholders.
- Improved transparency in decisions regarding the maintenance and rehabilitation of the pavement network.
- An improved understanding of pavement performance under different conditions.
- Improved decisions based on sound technical data.
- Better credibility with various stakeholders.
- Provides data that can be used to set performance criteria for performance specifications and warranty contracts.

For the most part, the benefits realized through the use of pavement management are relatively subjective in nature and difficult to quantify in monetary terms. However, as available resources become increasingly scarce, and transportation agencies look for methods to reduce costs, it is becoming more important to be able to quantify the benefits of pavement management to help justify the costs associated with data collection, software licenses, and personnel.

Two prominent studies have been conducted to try to quantify the benefits associated with pavement management. Hudson et al. (2000) reported that the Arizona DOT realized savings of at least $30 for every dollar spent on the development, implementation, and operation of the pavement management software. The study found that if user costs had been considered, the savings would have increased to approximately $250 for every dollar spent. As documented earlier in Section 2.1, Cowe Falls et al. (1994) reported that for every dollar spent on pavement management by the Province of Alberta over a five-year period, the return in terms of user cost savings or savings in asset value was nearly 100:1. In both studies, the benefits were based on improvements in pavement conditions associated with changes in the project and treatment selection process as the agencies shifted from a "worst-first" strategy to a mix of more cost-effective treatments.

## 2.7 CHAPTER SUMMARY

The importance of managing transportation assets effectively is a central theme throughout this chapter, which begins with an introduction to asset management and presents the philosophies upon which it is based. The five fundamental questions that every agency should be able to answer about its assets are also introduced.

Pavement management emerged in the late 1960s and early 1970s as one of the largest and most expensive assets maintained by highway agencies. This chapter introduces the concepts of pavement management and the components that are common to most pavement management systems being used today. The relationship between pavement management and asset management is also introduced, as are the benefits of the use of pavement management practices.

CHAPTER THREE

# Inventory Data Collection and Data Integration Issues

## 3.1 TYPES OF INVENTORY INFORMATION NEEDED TO SUPPORT PAVEMENT MANAGEMENT

### 3.1.1 Basic Inventory Information

Pavement inventory data are very important features of a pavement management system given that this information identifies, classifies, and quantifies various aspects of the pavement network. To be effective, these data items must be relevant to an agency's pavement management goals and kept up-to-date as new construction projects extend the highway network or change its characteristics. Fortunately, most major pavement inventory items are well defined through industry standard descriptions, with other unique features being included on an agency by agency basis. The level of detail per inventory feature, and the ability to integrate between pavement and other roadway information, is dictated by each agency's goals and how they want to support decision making over a wide range of critical pavement responsibilities (planning, design, maintenance, and construction).

Inventory features to describe the general pavement section include the following (Khattak 2008; Dewan and Smith 2003):

- Segment beginning and end points
- Route designation along with the route type (Interstate, U.S., County, City)
- Functional classification of the road
- Segment length
- Average pavement width
- Pavement type
- Shoulder type
- Shoulder width
- Number of lanes in each traffic direction

The information listed above should be considered the minimum amount of inventory information needed to support a pavement management system. This information is typically collected by logical pavement segments and the location of each segment is referenced through an offset to a known reference point or by Global Positioning System (GPS) coordinates.

Other pavement characteristics to be considered for inventory include:

- Layer type (e.g., HMA, portland cement concrete (PCC)).
- Layer thicknesses (all layers above subgrade).
- Layer material properties (e.g., strength, gradation).
- Joint spacing (for jointed PCC pavements).
- Transverse joint load transfer.
- Subgrade type and material classification (according to AASHTO or the United Soil Classification System (USCS)).
- Drainage information.
- Environmental or location information (e.g., region, climate factors, precipitation, freeze-thaw).
- Pavement history data (e.g., construction date, type and scope of original construction, and maintenance and rehabilitation projects).
- Cost data (e.g., construction, maintenance, or user costs, or some combination thereof).
- Ownership information (e.g., jurisdiction—state or local agency).

More detailed information may be needed to support pavement management activities for many reasons. For instance, calibrating the prediction models included in the MEPDG will require section-specific information about material properties, climate, and traffic. Additionally, establishing different treatment cost models for various geographic regions of the network will require more specific information regarding geographic location or region. Therefore, it is important that agencies evaluate the information needed to support their decision processes as they develop their pavement inventory.

### 3.1.2 Traffic Data Collection

Traffic volume and loading influence all phases of the pavement life cycle and are therefore essential elements of a pavement inventory. Existing and projected traffic demands influence both network- and project-level pavement management decisions. The service provided by road segments is a criterion in network-level prioritization decisions while estimates of the loads that a pavement will experience over its design life are an essential input for designing adequate pavements (Li et al. 2009). Agencies have varying traffic data needs; therefore, each agency might utilize different traffic data collection equipment, coverage, frequency, and reporting criteria. The *Traffic Monitoring Guide* prepared by the Federal Highway Administration (FHWA 2001b) provides a basic traffic data collection framework for agencies. This document provides guidance on traffic volume, vehicle classification, and truck weight monitoring. *NCHRP Report 509* entitled *Equipment for Collecting Traffic Load Data* is another good resource for use in developing or redesigning traffic monitoring programs (Hallenbeck and Weinblatt 2004). This report identifies the key issues in selecting traffic equipment and technology for collecting the truck volumes and load spectra needed for analysis and design of pavement structures.

Updated versions of the AASHTO *Guide for Design of Pavement Structures*, which is based on the equivalent single-axle load (ESAL) estimates, have been used for several decades in the United States (Banerjee et al. 2009). In this design approach, all types of expected wheel loads are converted into an ESAL, which is used as the standard traffic load input. The MEPDG proposes the use of axle load spectra instead of ESAL, which is a dramatic change for pavement design (NCHRP 2004b; Li et al. 2009). The use of axle load spectra provides a more accurate representation of the traffic loads for the design lanes. This new design approach considers load estimates by environmental condition, time (e.g., time of day and season), and vehicle classification. Typical inputs for a load spectrum are vehicle classification counts and weigh-in-motion (WIM) measurements.

The traffic data collection needs for MEPDG were addressed by another NCHRP project (Cambridge 2004). The data items that need to be collected were reported as follows:

- Short-duration classification counts (48-hour, site-specific truck volumes by class, lane, and direction-specific volumes; time of day distributions) where traffic loads will be needed.
- Long-term classification counts (e.g., collected for more than a year) at a limited number of locations around the state.
- WIM data (e.g., truck weights and counts; axle weights by type of axle such as single axle, tandem axle, tridem axle, or quad axle) collection at a limited number of locations.

These data needs are consistent with the general agency counting needs (such as the Highway Performance Monitoring System data) identified by the FHWA's *Traffic Monitoring Guide*. WIM data collection equipment collects both truck volume and load spectra but is more expensive and difficult to operate than equipment that can only count and classify vehicles (Hallenbeck and Weinblatt 2004). Therefore, agencies typically use a combination of WIM and simpler tools to collect necessary inventory data.

The types of equipment and technology available for vehicle classification counts and WIM can be categorized by the type of data collected or by whether the sensors are placed in or on the roadway surface (intrusive sensors) or whether they are placed above or beside the roadway (non-intrusive sensors) (Hallenbeck and Weinblatt 2004). While portable sensors such as road tubes, piezoelectric sensors, fiber-optic cable, portable inductance loops, and magnetometers are used for short-duration vehicle classification counts; in-place technologies, such as in-pavement sensors based on dual-inductance loops or piezoelectric cables, are more commonly used for long-duration vehicle classification counts. For WIM data, capacitance mats and BL-style piezoelectric sensors are usually preferred for short-duration; whereas permanently mounted weight sensors, such as bending plates, hydraulic load cells, piezoceramic cables, piezopolymer cables, and piezoquartz sensors, are commonly used for continuous WIM data collection.

### 3.1.3 Sources of Inventory Information

The information needed for pavement management within an agency typically comes from separate databases which are often maintained by different divisions. Traffic data are often collected and maintained by traffic or planning division staff, and the maintenance and rehabilitation history is typically archived by construction or maintenance division staff. An NCHRP synthesis on pavement management applications reported that only 25 percent of the road inventory data and less than 6 percent of the traffic data, which are used in pavement management, are collected by pavement management section staff (Flintsch et al. 2004).

Spatial databases are very useful for integrating data that comes from different sources when a common location reference system is used. Although coordinate-based referencing methods are becoming popular, the majority of pavement management data are still collected using a linear referencing method, such as an offset to a known reference post (Flintsch et al. 2004). This situation hinders effective integration of different data sets and increases data redundancy. The next sections address location referencing and data integration as a means to increase the efficiency of the pavement management process.

## 3.2 LOCATION REFERENCING SYSTEMS (INCLUDING SEGMENTATION)

The focus of state DOTs is changing from planning, designing, constructing, and then rebuilding assets to managing the life cycle of these assets. This new focus means that DOTs are taking on the role of operating facilities, which changes their data needs and requirements to not only include facility inventory and condition assessment but also real-time operations data (traffic), incident management, and driver information systems to support decision making.

Existing location referencing systems (LRSs) at the state and local levels are almost exclusively linear and highway or street oriented. The changing role and focus of DOTs, as well as the emergence of GPS and other spatial technologies, are driving the need for an LRS that can accommodate and integrate data expressed in multiple dimensions. Transportation agencies already manage data that are referenced in one, two, and three dimensions. However, these data are usually managed in incompatible formats and are reliant on technologies and databases that cannot be integrated.

The ability to relate multiple location referencing methods for a single asset is what makes an LRS an ideal tool when integrating data among different systems to support comprehensive decision making. For example, smoothness data (IRI) are based on fixed linear segments, while friction data or falling weight deflectometer (FWD) are based on point data.

An LRS contains multiple location reference methods, each referring to assets or attributes, or both, for a single asset within their reference framework. This feature is why an LRS can serve as an ideal tool when integrating data among different systems to support comprehensive decision making. Ten core functional requirements were synthesized from the results of an NCHRP 20-27(3) workshop in an effort to form the essence of the LRS data model in dealing with processes, attributes, or both (Adams, Koncz, and Vonderohe 2001). The list below describes the core functional requirements that might impact a management system implementation:

1. Spatiotemporal Referencing Methods—A comprehensive, multidimensional LRS data model must support the processes to locate and position objects and events in three dimensions and time relative to the roadway.
2. Temporal Referencing System/Temporal Datum—A comprehensive, multidimensional LRS data model must accommodate a temporal datum that relates the database information to field locations and that also provides the domain for transforming data across temporal referencing methods. For that reason, a known time is associated with the data.

3. Transformation of Data Sets—A comprehensive, multidimensional LRS data model must support transformation among linear, nonlinear, and temporal referencing methods without loss of spatiotemporal accuracy, precision, and resolution.
4. Historical Databases—A comprehensive, multidimensional LRS data model must support regeneration of object and network states over time and maintain the network event history.
5. Object-Level Metadata—A comprehensive, multidimensional LRS data model must store and express object-level metadata to guide general data use.
6. Temporal Topology/Latency—A comprehensive, multidimensional LRS data model must support temporal relationships among objects and events and support the latency of events (e.g., the difference in time between scheduled events and actual events occurring at a particular location).
7. Various conceptual data models to represent highway and highway systems.
8. Location reference methods and location referencing systems to support highway mile post systems.
9. Reference systems to support changes or updates of the linear datum; for example, as would occur when reference points were added or deleted, or when new measures were determined between reference points and/or along an entire route.

The LRS is the foundation of a road data management system and hence the key to data integration. Any LRS, by nature, is temporal due to roadway geometrical changes such as road realignment, adding or deleting lanes, and adding or deleting road segments.

An LRS can support transformations between location referencing methods and segmentation of data. This functional requirement is a critical component to integrating data from different sources. Segmentation is the process of transforming linearly referenced data that have been stored in a table into features that can be displayed and analyzed on a map using transformation rules. For example, a transportation agency may segment a highway network by pavement type or condition. Attribute information describing characteristics specific to each highway segment can then be maintained without splitting the highway network. This process facilitates the transformation of data from different sources to defined segments or to new segments based on user requirements. Figure 3-1 shows the segmentation and transformation of data from different sources (pavement condition data in terms of IRI, traffic data in terms of average annual daily traffic (AADT), and pavement inventory data in terms of pavement type). The transformed data allow the user to assess the pavement condition based on pavement type and at the same time determine the AADT for those segments. Transformation rules should be identified for each data item so that the data can be transformed accurately and consistently every time. In this example, the IRI values are transformed based on calculating an average IRI since the IRI segment lengths are constant, while AADT is based on a weighted average by length since the segments are variable in length.

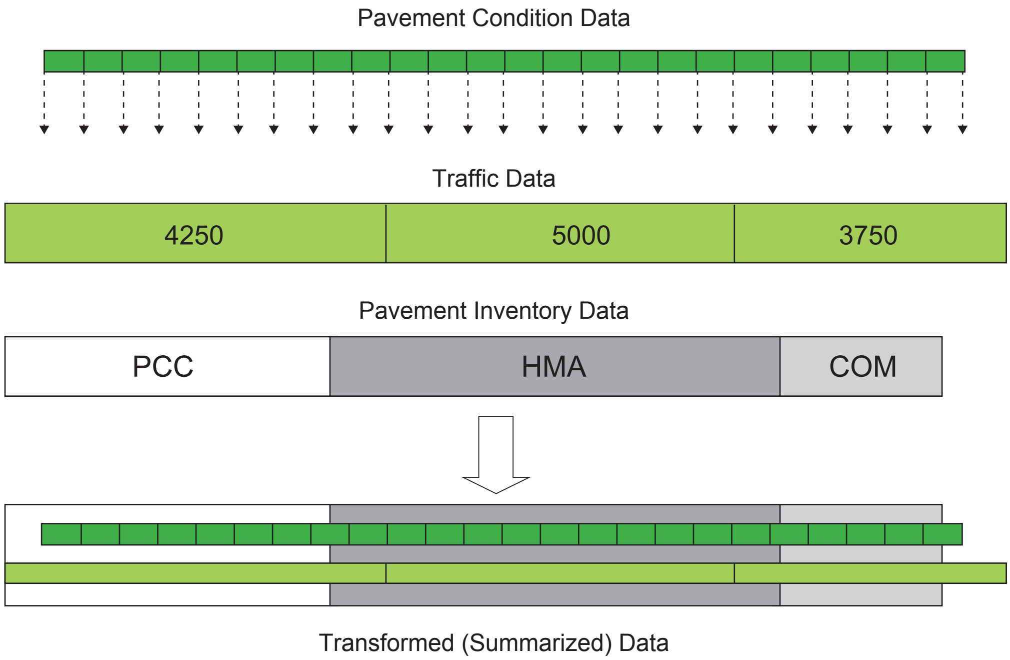



**Figure 3-1. Data Transformation from Different Sources**

## 3.3 DATA INTEGRATION APPROACHES

### 3.3.1 Background

Useful and reliable data are central to a fully functioning pavement management process (or any asset management system). Pavement management can be a data intensive process that involves the gathering, retrieval, storage, analysis, and communication of enormous quantities of information. The decisions that are drawn from these data are essential to the consistent, objective, and informed decision-making process underlying pavement management.

Data inputs are required to evaluate and monitor the condition and performance of the pavement asset, to maintain an asset inventory, to develop performance objectives and measures, and to identify cost-effective investment strategies. Although it is not necessary to store all of the transportation system's data in a single repository, it is critical that the data be readily accessible and comparable. Data integration and data sharing, therefore, are vital components of any management system.

FHWA defines data integration as the "process of combining or linking two or more data sets from different sources to facilitate data sharing, promote effective data gathering and analysis, and support overall information management activities in an organization" (FHWA 2001a).

In order to create the data integration process, sources of available data are considered in the context of likely needs of users. Applications are constructed that help translate the data into useable forms and formats, allowing for transformation of the information into new formats that meet those needs.

Beyond management systems, the incentives for data integration are readily apparent to organizations that collect, store, and manage disparate databases. Agencies that combine or link their multiple databases can reduce data collection and management costs, improve the accuracy and timeliness of the information output, and support a variety of applications that draw data from various sources.

### 3.3.2 The Need for Integrated Data

In an organizational context, stewardship refers to management's responsibility to properly utilize and develop its resources, including its people, its property, and its financial assets. Fiscal stewardship requires a balancing of investment which is affordable and sustainable over time (Walker 2007). Asset management, like pavement management, relies heavily on highly organized and integrated databases to drive its many decision support functions. With data integration, not only can individual departments within an agency access the information needed to make informed decisions about their own assets, but the impact of their decisions on other departments is also clearer, and the potential for synergistic decision making increases.

As more and more transportation agencies implement successful management systems, the importance of data integration rises. For example, information systems used for pavement management, including design, construction, rehabilitation, and maintenance, commonly draw inputs from several data sources within an agency. Many transportation agencies have thus created effective databases and procedures for populating them. However, bringing the information from these disparate systems into a common decision-making framework exponentially increases the value of the information collected.

In an age of information, the basic benefits of information sharing are easy to imagine. In a transportation era marked by increased demand for both mobility and accountability, certain benefits advance to the forefront.

Pavement decisions are an example of an agency consideration that benefits from the availability of integrated data. For example, with proper data integration, a pavement manager can have access to the maintenance history for each pavement section, even if the information is maintained by Operations and Maintenance. Similarly, the pavement performance trends developed by pavement management can be used by field personnel to help determine the most appropriate treatment for a given set of conditions. Together, these benefits improve agency performance and provide an enhanced return on the taxpayer's investment in the agency.

Other benefits driving the adoption of data integration practices among transportation agencies include the following (FHWA 2001a):

- **Availability/Accessibility**—Asset data that are easily retrieved, viewed, queried, and analyzed by anyone within an agency encourages the integration of such data into every area of an agency that can benefit from it, spurring both innovation and better decision-making.
- **Timeliness**—Well organized data can be quickly updated; one input will often apply the data across a variety of linked systems, and the information can be time-stamped to reflect its currency.
- **Accuracy and Integrity**—Errors are greatly reduced because the integration environment drives a higher quality of input and can include automatic or convenient error-checking and verification.
- **Consistency and Clarity—**Integration requires clear and unique definition of various types of data, avoiding confusion or conflict in the meaning of terms and usage.

- **Completeness—**All available information, including both historical and recent data, is accessible in an integrated database, with any missing records or fields identified and flagged via the integration process.
- **Reduced Duplication—**Identical data are eliminated, reducing the need for multiple updates and ensuring everyone is working from the exact same information.
- **Informed and Defensible Decisions—**Highly organized, comprehensive databases allow users to drill down through successive levels of detail for an asset, supplying more information to support decisions and supporting different types of analysis using various data combinations.
- **Greater Accountability—**Data integration allows rapid and more accurate reporting of costs and accomplishments, including full attribution of results to relevant agency units and functions.

### 3.3.3 Data and Process Flow

The data integration process includes major steps covering a requirements analysis, the modeling of data and process flow, and database design and implementation. This section further describes the data and process flow modeling.

The data and process flow modeling uses the information obtained from the requirements analysis to build diagrams depicting the flow and use of data across the agency. The objective of data and process flow modeling is to create a picture of the relationships between information and the business functions that the information supports. Data flow diagrams help database engineers and analysts determine the design specifications for the data integration system. All data and business processes identified in the requirements analysis can be captured in flow diagrams. A variety of software products exist to support this function (FHWA 2001a).

To understand how data flow through an organization or agency division, analysts must know who collects the data, where the data are stored, who uses the data, and what levels of access users need (e.g., whether they need to modify, to view, or to update the data). It is also important to find out who "owns" the data, to provide guidelines or structure for its stewardship, and to establish a system of governance that protects the integrity of the data. The example in Figure 3-2, illustrates a section of a Data/Process Flow Diagram for a pavement management system. It depicts data and process flow for three interrelated pavement management functions (inventory, condition assessment, and maintenance and rehabilitation evaluation). Note that the diagram shown is only one section of a larger flow diagram that would depict all the pavement management functions involved. In Figure 3-2, evaluation of maintenance requirements is dependent on both inventory and condition assessment.

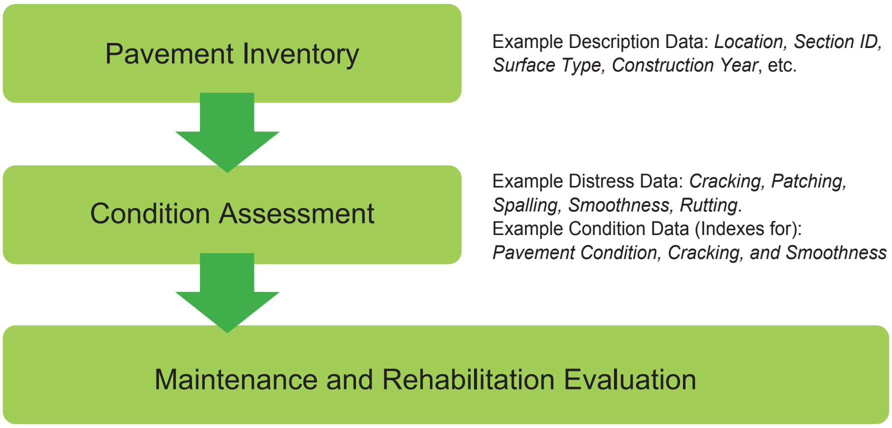



**Figure 3-2. Data and Process Flow Modeling: A Pavement Management Example**

### 3.3.4 Role of Geographic Information Systems

A geographic information system (GIS) is a computerized database management system for storing, managing, retrieving, querying, analyzing, and presenting spatial data. A GIS contains two types of information: spatial data and attribute data. Spatial data define line, point, or polygon objects (elements) located on the surface of the earth. Information associated with these objects is stored in attribute tables. A GIS differs from other graphical presentation systems, such as computer-aided design (CAD), in that the information attached to each graphic element is tied to a database in a very efficient manner. The efficiency of the link between the map and the information allows a management system that is tied to a GIS to be very fast and very efficient in retrieving data related to a specific physical location and allows for complex data analysis.

A traditional GIS database, without dynamic segmentation capabilities, is somewhat limited in its ability to manage and present multiple integrated data sets describing a single feature, such as a pavement section. The GIS database typically includes all data sets combined in a single database table. New records, and corresponding graphic elements, are then created when attribute values, such as pavement type, change. All data sets are reduced to the smallest segmentation, resulting in a significant amount of attribute data redundancy.

Another potential method to manage data sets is to maintain each attribute table separately. A one-to-one relationship between attribute records and graphic elements must be maintained within the GIS, resulting in network (graphic) redundancy. This redundancy may be reduced if all attribute records, in all attribute tables, share the same linear extents. Multiple attribute records can then share the same graphic representation. However, this separation limits flexibility in data collection and maintenance.

A final method, which is certainly the most robust, is dynamic segmentation. Dynamic segmentation facilitates data integration and allows for sharing of agency data internally and externally. As described in the section on LRS, dynamic segmentation is the process by which linearly-referenced data can be transformed so the information can be used for other purposes.

The spatial nature of GIS also enables the use of spatial referencing methods to identify the location of attribute data. In other words, coordinates identify the location of a point or linear extent along a highway. These coordinates may be either geographic (e.g., longitude, latitude) or projected (e.g., State Plane).

GIS tools facilitate better communication of the agency needs and resources and serve as a communications tool for staff at all levels. Maps showing the pavement condition color coded with red referring to *poor* pavements and blue indicating *excellent* pavements is just one example of how GIS can be utilized in communicating the information from the pavement management system. Figure 3-3 shows an example from the Iowa Pavement Management Program (IPMP) depicting pavement ratings based on a pavement condition index (PCI).

Figures 3-4 and 3-5 show how GIS can be utilized to perform quality assurance on pavement distress, data collection, and data quality. Figure 3-4 shows a GIS map of routes that need to have pavement data collected, data delivered so far in terms of batches, and the remaining system to be collected/delivered. Figure 3-5 shows continuous segments where all distress values are zeros. The map is used to assess the validity of the distress data.

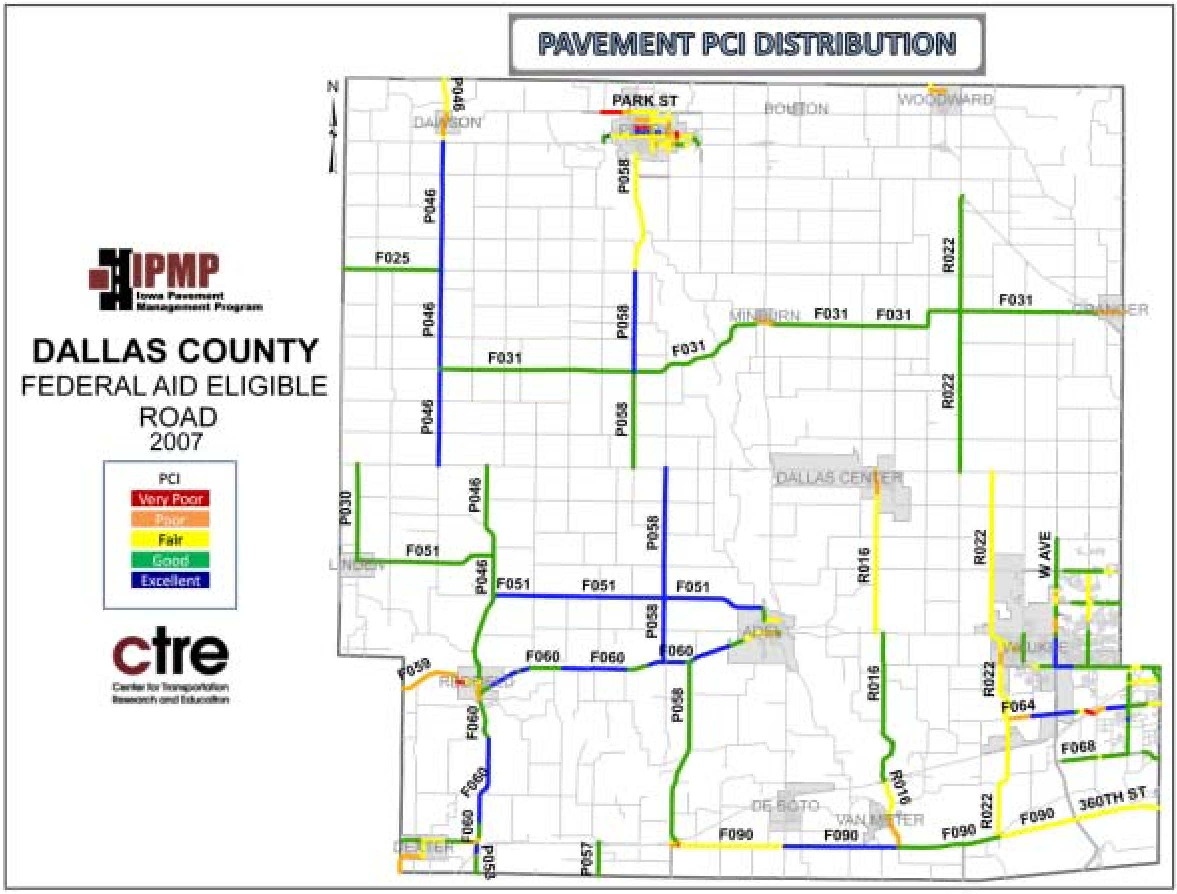



Figure 3-3. Map Indicating PCI Distribution for Dallas County, Iowa (ISU 2007)

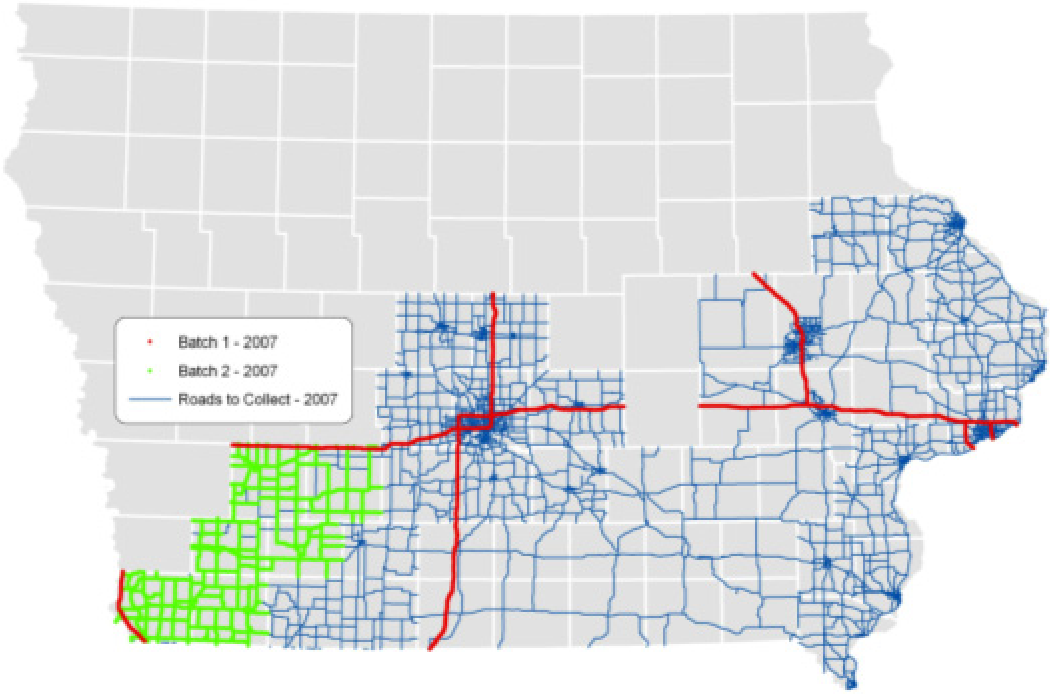



**Figure 3-4. Map Indicating Data Collection Progress Monitoring (Zhang and Smadi 2009)**

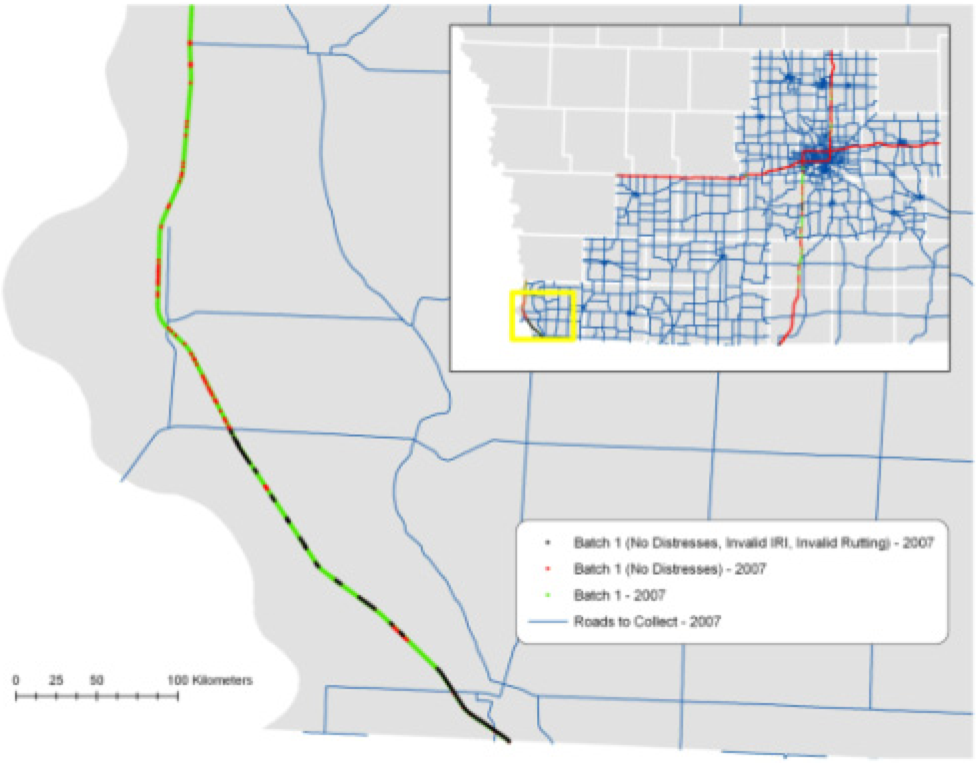



**Figure 3-5. Map Indicating Quality Assurance for Distress Data Using GIS (Zhang and Smadi 2009)**

## 3.4 DATA MANAGEMENT

### 3.4.1 Information Systems Infrastructure

Managing and integrating multiple data sources across an agency can be a significant challenge. For example, many agencies use GIS software to manage a wide range of data inputs; however, for the system to meet the users' needs, it is important to ask what other software platforms contain information that must be identified, understood in context, and, eventually, harvested, to build the integrated system. Developing a clear view of existing resources helps the agency determine which software, hardware, and communications strategies will be required to integrate databases.

From this analysis, the agency can then gauge its level of readiness for data integration. Most importantly, the analysis helps identify which potential data integration strategy can best marry the existing resources with the new infrastructure.

Useful information at this stage of the process includes an inventory of existing computer programming environments and database management or mapping software or servers, as well as computer hardware and operating systems.

### 3.4.2 Database and Database Management Characteristics

Key information to be considered when analyzing existing data and database systems within an agency might include:

- Data sources and individuals responsible for maintaining the data.
- Methods and frequency of data collection.
- Location referencing systems associated with the data.
- Data structure, format, and size.
- Methods of data transmittal, processing, and storage.
- Use of data (e.g., in business processes and in relationship to other user needs).
- Applications that draw data from existing databases (e.g., bridge management systems and pavement management systems).
- Types of reports that are currently produced or are needed.

### 3.4.3 Documentation (Metadata)

Metadata is a set of information that is needed to best access, understand, and use other information in a database or information environment. In other words, it is data about data.

Exponential growth in the Internet and other communications channels, as well as improved access to all forms of information, has challenged government, business, and others to effectively manage ever more complex sets of data. This change has driven the need for standardized ways to manage information about such content, spawning the concept of metadata.

Developing and associating metadata to database inputs is imperative to ensure the utility of the data collected and in securing the ability to update and access the information in the future. Metadata sometimes refers to information that a computer or program can read and understand in order to organize the location, delivery, or storage of data. Other times it refers to records that describe information available electronically. It can involve any level of information access, from a single record to a large, aggregated database.

A variety of metadata standards and models have evolved in the highway industry, and some of these have their own sub-layer of standards (e.g., taxonomy, vocabulary, thesauri) to convey additional information. Sets of metadata, often called metadata schemes, might be expressed in a variety of different programming languages, and communicated in a variety of forms or syntaxes, such as in HTML or XML. An example of metadata is provided in Table 3-1.

**Table 3-1.** Example of Metadata (ISU 2007)

| Field | Name | Type | Units | Comments/Description |
|---|---|---|---|---|
| 1 | Sec_num, Pave_ID | Decimal | | Unique record identifier |
| 2 | Ipmp_rte | Char | | IPMP GIS database/Iowa DOT road name |
| 3 | Loc_rte | Char | | Local agency road name |
| 4 | Lit_desc | Char | | Literal description of section location |
| 5 | Co | Char | | County number for the county where city is located |
| 6 | City | Char | | City number |
| 7 | Gen_surf_t | Char | | Current (general) surface type from local agency (P-PCC, A-ACC, C-Combination) |
| 8 | Const_yr | Decimal | | Year constructed from local agency |
| 9 | Fed_fc | Decimal | | Federal functional classification |
| 10 | Avg_liri | Decimal | m/km | Average left IRI, 999=invalid value |
| 11 | Avg_riri | Decimal | m/km | Average right IRI, 999=invalid value |
| 12 | Avg_lrut | Decimal | mm | Average left rut |
| 13 | Avg_rrut | Decimal | mm | Average right rut |
| 14 | Alig_m | Decimal | m^2 | Area of medium severity alligator cracking |
| 15 | Alig_h | Decimal | m^2 | Area of high severity alligator cracking |

Metadata can help organize a set of data, and it can also help facilitate the migration of existing blocks of information into an integrated environment, including both interoperable and fused databases. It also aids tremendously in the recovery of information from integrated databases.

## 3.5 CHAPTER SUMMARY

The availability and accessibility of reliable inventory and condition information is key to the success of a pavement management system. Because of the number of sources of pavement management data, data integration and data sharing are critical to the success of pavement management. This chapter introduces several methods of integrating pavement management data, including the use of a GIS for data storage, retrieval, analysis, and presentation. The chapter also identifies strategies for managing data effectively.

CHAPTER FOUR

# Pavement Condition Assessment

## 4.1 INTRODUCTION

Pavement condition assessment is the process of collecting and processing indicators of pavement condition. From the preceding discussion it is clear that information about the current condition of pavements is a key component of a data-driven pavement management process. Examples of this process are displayed in Figure 4-4. Pavement condition data allows an agency to answer essential questions related to the condition of pavements and make associated relevant decisions based on the answers (Table 4-1). A discussion about pavement performance is, in effect, a discussion about the results of a condition assessment. As such, assessing pavement condition is a part of every agency's pavement management process.

There are several different approaches to condition assessment, distinguished by the extent of the assessment, the level of the detail collected, and the assessment tools used. For example, at the most detailed level, a project-level investigation is conducted on isolated pavement sections. A project-level investigation may be conducted as a forensic study to explore the causes and possible solutions to specific performance problems, or it may be conducted to obtain the inputs needed to design an appropriate rehabilitation strategy on a pavement that has already been flagged for capital improvement. In either case, project-level evaluations are typically quite detailed and exhaustive, and may use many different destructive and nondestructive testing tools.

For pavement management purposes, a typical assessment is carried out at the network level and is referred to as a "network-level survey." Network-level surveys are usually less detailed than project-level surveys and are conducted on a large portion (or all) of the agency's pavement network. The results of a network-level survey are most commonly used to identify and prioritize treatment needs, to determine funding needs, and to allocate budgeted funds. A summary of an agency's pavement network conditions provides valuable insights on current pavement preservation and rehabilitation needs. Perhaps even more importantly, over time the regular collection of current conditions generates a historical record of the progression of pavement condition, and the collected information can be used to model and predict future conditions. In brief, pavement condition assessment provides the inputs required to describe current pavement performance, to track pavement performance over time, and to predict pavement conditions in the future (both with and without the application of treatments).

At the network level, issues of data quantity and quality are important. Data quantity, in terms of what and how much is measured, has associated implications of time and cost. Generally, the greater the volume of data collected, or the more detailed the data, the higher the cost of data collection. At the same time, better decisions are expected to result from having more, or more detailed, data available for analysis. As such, agencies must strike a balance between collecting all of the condition data that might ever be needed to assist in making effective network decisions versus collecting enough data to make good decisions. This trade-off is in large part governed by agency needs and associated resources. For most agencies, the goals for network-level surveys are to predict appropriate budgetary needs and to evaluate performance of previously implemented strategies. Additional data collection requirements at the network level may be associated with (a) the agency's Pavement Preservation program, (b) specific data required by the FHWA Highway Performance Monitoring System (HPMS) (FHWA 2009b), (c) the FHWA's Infrastructure Health Analysis (FHWA 2011), (d) data required in support of the agency's performance management activities, or (e) calibration and verification activities associated with implementing the new MEPDG (AASHTO, 2008).

Data quality is also an important consideration in data collection. While quality can be thought of as synonymous with accuracy, there are several ways in which the quality of performance data may be lacking, including misidentifying a distress or its severity and mislocating or mismeasuring it. No matter what the cause, inaccurate data leads to poor decisions over time, and as it becomes known that the data are inaccurate, agency confidence in the system will deteriorate, and the data will lose most of their value. Therefore, a section on improving data quality is included later in this chapter.

Data consistency is also an important consideration in data collection. There are currently no standardized data collection and processing techniques being used consistently by state DOTs, which makes it difficult for states to compare conditions with one another. The different approaches used in data collection may also result in variability in the condition ratings within a single agency from one year to another if different outside vendors are hired to collect the data. This variability may also be impacted by changes in equipment or technology, or both, used for data collection. National efforts to standardize some aspects of the data collection process are discussed in a section on data collection standards and protocols, which is included later in this chapter.

Finally, agencies should consider available resources in planning condition assessment activities because the data must be collected regularly to keep the pavement management system up to date and reflecting actual conditions. This is usually a challenge because agency personnel often try to collect as much information as possible. An important part of the planning process for condition assessments is determining exactly what information is necessary to support the key decision processes and then determining the most effective methods of collecting the data.

### 4.1.1 Types of Pavement Condition Data Collected

The quality of decisions made in pavement management is largely a function of the data available to support those decisions. There are many different types of data that may be collected and many different ways to collect those data. While there should be a direct link between data needs and decision-making, most agencies approach data collection in a manner that addresses the unique aspects of the agency's network, including network size, available resources, past practice, and many other factors. However, the types of pavement condition data normally collected by transportation agencies can generally be characterized into one of the following three categories:

1. Distress: observations of visible conditions on or along the pavement surface provide either direct identification of the cause of performance problems or are indications of underlying performance problems. Distress information is particularly helpful in selecting specific pavement preservation and rehabilitation treatments and in planning long-term management programs.
2. Structural capacity: the load-carrying capability of a pavement can be determined several different ways. Available tools measure a pavement's response to applied loads, identify sub-surface conditions that may lead to structural problems (such as sub-surface voids or moisture and poor joint load transfer), and provide indirect measurements of intrinsic strength/stiffness properties. Poor structural capacity indicates that major rehabilitation or reconstruction is needed.
3. Surface characteristics: measurements of a pavement's longitudinal profile or smoothness, surface texture (for frictional properties), and noise are all performance measures that relate to customer concerns. A pavement may be free from most visible distresses and have good structural capacity but still exhibit surface characteristics warranting some sort of surface repair. As discussed later in Section 4.3.3, longitudinal profile and surface texture properties may be collected with distress information as part of a network-level pavement condition survey, depending on the type of equipment used.

### 4.1.2 Data Collection Techniques

The techniques available for collecting pavement condition data vary based on data type. NCHRP Synthesis 401 (Flintsch and McGhee 2009) summarizes the different approaches to data collection. Two important issues are summarized below:

1. Data collection method: available methods include manual, automated, and semi-automated (a combination of automated and manual). Where once all assessments could be done by one person manually rating observed conditions, today the size of pavement networks, the need for objective measurements, the concerns associated with the safety of survey crews, and the complexities associated with generating and analyzing large amounts of data in a timely manner all point toward the use of more automated approaches.

   A related issue is nondestuctive testing (NDT) versus destructive testing. The results from destructive testing (e.g. coring and boring) can be analyzed to provide direct measures of material properties, including layer types and thicknesses, layer strength and stiffness, material quality, and the location of voids and saturated materials. However, destructive testing is usually slow, generates far fewer data points than NDT for the same amount of time, and is more disruptive to traffic. As such, most network-level data collection is nondestuctive in nature (e.g., longitudinal profile monitoring). Destructive testing is more commonly associated with project-level evaluations.
2. Data collection practice: data collection may be performed using either agency resources (in-house) or contractors. There are many factors that affect this decision, and most agencies use a combination of in-house resources and contracted services.

### 4.1.3 Current Data Collection Practices

Based on the results of a survey of state practices conducted by FHWA, a summary of the condition data typically conducted as part of an agency's pavement management practices is presented in Table 4-1.

**Table 4-1.** Condition Data Normally Collected at the Network Level (Adapted from FHWA 2004)

| | Hot Mix Asphalt Pavement | Jointed Plain and Jointed Reinforced Pavement | Continuously Reinforced Pavement | Composite Pavement |
|---|---|---|---|---|
| States Reporting | 50 | 47 | 21 | 41 |
| Roughness | 98% | 100% | 100% | 100% |
| Rutting | 100% | N/A | N/A | N/A |
| Fatigue or Alligator Cracking | 96% | N/A | N/A | N/A |
| Longitudinal Cracking | 86% | 81% | 90% | 100% |
| Transverse Cracking | 94% | 83% | N/A | 100% |
| Transverse Joint Faulting | N/A | 74% | N/A | N/A |
| Transverse Joint Spalling | N/A | 74% | N/A | N/A |
| Punchouts | N/A | N/A | 86% | N/A |
| Surface Friction | 68% | 66% | 81% | 68% |
| Other | 46% | 47% | 57% | 61% |

As shown in Table 4-1, roughness is most commonly collected on all surface types, but there are many other types of deterioration that are incorporated into network-level survey procedures. The next sections introduce the methods used to collect each of the following types of pavement condition data:

- Pavement Distress Measurement
- Surface Characteristics
  - Longitudinal Profile and Roughness
  - Surface Texture and Friction
- Sub-surface Characteristics
- Structural Evaluation

## 4.2 PAVEMENT DISTRESS MEASUREMENT

As pavements age and are exposed to the environment, vehicle loadings, and wear, they deteriorate. The signs of such deterioration are eventually seen in the form of pavement distress. Visible distresses are those that can be identified and quantified by visual examination of a pavement's surface. Measuring and cataloguing such distresses is commonly done as part of a pavement condition survey, and the results are often organized according to the distress type, severity, and extent. Visible distress surveys are a common component of many agencies' pavement management practices; they have been performed for decades and can be completed with a minimum investment in tools and technology. This section identifies common distress types that are included in pavement management surveys, introduces standards for reporting pavement distress, and describes common methods of collecting distress information.

### 4.2.1 Distress Types

There are at least two commonly used documents that describe pavement distress in detail: the FHWA's *Distress Identification Manual for the Long-Term Pavement Performance Program* (FHWA 2003) and ASTM D6433, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*. The FHWA Manual was first published in the late 1980s in support of the Strategic Highway Research Program's Long-Term Pavement Performance (LTPP) project. It was developed as a tool to help researchers around the country collect pavement performance data in a consistent, repeatable manner that was independent of the collector and perhaps even of the collection method, although it was aimed at the manual survey methodology. An intended side benefit was that "the manual will improve communications within the pavement community by fostering more uniform and consistent definitions of pavement distress (FHWA 2003)." Each distress type is defined in the manual and illustrated both with graphics and photographs; most distresses are subdivided into low, moderate, and high severity levels. Table 4-2 shows the organization of the content of this manual by surface type and distress type.

A second, widely used guide to pavement distresses is ASTM D6433, *Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys*. The distresses defined in this ASTM International standard are a part of a standardized pavement assessment process that results in the calculation of a pavement condition index (PCI), a rating on a scale of 0 to 100 that is used extensively by the U.S. Army Corps of Engineers, the Department of Defense, airports, and various local agencies to quantify pavement conditions. For evaluation purposes, PCI distresses are categorized by pavement type (asphalt pavements and jointed concrete pavements) and rated by severity (low, medium, and high). PCI distresses are summarized in Table 4-3.

**Table 4-2.** Pavement Distresses Identified in the FHWA's Distress Identification Manual (Adapted from FHWA 2003)

| Asphalt Concrete Surfaces | Jointed Portland Cement Concrete Surfaces | Continuously Reinforced Concrete Surfaces |
|---|---|---|
| **Cracking** | **Cracking** | **Cracking** |
| 1. Fatigue cracking | 1. Corner breaks | 1. Durability cracking ("D" cracking) |
| 2. Block cracking | 2. Durability cracking ("D" cracking) | 2. Longitudinal cracking |
| 3. Edge cracking | 3. Longitudinal cracking | 3. Transverse cracking |
| 4. Longitudinal cracking | 4. Transverse cracking | |
| 5. Reflection cracking at joints | | **Surface Defects** |
| 6. Transverse Cracking | **Joint Deficiencies** | 4. Map cracking and scaling |
| | 5. Joint seal damage | 4a. Map cracking |
| **Patching and Potholes** | 5a. Transverse joint seal damage | 4b. Scaling |
| 7. Patch/patch deterioration | 5b. Longitudinal joint seal damage | 5. Polished aggregate |
| 8. Potholes | 6. Spalling of longitudinal joints | 6. Popouts |
| | 7. Spalling of transverse joints | |
| **Surface Deformation** | | **Miscellaneous Distresses** |
| 9. Rutting | **Surface Defects** | 7. Blowups |
| 10. Shoving | 8. Map cracking and scaling | 8. Transverse construction joint deterioration |
| | 8a. Map cracking | 9. Lane-to-shoulder dropoff |
| **Surface Defects** | 8b. Scaling | 10. Lane-to-shoulder separation |
| 11. Bleeding | 9. Polished aggregate | 11. Patch/patch deterioration |
| 12. Polished aggregate | 10. Popouts | 12. Punchouts |
| 13. Raveling | | 13. Spalling of longitudinal joints |
| | **Miscellaneous Distresses** | 14. Water bleeding and pumping |
| **Miscellaneous Distresses** | 11. Blowups | 15. Longitudinal joint seal damage |
| 14. Lane-to-shoulder dropoff | 12. Faulting of transverse joints and cracks | |
| 15. Water bleeding and pumping | 13. Lane-to-shoulder dropoff | |
| | 14. Lane-to-shoulder separation | |
| | 15. Patch/patch deterioration | |
| | 16. Water bleeding and pumping | |

**Table 4-3.** Pavement Distresses Identified in ASTM D6433

| Distress in Asphalt Pavements | Distress in Jointed Concrete Pavements |
|---|---|
| Alligator cracking (fatigue) | Blowup/buckling |
| Bleeding | Corner break |
| Block cracking | Divided slab |
| Bumps and sags | Durability ("D") cracking |
| Corrugation | Faulting |
| Depression | Joint seal damage |
| Edge cracking | Lane/shoulder drop-off |
| Joint reflection cracking | Linear cracking (longitudinal, transverse, and diagonal cracks) |
| Lane/shoulder drop-off | Large patching (more than 5.5 $ft^2$) and utility cuts |
| Longitudinal and transverse cracking | Small patching (less than 5.5 $ft^2$) |
| Patching and utility cut patching | Polished aggregate |
| Polished aggregate | Popouts |
| Potholes | Pumping |
| Railroad crossing | Punchout |
| Rutting | Railroad crossing |
| Shoving | Shrinkage cracks |
| Slippage cracking | Scaling, map cracking, and crazing |
| Swell | Corner spalling |
| Weathering and raveling | Joint spalling |
| [Ride quality, a separate "distress," is actually an input in determining the severity level of bumps, corrugation, railroad crossings, shoving, and swells] | [Ride quality is an input in determining the severity level of blowup/buckling and railroad crossings] |

In addition to the FHWA and ASTM descriptions of distress, some agencies have developed their own distress identification manuals (e.g. Mn/DOT 2003, KTC 2006) either as a stand-alone reference or as a supplement to FHWA's manual. Developing and using agency-specific descriptors of pavement distresses may serve several purposes, including the following:

- More specifically apply to the different types of pavements for which the agency is responsible.
- More accurately reflect local performance, which can vary by environment, materials, and loading, for example.
- Identify severity levels that reflect local trigger or action levels.
- Be compatible with the methods that are used to collect visible distress data.

There is no universally used or correct approach to data collection. In a recent survey of agency practice, respondents indicated that their agencies collected a broad range of distress data (Flintsch and McGhee 2009). Only rutting was recorded by all responding agencies, as shown in Figure 4-1, and practices otherwise varied considerably.

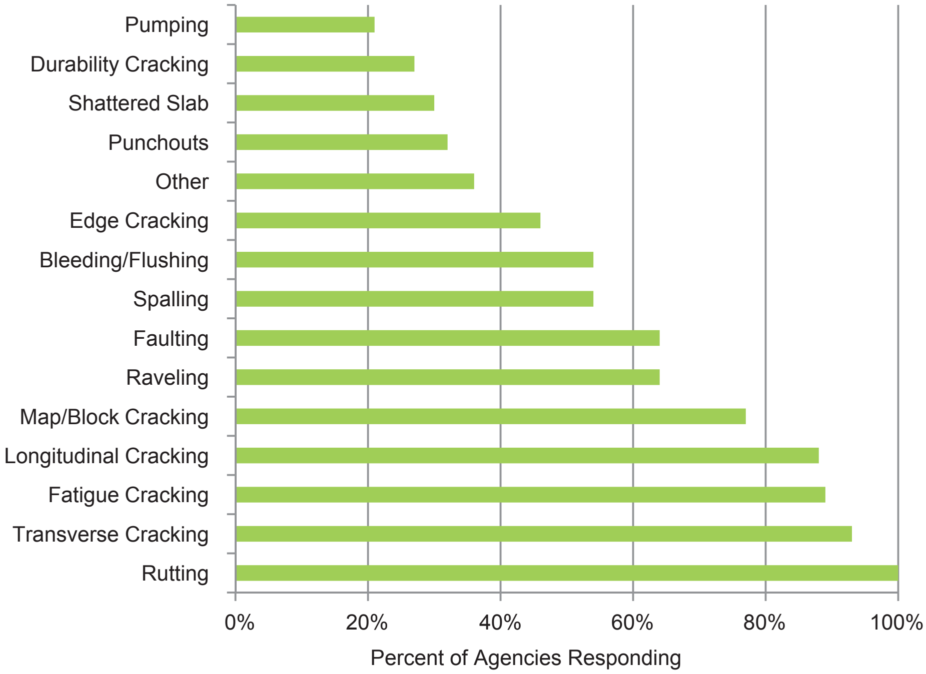



**Figure 4-1.** Types of Distress Data Collected (Adapted from Flintsch and McGhee 2009)

### 4.2.2 Distress Protocols

The previously cited FHWA and ASTM documents on distress identification provide useful details on how to identify and rate different types of distress; however, many highway agencies have developed survey procedures that do not follow these methodologies exactly. As a result, there is a great deal of variability in the way distress information is collected and reported. Because of this lack of consistency, the following specifications were developed:

- AASHTO R 48: *Standard Practice for Determining Rut Depth in Pavements (AASHTO 2010a)*
- AASHTO R 36: *Standard Practice for Evaluating Faulting of Concrete Pavements (AASHTO 2012)*
- AASHTO R 55: *Standard Practice for Quantifying Cracks in Asphalt Pavement Surface (AASHTO 2010b)*

The evolution of the standards is discussed in Section 4.9.1.

Potential benefits of that initiative include more standardized distress definitions that could be applied by all agencies (which in turn would permit comparisons among agencies) and availability of a standard that could be used in automated distress surveys by any manufacturer's vehicle.

One of the biggest obstacles to the implementation of standard distress definitions is that agencies have made significant investments in whatever technologies they are currently using. Furthermore, they may have many years of performance records and resulting performance models based on their current practices. As a result, they would have little incentive to change practices solely based on the ability to compare their pavement distress measurements with others.

### 4.2.3 Techniques for Collecting Pavement Distress Information

In this section, two additional characteristics associated specifically with collecting distress information, regardless of the data collection method, are presented:

1. The use of measured or estimated distress quantities.
2. The use of sampling techniques.

Each of these characteristics has a significant influence on the resources required to collect pavement condition information and the eventual use of the data. Therefore, it is important that each of these characteristics is understood by agencies as they develop their techniques for collecting pavement distress information.

Section 4.6 discusses the three approaches used to collect and process pavement condition information: manual surveys, automated surveys, and semi-automated surveys.

#### 4.2.3.1 Measured Versus Estimated Distress Quantities

The FHWA and ASTM distress data collection approaches cited in Section 4.2.2 both rely on raters who identify distress type, severity, and extent as part of the survey process. As described in the references, raters are responsible for measuring the amount of each distress and severity level present. Although the distress information can be obtained either in the field for manual surveys or from digital images for automated surveys, both survey approaches were initially developed based on concepts that did not consider the use of automated equipment. For instance, the depth of a pothole is a factor in determining its severity. Nevertheless, it is difficult to determine a third dimension, such as pothole depth, from a two dimensional image.

Depending on the size of the pavement network, a methodology that requires distress severity to be measured can be a very resource intensive way to collect pavement distress information; however, because distress quantities are measured, it is a survey method that produces relatively consistent results when collected manually, which is why it was chosen by the FHWA for its research activities. Because of the objectivity of this type of procedure, reasonable estimates of maintenance work requirements can be produced from the results.

Because of the resource requirements associated with survey procedures that require raters to measure distress quantities, a number of agencies have instead elected to use survey procedures in which the quantity of distress is estimated rather than measured. This adjustment simplifies the rating procedure considerably, which translates into a process that is less labor intensive. However, there is more subjectivity involved in estimating distress quantities, and unless the raters are well trained, there is the possibility that the results will have more variability than if distress quantities had been measured.

#### 4.2.3.2 Sampling

Another way to reduce the resource requirements associated with distress data collection is to inspect only a representative portion of each road section rather than the entire area. Because of the level of detail involved in the rating process, the ASTM methodology utilizes a sampling approach. For this type of survey, randomly selected sample units of a fixed length are inspected. These sample units are assumed to be representative of the conditions across the entire pavement section; therefore, the distress found in the sample unit can be assumed (or extrapolated) across the rest of the section to determine the pavement condition. If a randomly selected sample unit is NOT representative of the overall section condition, or if it falls within an atypical portion of the section (e.g., a bridge approach), a different sample unit should be inspected.

The number of sample units that are inspected in a given pavement section can be determined statistically or through a defined sampling plan. Many highway agencies, for example, elect to inspect the first 500 ft of every mile if they use a sampling approach. The ASTM standard, on the other hand, recommends the use of 2,500 $ft^2$ sample units on HMA roads and streets. In general, a higher degree of sampling is required when a higher level of confidence is required or when there is considerable variability in the overall pavement condition.

## 4.3 SURFACE CHARACTERISTICS

A pavement's surface characteristics affect key aspects of its performance, including ride and friction. More recently, attention has also been given to the relationship between surface characteristics and noise[1]. These three surface characteristics are all related to one property, surface texture, which is defined as the deviation of the pavement from a true planar surface (AASHTO 1993). Although surface characteristics are only a small part of the total pavement structure, it has a tremendous impact on the safety and comfort of highway users. Pavements that are built and maintained to have good surface characteristics typically exhibit fewer crashes and improved rideability (TxDOT 2003, Viner et al. 2004, Hill and Starrs 2011).

Pavement surface texture is subdivided into three distinct groupings by their wavelength ($\lambda$) and peak-to-peak amplitude (A) and defined by the Permanent International Association of Road Congresses (PIARC 1987), as follows:

- Microtexture ($\lambda$ < 0.02 in. [0.5 mm], $A$ = 0.04 to 20 mils [1 to 500 $\mu$m])—Surface roughness quality at the sub-visible/microscopic level. It is a function of the surface properties of the aggregate particles within the asphalt or concrete paving material.
- Macrotexture ($\lambda$ = 0.02 to 2 in. [0.5 to 50 mm], $A$ = 0.005 to 0.8 in. [0.1 to 20 mm])—Surface roughness quality defined by the mixture properties (shape, size, and gradation of aggregate) of a bituminous paving material and the method of finishing/texturing (dragging, tining, grooving; depth, width, spacing and orientation of channels/grooves) used on a portland cement concrete paving material.
- Megatexture ($\lambda$ = 2 to 20 in [50 to 500 mm], $A$ = 0.004 in to 2 in [0.1 to 50 mm])—This type of texture has wavelengths in the same order of size as the pavement–tire interface. It is largely defined by the distress, defects, or "waviness" on the pavement surface.

1 Considered as a group, these characteristics refer to a pavement's functional performance, defined as the ability of the pavement to serve the users for whom it was designed (AASHTO 1993). Functional performance measures focus on characteristics important to the driver, while structural performance, or the pavement's ability to carry the loads for which it was designed, are a primary concern of the designer and owner.

Wavelengths longer than the upper limit (20 in [500 mm]) of megatexture are defined as roughness or unevenness (Henry 2000). Figure 4-2 illustrates the three texture ranges, as well as a fourth level—roughness/unevenness—representing wavelengths longer than the upper limit (20 in [500 mm]) of megatexture.

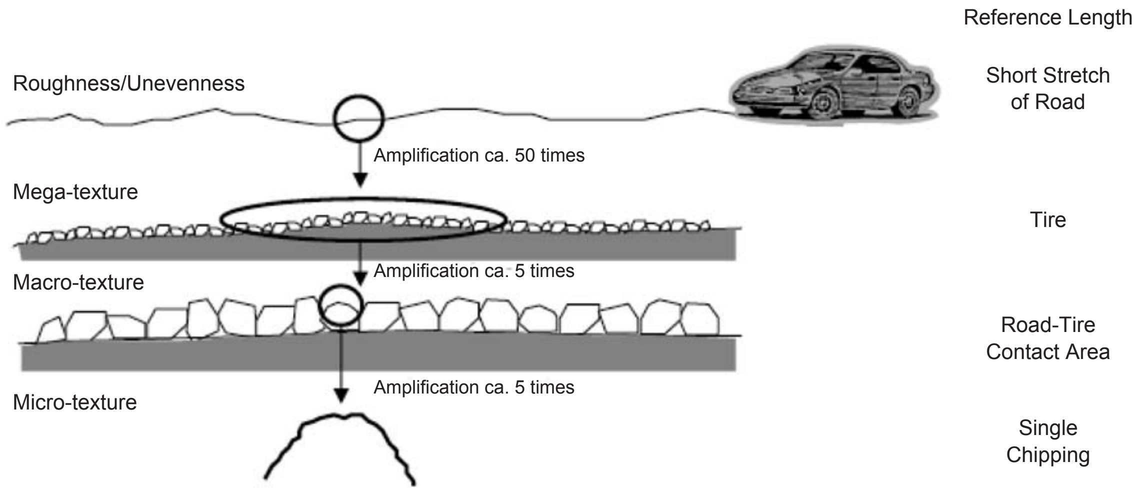



**Figure 4-2. Surface Texture Ranges (Sandburg 1998)**

As shown in Figure 4-3, pavement surface texture influences many different pavement–tire interactions, including friction, interior and exterior noise, splash and spray, rolling resistance, and tire wear (Rasmussen et al. 2011). As shown, friction is affected primarily by microtexture and macrotexture, ride is primarily affected by megatexture and roughness/unevenness, and noise is affected by macrotexture and megatexture.

Surface characteristics are of varying importance to those charged with managing pavements. There are several potential reasons for this variance, including the following:

- They are measures that are important to users, and different users may attribute different levels of importance to these attributes. For example, tire–pavement noise is not a big concern to users in rural areas, while the noise may be a very important concern to those living along urban freeways.
- Functional performance is not necessarily linked to structural performance, which is very important to the owner.
- As a surface characteristic, there are several different, comparatively inexpensive techniques that can be used to alter the surface texture of a structurally sound pavement, including partial removal (e.g., diamond grinding and milling), retexturing (e.g., shot blasting and hydroblasting), and thin resurfacing (e.g., certain pavement preservation treatments).

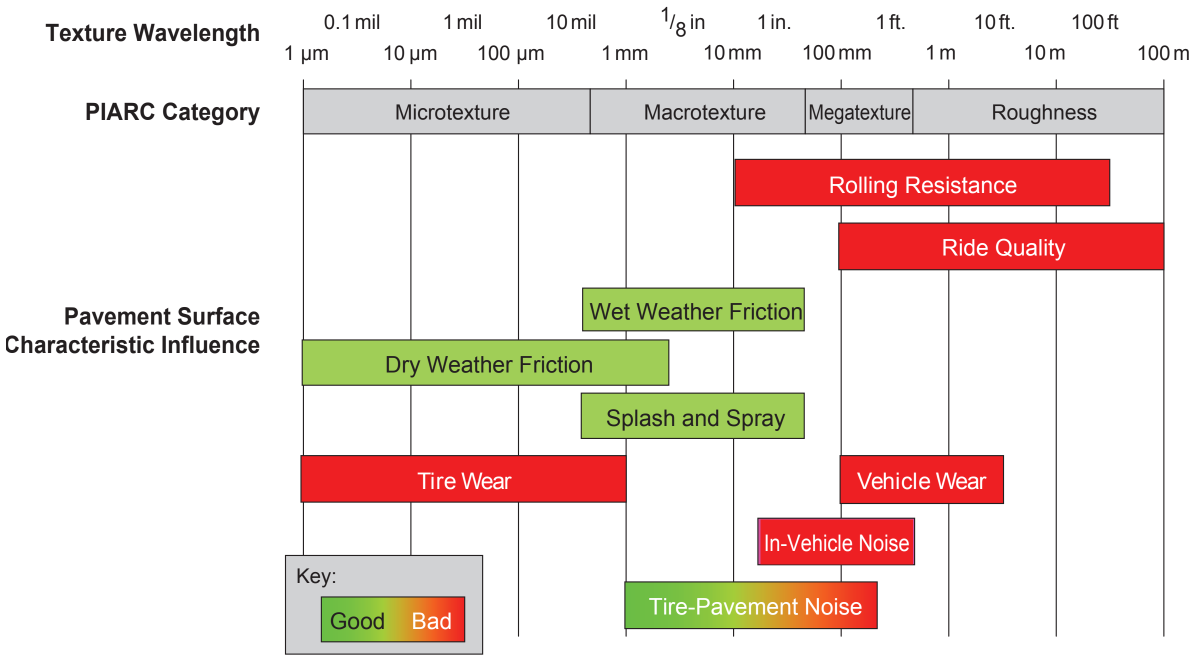



**Figure 4-3. Illustration of PIARC Pavement Surface Characteristics (Rasmussen et al. 2011)**

At the present time, the regular monitoring of surface characteristics as part of pavement management is primarily restricted to longitudinal profile (Flinch and McGhee 2009). In addition to monitoring longitudinal profile, some agencies monitor surface texture either directly or indirectly (by measuring friction or skid); however, with the increasing emphasis on safety concerns, there is growing interest in incorporating this type of information into a pavement management analysis. Because of the repeatability of these measures, they are also becoming increasingly important as criteria for developing performance metrics for use with warranties and other performance-based contracts. Few agencies monitor noise at a network level, but this practice could also become more common in the future.

### 4.3.1 Longitudinal Profile and Roughness

The attribute that is probably of most interest to the traveling public is a pavement's ride, roughness, or smoothness, all of which are ways of referring to the unevenness of the pavement's longitudinal profile affecting pavement–vehicle interaction. There are several different ways of measuring the longitudinal profile. One indirect measurement method is the present serviceability rating (PSR) or some variation thereof, developed during the AASHO Road Test, in which users ride the road and rate its acceptability on a scale from 0 to 5, where 5 is the best possible condition.

Because individual ratings can be highly subjective, the PSR was replaced for analysis and design purposes with the present serviceability index (PSI), in which road roughness and distress are measured and the results are reported on the same 0 to 5 scale. The primary component of the PSI is roughness, which was often monitored using response-type road roughness measurement devices (such as the Mays Meter) that measured the response to irregularities in the longitudinal profile of a vehicle or towed trailer and reported the results in inches per mile.

Over time, as technology has advanced, the measurement of longitudinal profile has evolved to the use of laser-based inertial referencing systems (profilers) in which accelerometers are used to create an inertial plane of reference and vehicle-mounted lasers are used to measure vertical deviations from that plane. These profilers offer very good repeatability and can operate at posted highway speeds, so they are commonly used for network-level surveys.

Other types of devices for measuring roughness satisfy other purposes. For instance, walking profilers are typically used for calibrating profiling equipment. Other devices, such as straightedges, rod-and-level, profilographs (primarily on PCC pavement), non-contact lightweight profilers, and portable profilers are typically used for construction quality control. A summary of the various types of equipment used for measuring roughness is provided in Table 4-4.

**Table 4-4.** Summary of Roughness Measurement Equipment (Smith et al. 1997; Grogg and Smith 2002)

| Device | Advantages | Disadvantages |
|---|---|---|
| Dipstick® | • Lower initial cost.<br>• Easy operation.<br>• Accurate.<br>• Can be used to calibrate other profile devices. | • Slow operating speed of 0.2 mph (0.3 kph).<br>• Not ideal for measuring long project lengths.<br>• Not suitable for network level data collection. |
| Walking Profilers | • Lower initial cost.<br>• Easy operation.<br>• Accurate.<br>• Can be used to calibration other profile devices. | • Slow operating speed of 0.5 mph (1 kph).<br>• Not suitable for network level data collection. |
| Profilographs | • Low cost.<br>• Easy operation.<br>• Lightweight.<br>• Analog trace of pavement deviations.<br>• Locates bumps and most grinds. | • Slow operating speeds of 2 to 3 mph (3 to 5 kph).<br>• Lack of precision.<br>• Does not provide true profile.<br>• May not relate to user response. |
| Response-Type Road Roughness Measuring System (e.g., Mays Ride Meter, the PCA Roadmeter, and the CHLOE profiling device) | • Initial and operating costs are low.<br>• Data normally collected at a speed of 50 mph (80 kph).<br>• Reasonably accurate and reproducible. | • Roughness results affected by the mechanical system and the speed of travel.<br>• Does not provide true profile.<br>• Devices require calibration over a range of speeds and pavement roughness levels.<br>• Comparability of roughness results between devices is poor. |
| Profilers | • Very good repeatability.<br>• Operates at posted highway speed.<br>• Measures true profile. | • Higher initial cost.<br>• Not conducive to quality control during paving operations. |
| Non-contact Lightweight profilers | • Lower initial cost than high-speed profiler.<br>• Lightweight design allows use within hours of paving.<br>• Measures true profile.<br>• Identifies areas of bumps and dips. | • Not suitable for network level data collection.<br>• Requires traffic control during operation. |

There are a number of specifications and test methods available for profile measurement. For network-level activities, the following specifications are most relevant:

- AASHTO M 328, *Standard Specification for Inertial Profiler*—defines the equipment specifications for inertial profiler systems.
- AASHTO R 54, *Standard Practice for Accepting Pavement Ride Quality when Measured Using Inertial Profiling Systems*—provides guidance for developing incentive and disincentive specifications.
- AASHTO R 56, *Standard Practice for Certification of Inertial Profiling Systems*—provides instructions for profiler certification.

- AASHTO R 57, *Standard Practice for Operating Inertial Profiling System*—provides operational and maintenance guidelines for inertial profilers.

In addition, the FHWA has developed a *Manual for Profile Measurements and Processing* (Perera, Kohn, and Rada 2008) as part of its LTPP program. The manual includes the following recommendations:

- A full calibration check of the laser sensors every 30 days.
- Calibration of the accelerometers under the following conditions:
  - Values exceed the allowable range.
  - The results of the bounce test indicate a potential problem.
  - Repairs have been made to the accelerometers or anything associated with the accelerometers.
- Calibration of the Distance Measuring Instrument (DMI) and temperature probe every 30 days.

While a focus on longitudinal profile is warranted solely because it represents how road users respond to a pavement's condition, there are other important reasons to monitor it. These include the effect of rough roads on vehicle operating costs (such as tire wear, vehicle maintenance, and vehicle repairs) and the increase in fuel consumption associated with riding on rougher roads.[2]

### 4.3.2 International Roughness Index

Longitudinal profile is typically reported in terms of the International Roughness Index, or IRI, a standardized method of reporting roughness that is designed to be independent of the measurement device. Originally developed by the World Bank for use in the Highway Development Model (HDM), today it is widely used around the world to help manage pavement networks. In the United States, IRI roughness results are usually reported in inches per mile (in/mi) or meters per kilometer (m/km) on an increasing, boundless scale (1 m/km = 63.36 in./mi). Therefore, a perfectly smooth pavement (which is generally considered to be impossible to achieve) would have an IRI of 0. Acceptable IRI values are influenced by the normal traffic speed on the facility, since roughness is less acceptable at higher traffic speeds. For example, the FHWA uses an IRI value of 170 in./mi as the dividing line between *good* and *bad* interstate pavements. Higher IRI values would typically be allowed on non-interstate pavements with lower traffic speeds. This relationship to traffic speeds is reflected in Figure 4-4, which shows typical IRI ranges.

2 AASHTO's *Rough Roads Ahead* report estimated that driving on rough roads adds $334 annually to the cost of operating a car (2009). Amos (2006) reports a 2.4 percent improvement in fuel consumption following a 53 percent improvement in smoothness in Missouri, while an analysis of vehicle operating costs from the WesTrack study showed that trucks consumed 4.5 percent less fuel operating on smooth roads (FHWA 2000a).

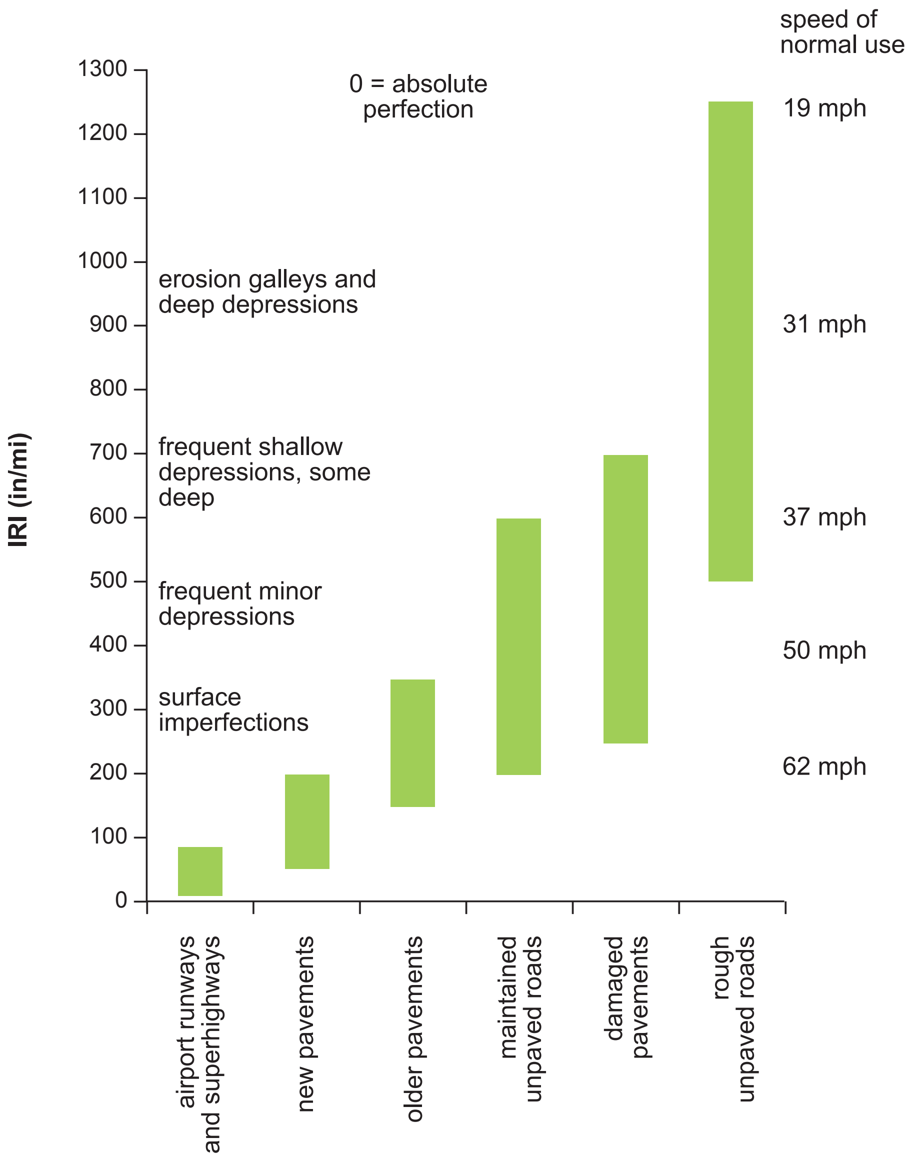



**Figure 4-4. IRI Range by Roadway Type (Adapted from Sayers and Karamihas 1998)**

Guidance on the calculation of IRI can be found in the AASHTO *Standard Practice for Quantifying Roughness of Pavements*, AASHTO R 43M/R 43, which calls for the use of a longitudinal profile measured in accordance with ASTM E950 as a basis for estimating IRI.

### 4.3.3 Surface Texture and Friction

Pavement surface texture is becoming increasingly important in pavement management because of national efforts to improve safety. The surface texture characteristics described earlier, including micro-texture and macrotexture, influence a pavement's wet weather friction characteristics and the potential for hydroplaning. Good surface texture characteristics can also help to reduce splash/spray, provide good visibility in wet and dark conditions, and help to reduce pavement–tire noise and rolling resistance. A 2005 survey of highway agencies found that few agencies test and monitor surface characteristics such as microtexture and macrotexture (Hall et al. 2009). Rather, the survey revealed that most agencies monitor wet pavement friction or highway crash rates, or both, to identify potentially unsafe areas. Friction and surface texture results are not normally part of the network-level pavement management surveys, and the results are not frequently considered in pavement management software when developing treatment recommendations. For the most part, this is because testing has been conducted on an as-requested basis rather than as part of a network-level survey. However, there is evidence that the macrotexture information used to estimate IRI can also produce profile statistics such as the Mean Profile Depth (MPD), which can be correlated with the sand patch test used for measuring surface texture (Cairney and Styles 2005). ASTM E1845 provides a method for calculating the mean profile depth from a profile of pavement macrotexture.

Surface texture is an important consideration in managing pavements because relatively minor improvements in surface texture can have a significant impact on reducing crash rates. For instance, the literature indicates that increases in texture depth from 0.3 mm to 1.5 mm can reduce the crash rate by approximately 50 percent, while increasing the skid resistance from 0.35 to 0.6 reduces the crash rate by about 65 percent (Viner et al. 2004). In the United States, the Texas Department of Transportation estimates that its pavement surface texture measurement system will save twelve lives, prevent 1,100 accidents, and save $5,922,000 in its first 10 years (TxDOT 2003). Initiated in 1999 as part of its Wet Weather Accident Reduction Program (WWARP), laser macrotexture measurements are collected in conjunction with friction testing to develop correlations between macrotexture and friction numbers. Approximately 25 percent of the network is collected each year, with the exception of the interstate where 50 percent of the network is collected yearly.

Techniques for measuring surface texture differ depending on whether devices are intended to measure surface friction (e.g., skid) or surface texture characteristics. There are four basic types of full-scale friction measuring devices: locked wheel (such as ASTM E274 trailer), side force (such as the MuMeter or SCRIM), fixed slip (such as Griptester), and variable slip (such as Norsemeter) (Henry 2000). There are also devices for measuring surface texture. Some, such as the British Pendulum Tester and Dynamic Friction Tester, are static tests to measure pavement microtexture. Others, such as the sand patch, are static measures of macrotexture. For pavement management purposes, there is promise in the use of high-speed, noncontact laser-based systems that include a point-type laser sensor mounted on the bumper of a vehicle. These devices are now being manufactured by a number of different companies and many automated data collection vendors have integrated these sensors into their vehicles.

There are numerous ASTM standards and other specifications applicable, as noted throughout this portion of the guide. These standards apply to standard test methods as well as methods of calculating surface texture parameters.

## 4.4 SUB-SURFACE CHARACTERISTICS

Both visual distress and surface characteristics relate to performance characteristics that are observed or measured at the pavement surface. Observed surface characteristics can be an indication that there is a sub-surface problem; however, sub-surface characteristics may also be directly evaluated to identify conditions that may lead to the development of performance problems before they occur.

Since the late 1980s, ground penetrating radar (GPR) has been available to examine a pavement's sub-surface characteristics. GPR is a nondestructive testing (NDT) method in which radar pulses are used to locate pavement layers with different dielectric constants or permittivity. The most common pavement application for GPR is determining layer thicknesses. However, to the extent that the dielectric constant of many pavement materials is not significantly different, cores are needed to interpret the data. Additional uses of GPR are to identify saturated layers or sub-surface moisture and voids, as the dielectric constants of air (1) and water (80) are significantly different from soils and built up materials. More recent applications include the identification of layers with differential density, such as evaluating an HMA layer, and in performing an initial assessment of sub-surface consistency in support of pavement maintenance and rehabilitation decisions. One difficulty in the use of GPR data is the interpretation of the results. This analysis can be greatly enhanced through selective coring to provide known layer thicknesses.

GPR works by transmitting a pulse of radar energy into the pavement and then measuring the time required for the reflection of the signal to return to the receiver and its amplitude. Cores can be used to calibrate the GPR signal velocity in different types of pavement materials at the project level. The pulse is transmitted to the pavement using an antenna, which is either a ground coupled dipole antenna or an air launched horn antenna. Ground coupled antennas are designed to operate in direct contact with the pavement, and the efficiency of the antenna drops dramatically once it is removed from the surface. In contrast, the air launched horn antenna operates 1 to 2 feet above the pavement. This distance makes the air launched horn antenna ideal for use on pavements and is the type of equipment (with multiple antennas) most commonly used to collect useful pavement layer thickness information at close to highway speeds (Scullion and Saarenketo 2000). The depth to which a GPR can penetrate a pavement structure is dependent on the conductivity of the pavement layers, the signal frequency, and the signal power. These relationships are shown in Table 4-5.

**Table 4-5.** Relationship Between Selected Factors and Depth of Radar Penetration (Noureldin et al. 2005)

| Factors | High | Low |
|---|---|---|
| Material conductivity | Penetration depth is lower with highly conductive materials, including some clays and saturated soils. | Low conductive materials, such as stone or asphalt concrete, generate higher depths of penetration. |
| Radar signal frequency | High frequency radar signals do not penetrate as deeply as low frequency but provide much greater resolution. | Low frequency radar gives greater depth of signal penetration but at a lower resolution. |

The use of GPR as part of a pavement evaluation provides certain benefits, including a reduction in the number of cores that must be taken. Since GPR tests can be performed at near traffic speeds, large amounts of testing can be performed quickly. In addition, characteristics of underlying layers, which cannot be seen from the surface, can be evaluated. However, the testing requires experienced and knowledgeable operators and realistic expectations about its capabilities. For example, pavement thickness studies have shown that differences between GPR thickness measurements are generally within 2 to 10 percent of thicknesses measured from cores, with lower differences generally associated with newly constructed pavements (SDDOT 2006).

## 4.5 STRUCTURAL EVALUATION

A pavement structural evaluation is used to estimate the structural adequacy of an existing pavement to determine whether the pavement can sufficiently meet projected traffic loadings. In situations when the pavement is not adequate to meet projected loadings, the results of the structural evaluation can provide the information needed to design the appropriate treatment.

Because of the level of detail normally associated with this type of an evaluation, structural evaluations are typically conducted as part of a project-level investigation. This may include more extensive pavement condition surveys conducted in conjunction with destructive testing (such as coring and boring) and nondestructive testing using pavement deflection devices. Although this type of evaluation is normally conducted at the project level, there are some state DOTs that utilize the results of nondestructive testing at the network level to help determine the appropriate treatment. Coupled with the development of new equipment that can provide an indication of pavement strength at traffic speeds (e.g., the rolling wheel deflectometer), the number of agencies using a structural evaluation to support their pavement management activities is expected to increase.

### 4.5.1 Pavement Deflection Testing

Pavement deflection testing measures the response of the pavement to a load in terms of the resultant pavement deflection. This type of nondestructive testing does not disturb the underlying pavement structure and does not require pavement materials to be removed for laboratory testing. However, it does require accurate pavement thickness information at each test location, so coring is often conducted to verify pavement layer thicknesses.

An example of a typical deflection basin is shown in Figure 4-5. At the project level, the deflection data obtained in the field are used to backcalculate in situ material properties, to calculate pavement stiffness and strains in response to load, and as inputs to other pavement analyses. By plotting maximum deflection measurements with road stations, areas of high deflections can be easily delineated to define project or subproject limits. The deflection information can also be used in deflection-based overlay design procedures.

At the network level, some agencies utilize limited network-level deflection testing to help identify and prioritize rehabilitation needs and treatment strategies. For example, an Indiana Department of Transportation research study found that conducting three deflection tests per mile in the driving lane (in one direction) would allow 100 percent coverage of the network over a five-year period (Noureldin et al. 2005). The information was proposed to be used as part of the Department's pavement management system to supplement the pavement surface condition data already being collected with estimates of pavement structural characteristics. The study also recommended the use of GPR to provide pavement thickness information.

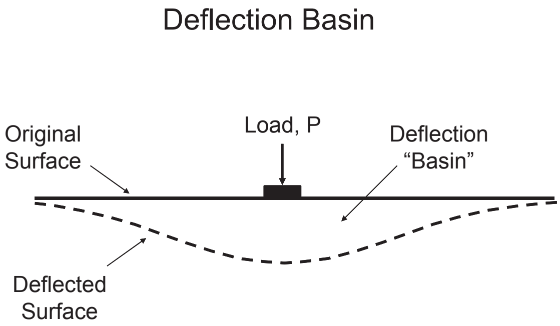



**Figure 4-5. Typical Pavement Deflection Basin (FHWA 2009d)**

### 4.5.1.1 Types of Equipment

There are several different types of pavement deflection devices available, including impulse deflection devices (such as the falling weight deflectometer), steady-state dynamic deflection devices (such as the Dynaflect), and static deflection devices (such as the Benkelman Beam). The falling weight deflectometer (FWD) is the deflection device used most commonly to assess pavement responses (Shahin 2005).

The FWD is capable of simulating the dynamic loads applied to a pavement by wheel loads. The device includes weights, a load plate, and transducers that measure the deflection caused by the load. During testing, a load is applied by dropping a set of weights onto a plate that transmits the load to a circular plate. A range of load magnitudes can be achieved by varying the number of weights used and the heights from which they are dropped. The resulting deflections are measured by transducers located at the center of the load plate and at various operator-selected distances away from the load plate. This is illustrated in the schematic provided as Figure 4-6. Both the maximum surface deflection under the load and the magnitude of the deflection basin are used to provide information on the structural capability of the pavement structure.

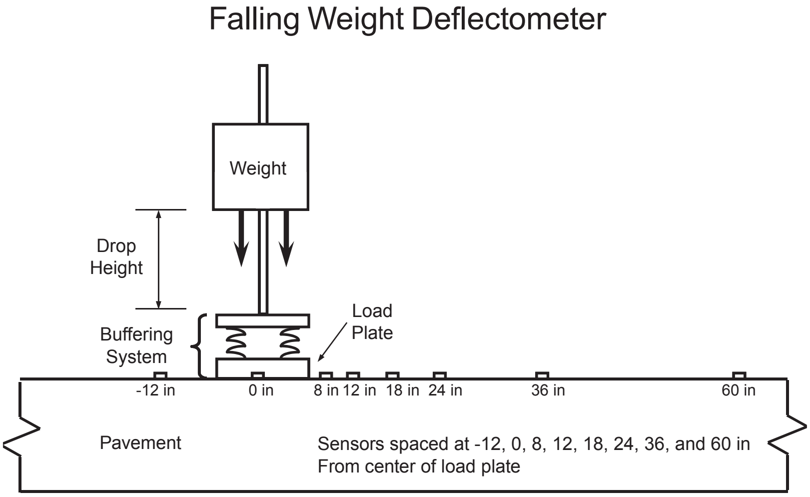



**Figure 4-6. Schematic Diagram of FWD Testing Equipment**

Rather than apply an impulse load, steady-state dynamic deflection devices apply a static preload to the pavement and then apply a sinusoidal load that is measured in terms of amplitude and frequency. The magnitude of the load that can be applied using this type of device is limited and the preload may alter the pavement properties, so that the resulting deflections may not be representative of the deflections that would occur under a moving wheel load. For these reasons, this type of equipment is not used as extensively as the FWD.

The original deflection devices applied a static load to the pavement surface and measured the resulting deflections. The most well-known of the static deflection devices is the Benkelman Beam, which was developed in the early 1950s at the Western Association of State Highway Officials (WASHO) Road Test. The beam is placed on the pavement surface with its probe located between the dual tires of a loaded truck. The rebound of the pavement as the truck moves away is measured and reported. This device has also been replaced by the FWD.

One of the most recent advancements in this area is the work that has been done on advancing the collection of continuous deflection data along the length of a project (FHWA 2009d). The FHWA has supported the development of a Rolling Wheel Deflectometer (RWD), a portion of which is shown in Figure 4-7. This device can provide a relative measure of the structural capacity and stiffness of HMA pavements at traffic speeds, thus overcoming one of the primary disadvantages to the FWD. A plot of deflections versus highway station can be used to identify areas for more detailed inspection and testing using the FWD. The FHWA's RWD is constructed using a specially designed tractor-trailer, which has been designed to control pitch and roll. It has four high precision laser measuring devices that are mounted 8.5 ft apart, with the back laser placed between the rear wheels and just behind the centerline of the rear axle.

**Figure 4-7. Rolling Wheel Deflectometer (FHWA 2008d)**

Another form of continuous deflection-measuring equipment is the Traffic Speed Deflectometer, which was originally developed in Denmark as a deflection measuring device that could operate at traffic speeds and is now available for sale through a private company (Ferne et al. 2009). This device measures pavement response under the rear wheels of the rear trailer using four measurement lasers attached to a rigid steel beam. Testing of the device in both Denmark and the United Kingdom has shown that it can distinguish between strong and weak pavements and shows promise for enabling relationships with stationary testing devices (Ferne et al. 2009).

Another type of nondestructive deflection testing devices includes portable lightweight deflectometers. These devices are more portable than the other devices and are commonly used for localized testing and as QC/QA testing tools for new construction.

#### 4.5.1.2 Testing Approach

Pavement deflection testing with an FWD requires traffic control since the testing device must be stopped at each test location. On flexible pavements, deflection testing is typically conducted in the outer wheelpath, but a testing configuration may test both the inner and outer wheelpaths at staggered intervals. Additional information on recommended FWD testing frequencies is provided in ASTM D4694, *Standard Test Method for Deflections with a Falling-Weight-Type Impulse Load Device*.

## 4.6 NETWORK-LEVEL PAVEMENT CONDITION SURVEY APPROACHES

Pavement management systems are dependent on the availability of reliable pavement condition information for forecasting future conditions, providing project and treatment recommendations, and justifying budget concerns. As one of the most expensive aspects of a pavement management system, it is important that the pavement condition surveys are designed to provide appropriate details so the data can be collected and updated on a regular basis with available resources.

There are two primary methods of collecting pavement condition data: manual and automated. Manual surveys are generally considered to be visual assessments of field conditions conducted by one or more individuals who view the pavement through the windshield of a vehicle or as they walk the pavement. Data from a manual survey may be recorded on a sheet of paper or in a computer. Automated surveys are conducted using vans fitted with specialized equipment. NCHRP Synthesis 334 defined automated data collection as "data collected by imaging or by the use of noncontact sensor equipment" (NCHRP 2004a).

Data collected using automated equipment must be processed to convert it into a usable format. Each agency generally specifies the format in which automated data will be processed. The processing is done using either automated or semi-automated methods. Automated data processing uses computers to interpret, reduce, and analyze the data collected in the field without human intervention. Data collected using noncontact sensors is almost always processed automatically because of the volume of the data collected. Distress images may be processed automatically using computer algorithms that rely on digital recognition software to recognize and quantify differences in the grayscale that relate to striations on the pavement surface (NCHRP 2004a). Data processed in this manner are typically referred to as "fully automated" data collection and processing. Alternatively, the data may be processed at a work station where a human views the images to identify distress information. This approach is referred to as a semi-automated data collection process because it makes use of both automated and manual techniques.

More information on each of these approaches is provided in the remainder of this section.

### 4.6.1 Manual Surveys

According to Automated Pavement Distress Collection Techniques. NCHRP Synthesis of Highway Practice 334 (NCHRP 2004a), approximately half of the state and provincial highway agencies responding to a survey reported using manual survey approaches for collecting pavement condition information. In most cases, these efforts are focused on collecting pavement distress information that is used to report pavement conditions and to identify and prioritize pavement improvement needs. Therefore, many of these agencies use a combination of manual and automated data collection techniques, since other information (e.g., roughness and surface texture information) may be collected using automated equipment. Manual surveys are also more common on low-volume roads where traffic volumes are at levels that do not pose a substantial safety hazard to the survey crews.

There are a number of advantages and disadvantages associated with manual surveys. For instance, since manual surveys include those in which survey personnel walk each pavement section, very detailed distress type, severity, and quantity information can be obtained. These can be relatively subjective surveys, which are easy to conduct, or they can be objective, where distress quantities are usually measured to improve accuracy. Manual surveys do not require any specialized equipment and they provide a means of including assets outside the mainline of the roadway, such as culverts. However, because manual surveys are generally conducted at low speeds by two-person crews, they are slow and fairly labor intensive. The slow speeds increase the potential for safety hazards and many agencies have moved toward automated surveys for this reason. Finally, if subjective survey procedures are used, there is a high potential for variability in the data unless strong training programs are implemented along with quality control checks as surveys are being conducted.

### 4.6.2 Automated Surveys

Many agencies elect to collect pavement condition data using automated equipment because it can be easily obtained using noncontact sensors (e.g., roughness, rutting, and faulting). As technology for this type of data collection activity advanced in conjunction with improvements in digital images, equipment vendors began outfitting vans with cameras, which would allow them to capture pavement images as well as sensor data. Many agencies began using this type of equipment to reduce the potential safety hazards associated with manual survey procedures. Today, automated data collection equipment is available with fully integrated systems that enable a variety of data to be collected in a single pass of a pavement. In addition to pavement condition information, these vehicles can also obtain right-of-way images, grade and cross-slope information, GPS coordinates, and three-dimensional (3-D) images using Light Detecting and Ranging (LIDAR) technology. As technology continues to improve, it is inevitable that the types of data that can be collected, the speed at which it is collected and processed, and the accuracy of the data will continue to evolve.

The accuracy and reliability of the distress data from automated surveys is largely dependent on the quality of the images obtained in the field. Recent enhancements to equipment have focused on improving camera resolution and eliminating the distortions associated with lighting and shadows. Additionally, changes in the availability of scanning lasers have facilitated the collection of 3-D characteristics of the pavement surface, primarily for roughness and rutting (NCHRP 2004a). However, there are some vendors who are using the 3-D images for crack detection by stitching together successive laser scans (NCHRP 2004a).

Agencies that utilize automated data collection technology often deal with inconsistencies in the data collected with different equipment, especially when manufacturers upgrade equipment to take advantage of new technology. Therefore, it is imperative that agencies develop and implement strong quality control/quality assurance procedures to repeatedly and consistently obtain reliable results.

There are also advantages and disadvantages associated with automated surveys. For example, the equipment can capture large amounts of information, which lends itself to collecting information about surface profile and texture characteristics. The right-of-way images allow agencies to collect auxiliary information about the road network beyond what is needed for pavement condition surveys. In agencies that are trying to consolidate data collection activities, this is an important consideration and many agencies have benefited from the availability of roadway images for conducting sign inventories, to review project conditions from the central office, and to address customer complaints. The data from these vehicles can be collected at near traffic speeds, so data collection can be done quickly without negatively impacting traffic and causing potential safety hazards.

While automated surveys have many advantages, fully integrated equipment is expensive and must be updated regularly to take advantage of new technology. Some agencies contract with the manufacturer to collect data, but costs associated with mobilizing the equipment can be expensive and scheduling must be coordinated with the vendor. The vehicles utilize very sophisticated equipment, which requires specialized skills to operate. Also, automated equipment is only appropriate for data that can be seen from the mainline pavement, and there are some limitations to its effectiveness regarding types of distress information that can be easily interpreted. For example, it is difficult to rate weathering and raveling, and it is a challenge to rate crack severities that rely on the presence of faulting along the crack as a criteria.

### 4.6.3 Fully Automated and Semi-Automated Data Processing

Information collected in the field must be processed so it can be used to report pavement conditions. These activities involve data captured in Steps 2, 3, and 4 in Figure 4-8.

Primarily, sensor data collected in the field is processed in real time as it is being collected in the field. The key products of the sensor data include roughness in terms of IRI, rut depth, and faulting measurements. Distress data collected using automated equipment may be processed using either automated or semi-automated methods. The automated processing of distress data may either be conducted in real time or it may be post processed once the field work has been completed. With the development of 3D laser technologies, fully automated data processing is feasible.

Fully automated methods of distress data processing are typically conducted separately from the data collection activities, although in recent years a method of real-time processing has been developed and reported in the literature (Wang et al. 2002). These methods of distress identification require very little human intervention, relying instead on software that can interpret differences in grayscale images to identify cracks and other surface imperfections. Fully automated distress identification methods are very dependent on the quality of the digital images, so image resolution is extremely important. Without high-resolution images, fine, hairline cracks may not be easily detected. Additionally, it is difficult to detect cracks in certain types of pavement surfaces, including chip seals and open-graded friction courses. It is also difficult to develop algorithms for identifying random forms of deterioration (e.g., patching), so most vendors have limited their automated distress interpretation to certain forms of cracking.

Because of the limitations associated with fully automated distress identification, some agencies that collect distress images utilize semi-automated processes to quantify distress. This approach involves the participation of a human in the distress identification process. However, rather than having the ratings conducted in the field, they are conducted at a workstation in an office. Therefore, this approach capitalizes on the safety benefits associated with automated surveys and approximates the benefits of a manual survey because a set of eyes is evaluating pavement conditions. Unfortunately, it can be tedious to conduct pavement condition surveys at a workstation for an extended period of time and so data quality can suffer if raters are not provided sufficient breaks.

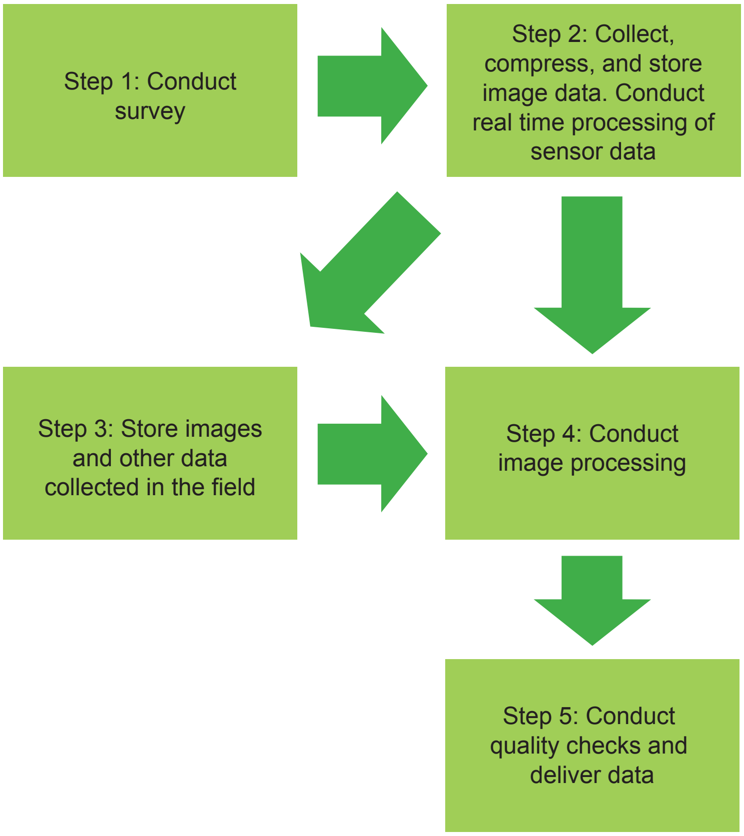



**Figure 4-8. Data Processing Activities**

When conducting a distress survey at a workstation, several images of the pavement survey are normally viewed. The perspective view is provided for identifying the general location and finding the beginning and end of inspection samples. In addition, downward views of the pavement are provided; these images are used for distress identification. To link images to field locations, images are date, time, and distance stamped using distance measuring equipment or GPS instrumentation found on the vehicle. Most manufacturers have developed programs for conducting pavement condition surveys at a workstation, which allow the rater to point and click on the beginning and end points of a distress, utilizing drop-down boxes and other features for classifying distress type and severity. Most of these software programs are proprietary and specific to the particular manufacturer.

## 4.7 SAMPLING

As discussed in Section 4.2, data collection is one of the most expensive aspects of pavement management, and agencies rarely have unlimited resources to spend on this activity. Therefore, some agencies use a sampling approach to evaluate pavement conditions as a way to minimize the amount of data collected. Very simply, sampling limits the amount of data collected by identifying and inspecting representative areas of pavement that are used to characterize the condition of a larger area. For example, an agency that collects data in the first 500 ft of every mile is using a sampling approach (see Figure 4-9). In this instance, the 500-ft sample is assumed to be representative of the condition of the entire mile. If it is not representative of the entire mile, a more appropriate sample should be identified, or a method of accounting for an isolated area with an unusual condition must be developed.

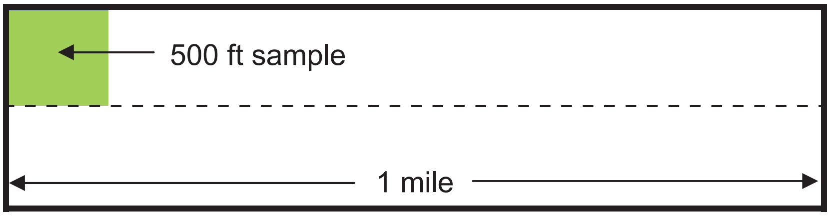



**Figure 4-9. Example of a Sampling Approach**

There are two primary approaches to sampling that are used in pavement management data collection activities: sampling as part of a pavement distress survey and sampling as part of an automated condition survey. Each of these is discussed separately.

### 4.7.1 Sampling as Part of a Distress Survey

A pavement management system requires pavement condition information on each section in the database. Depending on the type of condition survey being used, this requirement may stretch available resources. Therefore, survey approaches in which distress type, severity, and quantities are typically reported use a sampling approach to reduce resource demands. The pavement condition index (PCI) procedure developed by the U.S. Army Corps of Engineers and documented in ASTM standard D6433-11 is an example of a survey procedure that utilizes a sampling approach.

Since these surveys are being conducted to support network-level decisions, the use of representative samples to characterize the condition of a larger area is assumed to be reasonable. To determine the number of samples that should be inspected to achieve a representation of the area, statistics can be used based on the variability between the ratings, the level of confidence desired, and the size of the area. Guidance on determining the number of samples to inspect can be found in *Pavement Management for Airports, Roads and Parking Lots.* (Shahin 2005).

The PCI procedure requires the calculation of the section area, which is then divided by the size of a sample unit (typically assumed to be 2,500 sq ft ± 1,000 sq ft). Therefore, on a street that is 25 ft wide, a sample unit would be 100 ft long. The number of samples inspected depends on the total size of the section. For instance, in a section with only 1 to 5 sample units, only one sample unit may be inspected; two samples might be inspected in a section with 6 to 10 sample units; three sample units might be inspected in a section with 11 to 15 sample units; four sample units might be inspected in a section with 16 to 40 sample units; and 10 percent of the sample units in a larger section might be inspected (Shahin 2005). The total distresses found in the inspected sample units are extrapolated over the remaining area to determine the condition of the section.

Inspection sample units are generally selected at random; however, care should be taken to ensure that they are representative of the condition of the entire section. If they are not representative, either a different sample should be selected or a process for considering nonrepresentative samples must be developed. In the PCI procedure referenced earlier, additional (nonrandom) sample units may be incorporated into the condition survey if the sample represents conditions that are either far better or far worse than the rest of the section. The PCI calculation treats additional sample units differently than randomly selected samples so the distress found in the isolated area are not extrapolated across the entire section.

A comparable method of sampling is used by maintenance personnel as part of their Maintenance Quality Assurance (MQA) programs. In these instances, randomly selected samples of the road network are selected and condition surveys are conducted on the maintenance assets that are present (e.g., guardrail, striping, signs, and drainage features). Since not all assets will be found in each randomly selected sample, MQA surveys use different statistical procedures for selecting samples and analyzing the data.

### 4.7.2 Sampling as Part of an Automated Survey

Oftentimes, agencies collect data on a limited number of lanes to reduce their data collection costs. Most commonly, agencies collect pavement condition data on a single pavement lane on undivided highways and a single lane in each direction on divided highways. Since all pavements being maintained by the agency are not being inspected, this is a form of sampling.

## 4.8 SURVEY FREQUENCY

In 2004, a survey of practices in state DOTs found that pavement condition data are collected at one-, two-, or three-year intervals, depending on the type of facility and type of data collected (NCHRP 2004a). In general, the survey found that data that are fairly easy to collect (e.g., roughness) or data needed for national monitoring (e.g., HPMS data) tend to be collected more frequently than other data.

The HPMS reporting requirements generally drive the data collection requirements for the National Highway System (NHS), and data on the rest of the network may be collected on the same frequency or on a different frequency. Agencies on a two-year cycle may inspect half of the road network each year, or the entire network each year with a year off between cycles. A similar approach may be used with a three-year cycle, where one third of the network may be inspected each year or three years may pass between inspection cycles.

Some agencies that use two- or three-year cycles prefer to inspect their entire network at one time rather than inspect a portion of the network each year due to the advantage associated with having all conditions updated at one point in time. However, there is nothing wrong with inspecting a portion of the network each year. In the end, each agency must determine a survey frequency based on the need for condition data and the resources available for this effort.

## 4.9 IMPROVING DATA QUALITY

As stated in NCHRP Synthesis 401, "To ensure that the quality of the data collected meets the needs of the pavement management process, agencies are developing procedures and guidelines for managing the quality of pavement data collection activities" (Flintsch and McGhee 2009). That synthesis, *Quality Management of Pavement Condition Data Collection*, addresses the issue of data quality in detail.

With respect to pavement management data collection, it is important to understand the differences between quality control (QC) and quality assurance (QA) activities. QC encompasses "those actions and considerations necessary to assess and adjust production processes so as to control the level of quality being produced in the end product" (Flintsch and McGhee 2009). Therefore, QC processes include the activities performed by the data collector (whether performed in-house or contracted) that help to ensure that the processes used to collect the data result in quality data. Equipment calibration and data collection rater training are examples of QC activities. QA activities, on the other hand, relate to verification that the data received is of sufficient quality to be used for pavement management purposes. According to Flintsch and McGhee (2009), a better term to describe these activities is quality acceptance, although the pavement management community more commonly uses the term quality assurance. Setting up tests to verify the reasonableness of the data provided by a vendor is an example of a typical QA process in pavement management. However, even if the data are collected by in-house personnel, QA activities should be performed before the data are entered into the pavement management system in order to ensure the reasonableness of the data. General guidance on who should perform these activities is provided in Table 4-6.

In some cases, agencies have hired independent parties to perform QA activities for the agency. For instance, the Virginia Department of Transportation hired a contractor to manually verify 10 percent of the data collected and analyzed by a separate vendor (Flintsch and McGhee 2009). The results of the analysis led to the discovery of an error in the classification of a particular distress type, which led to an $18 million decrease in the recommended treatments from the pavement management system (Flintsch and McGhee 2009).

The Oklahoma Department of Transportation hired a contractor to develop a data quality acceptance software tool to perform four types of data checks (Wolters et al. 2006):

1. Preliminary checks, to verify the presence of general inventory information about each section.
2. Sensor checks, to check for duplicate records, out-of-range roughness values, and the number of sensors used for reporting rut depths.
3. Distress checks, to verify that distress types match surface types and to determine the reasonableness of the distress values.
4. Special checks, to evaluate the presence of special features in a section.

The tool has served as an interface for correcting data in their database and for quickly and efficiently evaluating the data provided by their data collection vendor.

**Table 4-6.** General Guidance for Pavement Management QC/QA Activities

| | QC Activities | QA Activities |
|---|---|---|
| **Approach 1: Data Collection by Agency Personnel** | | |
| Primary Responsibility: | Agency | Agency |
| Examples: | • Rater training<br>• Equipment calibration | • Duplicate inspections on select sections<br>• Comparison of ratings between inspections to determine reasonableness of data |
| **Approach 2: Data Collection by Contractor** | | |
| Primary Responsibility: | Contractor | Agency |
| Examples: | • Agency verification that equipment meets minimum acceptable standards<br>• On-vehicle real-time data checks during inspection<br>• Control site checks during inspection<br>• Data processing checks during post-production | • Field calibration checks for consistency<br>• Checks for completeness of data<br>• Workstation or field inspections of select samples |

One of the challenges in developing QC/QA guidelines is determining the minimum level of quality needed to support pavement management activities. One approach to this issue is to tailor the data collection activities to the appropriate degree of sophistication and level of quality for the type of decision being made. In the World Bank's *Data Collection Technologies for Road Management*, this concept is covered through a discussion of Information Quality Levels (IQL) and the relationship between the amount of data collected, the types of decisions being made, and the level of quality required, as described below by Bennett et al. (2007):

> *Five levels of road management have been identified for general use and are illustrated in Figure 2.1. IQL-1 represents fundamental, research, laboratory, theoretical, or electronic data types, where numerous attributes may be measured or identified. IQL-2 represents a level of detail typical of many engineering analyses for a project-level decision. IQL-3 is a simpler level of detail, typically two or three attributes, which might be used for large production uses like network-level survey or where simpler data collection methods are appropriate. IQL-4 is a summary or a key attribute which has use in planning, senior management reports, or in low effort data collection. IQL-5 represents top level data such as key performance indicators, which typically might combine key attributes from several pieces of information. Still higher levels can be defined as necessary.*

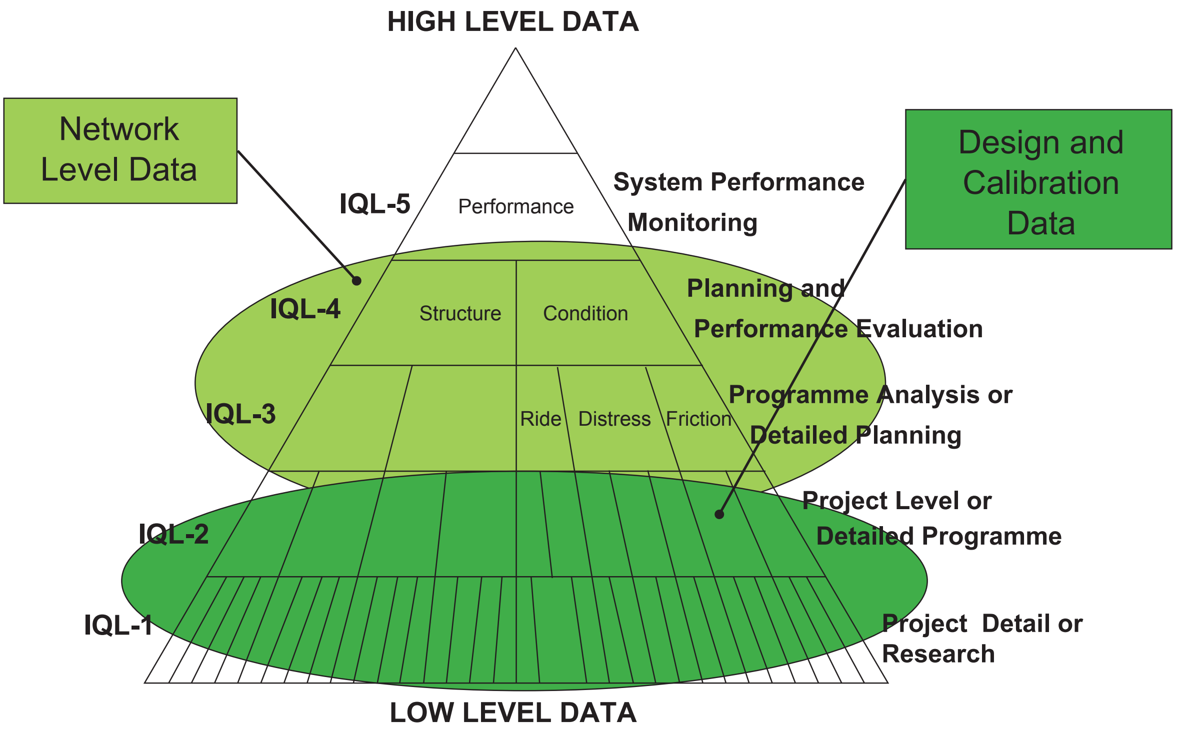



**Figure 4-10. Information Quality Levels (Bennett et al. 2007, Figure 2.1)**

Using this approach, an agency would first identify the expected use of the data to determine the level of detail and quality required to support the decision. The expected level of variability in the data and the consequences (e.g., risk) associated with inaccurate data will also have a role in determining data requirements.

Flintsch and McGhee (2009) recommend the development of a data collection quality management system that includes a formal quality management plan, agency-specific procedures that outline data acceptance criteria, and guidelines to monitor the entire system. The primary focus of the management system should be on eliminating systemic errors because of the large amount of data being collected. Since systemic errors can easily be compounded, it is especially important that pavement management practitioners address each component of the data collection process in their plan. This process involves defining data collection procedures, training raters, calibrating equipment, and implementing the types of QC/QA procedures discussed earlier.

Other agencies, such as the City of Portland, have formally assessed data quality by assigning a rating to their degree of confidence in the data. For example, in its Pavement Asset Management Plan, the City of Portland Office of Transportation included a table in which they rated their confidence in both the inventory and condition assessment procedures for each functional classification of streets using general definitions for each rating level (City of Portland Office of Transportation 2006). For instance, a low rating associated with *No Confidence* in the data was assigned to data with no information or processes in place. If a partial inventory existed, or if conditions could be estimated based on information provided by the manufacturer, the second level rating was assigned, signifying *Low Confidence* in the data. The highest level rating, associated with *Optimal Confidence*, was assigned to assets with a complete inventory and a documented method of conducting a condition assessment. Not only did this assessment help them determine where efforts to improve data quality should be focused, it also provided a framework for disclosing to various stakeholders the agency's degree of confidence in the recommendations provided.

The *International Infrastructure Management Manual* includes an alternate grading system for describing data accuracy and degree of confidence (INGENIUM 2006). In this scheme, the highest grade is assigned to data with a high degree of accuracy. Lower grades are assigned based on lesser degrees of accuracy, with the lowest score assigned when all data are estimated rather than measured.

To improve the quality of pavement condition data, the following recommendations are provided:

1. **Monitor data quality at each stage of the data collection process**. Investing in effective QC techniques can have a significant impact on preventing data quality issues from occurring. Even with strong QC procedures in place, it is important that QA activities be performed before the data is imported into the pavement management database.
2. **Track data sources and accuracy using ratings systems such as the ones presented in Section 4.9.1**. Formal audits of these processes are strongly recommended.
3. **Periodically review the QC/QA processes to ensure that they reflect changes in the technology used for data collection**. As changes in technology modify data collection procedures, agencies must update their QC/QA processes accordingly. For example, rut measurements vary considerably based on the type of equipment used to collect the data.

### 4.9.1 Data Collection Protocols and Standards

In an effort to standardize the many different methods of collecting and analyzing pavement condition data, several national organizations have initiated efforts to develop more uniform terms and methodologies. These organizations recognize the potential benefits associated with consistency in data collection and reporting, including the ability to compare results across agencies and reduce data collection costs. However, because of the historical condition data that many agencies have accumulated using alternate methodologies, some agencies have been hesitant to change their data collection methods. Other agencies have used the existing protocols and standards to some degree, with slight variations to adapt them to local conditions.

One of the more successful efforts at standardizing pavement distress definitions resulted from the Long-Term Pavement Performance studies, first conducted under the Strategic Highway Research Program (SHRP) and later through the FHWA. The *Distress Identification Manual*, which can be downloaded from www.fhwa.dot.gov/publications/research/infrastructure/pavements/ltpp/reports/03031/03031.pdf is commonly referenced as the basis for many defining distress types and severities in state DOTs (pocket guides are available at www.fhwa.dot.gov/pavement/ltpp/pubs/06119/index.cfm).

However, the procedure describes a research-oriented survey procedure that may be too labor intensive for network-level pavement management applications. Regardless, the document provides an excellent resource for standardizing pavement distress definitions.

A summary of some of the other efforts at standardizing pavement condition data collection activities is provided below.

#### 4.9.1.1 AASHTO

For much of the past 10 years, AASHTO has been working with an FHWA Expert Task Group on the development and implementation of protocols and standards for pavement data collection. Today, the following standards (beginning with the letter "R") and provisional standards (beginning with the letters "PP") have been developed on pavement condition data collection:

- R 36 (formerly PP 39), Standard Practice for Evaluating Faulting of Concrete Pavements
- R 43M/R 43 (formerly PP 37), Standard Practice for Quantifying Roughness of Pavements
- R 48 (formerly PP 38), Standard Practice for Determining Rut Depth in Pavements
- R 55 (formerly PP 44), Standard Practice for Quantifying Cracks in Asphalt Pavement Surfaces
- R 56 (formerly PP 49), Standard Practice for Certification of Inertial Profiling Systems
- R 59 (formerly PP 50), Standard Practice for Recovery of Asphalt Binder from Solution by Abson Method
- PP 67, Standard Practice for Quantifying Cracks in Asphalt Pavement Surfaces from Collected Images Utilizing Automated Methods
- PP 68, Standard Practice for Collecting Images of Pavement Surfaces for Distress Detection
- PP 69, Standard Practice for Determining Pavement Deformation Parameters and Cross Slope from Collected Transverse Profiles
- PP 70, Standard Practice for Collecting the Transverse Pavement Profile

Through the use of these standards and with the changes in HPMS requirements for the states that began in 2010 and the increased importance of performance measures within highway agencies, it is likely that the importance of consistency in data collection methodologies will increase.

#### 4.9.1.2 ASTM

ASTM has a Technical Committee on Vehicle-Pavement Systems (E-17) that has been involved in efforts to standardize data collection terminology for many years. In fact, the committee has 10 technical subcommittees with jurisdiction over 65 standards. The relevant technical areas served by this committee include the following:

- Field methods for measuring tire pavement friction
- Surface characteristics related to tire–pavement slip resistance
- Tire and slider characteristics
- Methods for measuring profile and roughness
- Methodology for analyzing pavement roughness
- Pavement testing and evaluation

- Pavement management and data needs
- Measurement and evaluation of pavement-related noise
- Vehicle roadside communication
- Traffic monitoring

## 4.10 DATA CONSISTENCY ISSUES

One of the most recent issues that agencies are facing is data consistency between data collected using different condition survey procedures, updated equipment, or different vendors. Changes in any of these factors influencing the way in which pavement condition data are collected or analyzed can have a significant impact on the overall reported network conditions and the value of historical data.

### 4.10.1 Inherent Variability in Pavement Data Collection

It is important to recognize that variability is inherent to all pavement condition data procedures. However, the degree of variability differs dramatically depending on the type of data being collected and the method used to collect it. Methods of estimating variability and setting conditions for determining acceptability when comparing data from two independent sources are available in *Quality Management of Pavement Condition Data Collection* (Stoffels et al. 2001).

Variability in pavement condition can be influenced by a number of factors, and effective QC/QA processes can help to reduce the amount of variability in the survey results. Flintsch and McGhee (2009) reported on different types of variability for surface distress, smoothness, surface friction properties, structural evaluation, and ground penetrating radar. Based on their findings, some of the primary sources of variability that can be controlled during the survey procedure include the following:

- The type of equipment or data collection method used (including the type and number of sensors).
- The consistency and repeatability of the raters conducting distress surveys.
- Wander of the survey equipment within a road lane.
- The survey conditions, including the amount of light, the temperature, the presence of moisture or surface contaminants, and so on.
- The availability of data collection protocols to define survey procedures.
- The speed at which surveys are conducted.

Obviously, each of these factors influences data collection procedures differently depending on the data being collected. However, it is important that these sources of variability are understood and agencies have taken steps to minimize their presence whenever possible.

### 4.10.2 Changes in Data Collection Equipment

As data collection technology continues to improve, manufacturers can be expected to incorporate new capabilities into their data collection vehicles. Transportation agencies that purchase equipment for their own use are usually aware of the new capabilities of the equipment they purchase, and often have the opportunity to perform calibration runs with both the old and new equipment. For example, the Eastern Federal Lands Highway Division (EFLHD) of the FHWA recently purchased a new data collection vehicle for conducting pavement condition surveys at the parks managed by the National Park Service (FHWA 2009c). Upon delivery of the new data collection van, pilot surveys were conducted at a representative number of parks using both the old equipment and the new equipment so that correlations between data could be developed. Increases in the amount of low-severity cracking are expected due to the higher resolution of the digital images, as are differences in rut measurement due to changes in the number of lasers used.

Agencies that contract with vendors for data collection do not always know of changes in technology that occur from year to year, even if the same vendor is used. This lack of awareness emphasizes the importance of establishing local calibration sites that are tested at the beginning of each inspection cycle to identify any variations in the measurements being provided. If substantial differences are discovered, correlations to previous years' data may have to be developed. Otherwise, there could be substantial changes in the conditions reported from the pavement management analysis.

### 4.10.3 Changes in Data Collection Methodology

For an agency that has been collecting pavement condition data for an extended period of time, one of the most difficult decisions can be to change the survey methodology from a manual procedure to an automated procedure or to change the distress rating protocols. These types of changes are difficult because of challenges associated with the potential loss of historical data obtained using the original procedures.

While it is tempting to try to develop correlations between the old and new procedures, it may be more practical to recognize the differences in the procedures and make a clean break from the historical procedures, especially if dramatic differences exist between the two. This does not mean that agencies have to delete the historical data from their files, because it may still be useful for determining general pavement deterioration trends; however, most agencies that adopt substantially new data collection procedures have found that it is difficult to exactly mimic the old procedures, and many of the reasons for creating the old procedures no longer exist. For example, some agencies that use manual survey methods estimate the amount of cracking from the shoulder of the road because it is difficult to obtain actual measurements under trafficked conditions. If this agency is moving towards an automated method of collecting pavement condition information, more detailed crack quantities can now be obtained. Therefore, it is logical to modify the rating procedure to account for the capabilities of the new technology.

Agencies that have tried to develop correlations between their historical data collection procedures and new methodologies have found the process to be difficult. In 2008, the FHWA and the North Carolina Department of Transportation (NCDOT) sponsored a National Workshop on Highway Asset Inventory and Data Collection in which the results of a comparative analysis of distress information collected both manually and using automated equipment were provided. Three data collection vendors participated in the study and their results were compared to the NCDOT manual survey methodology and the FHWA's LTPP distress identification survey methodology. The study presents the following observations (Underwood and Kim 2008):

- Cracking in asphalt pavements is underestimated by vendors due to differences in definitions and the lack of sensitivity of the automated equipment.
- The NCDOT survey procedure was less sensitive to rutting than the automated equipment.
- Ride quality between the manual and automated methods was not comparable because of differences in definitions.
- Spalling and joint seal damage on concrete pavements was difficult to assess with the automated methods.
- The vendors demonstrated a lot of variability in their interpretation of concrete distresses using the LTPP methodology.

In addition, the study found that there was so much variability in the results from the manual NCDOT procedure that it was difficult to develop meaningful statistics of ground truth to use in assessing vendors' results (Underwood and Kim 2008). These same types of issues were found in earlier studies comparing automated and manual survey results (Smith et al. 1998). Close communication between the agency and the vendor is required to assure common understanding of distress types and severities.

### 4.10.4 General Recommendations

The following recommendations are provided to help guide agencies who are facing these data consistency issues due to changes in data collection equipment or methodologies:

- Establish and utilize data collection quality management programs that include calibration of the equipment, field calibration before and during data collection, and QA checks to determine the completeness and reasonableness of the data before entering it into a database.
- Recognize that variability is inherent to each type of pavement condition being collected. Without understanding the degree of variability associated with that data, data from different survey years or equipment should not be compared.
- Store historical condition information with both the date the inspection dates was performed and the surface type linked. This enables the raw data to be used to calculate new indices if the method of computing a condition index changes or new technology is used to collect the information.
- Don't waste time trying to preserve historical survey procedures when major changes to data collection methodologies are implemented. When these changes occur, such as the change from manual to automated surveys, agencies should recognize that correlations with historical data may not be meaningful and that it may be a better use of time to begin rebuilding the historical records from the point at which the change occurred. It is often easier to explain one period of inequality in the data being reported due to the change in methodology than it is to attempt to correlate very different pavement condition surveys needlessly.

## 4.11 DEVELOPING PAVEMENT CONDITION INDICES

One of the primary objectives of collecting pavement condition information is reporting network conditions. Pavement condition indices, or condition ratings, are frequently used in pavement management to report and compare pavement conditions, predict changes in pavement condition, and identify the appropriate treatment type and timing. Pavement condition data are also used to establish rates of pavement deterioration to forecast future conditions. Therefore, having a reliable method of converting the data collected from the condition surveys into meaningful information is an important requirement for building buy-in among stakeholders.

The type of pavement condition index that is used is typically dependent on the needs of the agency and the types of condition data that are available. The two main types of condition indices used in pavement management are:

- Composite indices
- Individual indices

Composite indices, like the PCI, aggregate multiple types of condition data into a single index that is representative of the overall condition of a pavement. Composite indices are usually tied to descriptive ratings, such as *good*, *fair*, or *poor*. Individual indices are typically calculated for a single type of pavement deterioration (e.g., structural cracking) or single distress type (e.g., alligator or fatigue cracking). Individual indices are typically used only for treatment decisions and for calculating an overall composite index. Both composite and individual indices are discussed further in the following sections.

## 4.11.1 Composite Indices

### 4.11.1.1 Subjective Composite Indices

Composite indices are determined in one of two ways. The simplest approach to assigning a composite condition index is to define a numerical scale and to assign descriptors to each of the scores. The Pavement Surface Evaluation Rating (PASER) condition survey procedure developed by the University of Wisconsin is an example of a subjective composite index (Wisconsin Transportation Information Center 2002). It is considered to be subjective because of the degree of interpretation that is required to assign a score to a pavement section.

The PASER survey procedure is a windshield survey procedure in which a rater assigns a pavement a score of 1 to 5 for unsurfaced roads and 1 to 10 for paved surfaces such as asphalt or concrete. These scores are then used to assign a descriptive rating to the pavement, such as assigning an excellent rating to pavements with the highest scores and a failed rating to a pavement with a lower score and a loss of surface integrity. Photographs and descriptions provided in the PASER rating manuals help the rater assign the appropriate scores to each section. The procedure is easy to follow and provides useful information to agencies without extensive resources for data collection, but there are some important limitations to this method of assigning a condition index. First, the subjectivity of the assigned scores may result in substantial variability between index values from one year to the next or between raters in the same year. Secondly, although the indices (or scores) provide a reasonable method of comparing roads and determining treatment levels, they do not provide the agency with information about the types of distress observed or the amount of distress present. Each agency must determine whether the advantages associated with the cost of collecting the data reasonably offset the amount of data provided. An example of the type of guidance provided in a PASER manual is provided in Figure 4-11.

Rating pavement surface condition 15

## Rating system

| *Surface rating* | *Visible distress** | *General condition/ treatment measures* |
|---|---|---|
| **10 Excellent** | None. | New construction. |
| **9 Excellent** | None. | Recent overlay. Like new. |
| **8 Very Good** | No longitudinal cracks except reflection of paving joints. Occasional transverse cracks, widely spaced (40′ or greater). All cracks sealed or tight (open less than ¼″). | Recent sealcoat or new cold mix. Little or no maintenance required. |
| **7 Good** | Very slight or no raveling, surface shows some traffic wear. Longitudinal cracks (open ¼″) due to reflection or paving joints. Transverse cracks (open ¼″) spaced 10′ or more apart, little or slight crack raveling. No patching or very few patches in excellent condition. | First signs of aging. Maintain with routine crack filling. |
| **6 Good** | Slight raveling (loss of fines) and traffic wear. Longitudinal cracks (open ¼″–½″), some spaced less than 10′. First sign of block cracking. Sight to moderate flushing or polishing. Occasional patching in good condition. | Shows signs of aging. Sound structural condition. Could extend life with sealcoat. |
| **5 Fair** | Moderate to severe raveling (loss of fine and coarse aggregate). Longitudinal and transverse cracks (open ½″) show first signs of slight raveling and secondary cracks. First signs of longitudinal cracks near pavement edge. Block cracking up to 50% of surface. Extensive to severe flushing or polishing. Some patching or edge wedging in good condition. | Surface aging. Sound structural condition. Needs sealcoat or thin non-structural overlay (less than 2″) |
| **4 Fair** | Severe surface raveling. Multiple longitudinal and transverse cracking with slight raveling. Longitudinal cracking in wheel path. Block cracking (over 50% of surface). Patching in fair condition. Slight rutting or distortions (½″ deep or less). | Significant aging and first signs of need for strengthening. Would benefit from a structural overlay (2″ or more). |
| **3 Poor** | Closely spaced longitudinal and transverse cracks often showing raveling and crack erosion. Severe block cracking. Some alligator cracking (less than 25% of surface). Patches in fair to poor condition. Moderate rutting or distortion (1″ or 2″ deep). Occasional potholes. | Needs patching and repair prior to major overlay. Milling and removal of deterioration extends the life of overlay. |
| **2 Very Poor** | Alligator cracking (over 25% of surface). Severe distortions (over 2″ deep) Extensive patching in poor condition. Potholes. | Severe deterioration. Needs reconstruction with extensive base repair. Pulverization of old pavement is effective. |
| **1 Failed** | Severe distress with extensive loss of surface integrity. | Failed. Needs total reconstruction. |

** Individual pavements will not have all of the types of distress listed for any particular rating. They may have only one or two types.*

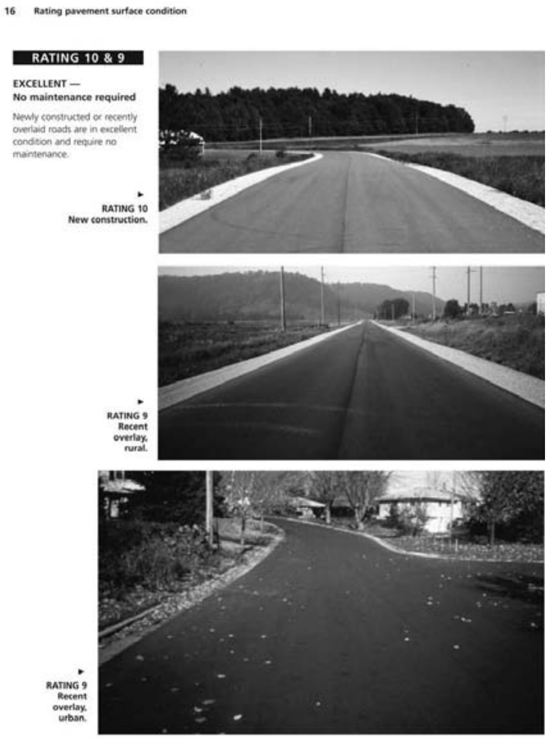



**Figure 4-11. Method of Assigning a Composite Condition Index Using PASER (Wisconsin Transportation Information Center 2002)**

### 4.11.1.2 Objective Composite Indices

There are also more objective methods of determining a composite index, which rely on the use of information about distress type, severity, and extent. Survey procedures that use this methodology typically subtract points from the index associated with a perfect score, depending on the combination of distress type, severity, and extent observed in the field. For instance, methodologies that use this type of approach to calculate a condition index generally subtract more points for what might be considered more substantial distress (e.g., severe alligator cracking) than for less serious distress, such as transverse cracking.

This is a common approach for calculating condition indices. The calculations vary depending on the types of distress information included in the survey procedure and the relative importance that each agency places on the combination of distress type and severity.

Perhaps the most well documented index within this category is the PCI procedure, which is recognized as ASTM standard D6433-11. In the PCI calculation, distress type, severity, and extent are recorded using the guidance provided in the survey documentation.

Once the surveys are completed, the results are used to calculate the PCI for each section. Deduct points are assigned to each combination of distress type, severity, and extent combination observed in the field in accordance with deduct curves available in *Pavement Management for Airports, Roads, and Parking Lots* (Shahin 2005). Deduct points are assigned so that a higher number of deducts are associated with a form of structural deterioration (such as alligator cracking) and fewer points are associated with a less serious form of deterioration (such as bleeding). Once all the deduct points associated with the distress combinations are determined, they are summed, adjusted for the presence of multiple distress and subtracted from a perfect score of 100.

Because of the requirement to record each distress type, severity, and extent in an inspection sample, this type of survey procedure is more labor intensive than the PASER approach introduced earlier. However, it provides an agency with information about the percent of the deduct points associated with different forms of deterioration (e.g., load or climate), and it provides estimates of distress quantities that may be useful when estimating maintenance and repair activities.

Another way to calculate composite indices is to use an average weighted index concept. For example, if an agency has a distress index and a roughness index, both of which are on a 100-point scale, the overall condition index for the section might be calculated from an equation such as the one shown below as Eq. 4-1. This example puts slightly more emphasis on the distress index than the roughness index:

$$\text{Composite Condition Index} = 0.6 * \text{Distress Index} + 0.4 * \text{Roughness Index} \qquad (4\text{-}1)$$

Agencies that use this method of calculating a composite condition index should base the weighting factors on the relative level of importance of one index to another in terms of overall pavement condition.

The South Dakota Department of Transportation (SDDOT) calculates its combined condition index using Eq. 4-2, which is based on the mean and standard deviation of all the individual indices for a given section (SDDOT 2010):

$$\text{Composite Condition Index} = \text{Mean} - (12.5 * \text{SD}) \qquad (4\text{-}2)$$

where

Mean = the mean of all contributing individual condition indices, and

SD = the standard deviation for the above mean.

This method was selected to prevent an individual index with a low score from being lost in a weighted average calculation. Regardless of what approach is used to determine a composite index from individual indices, the objective is to determine a single value that is representative of the pavement condition that can be reported.

A third method of calculating a condition index was introduced during the *Highway Pavement Training Course* developed in 1990 (FHWA 1990). The approach can be used to determine the number of deduct points associated with different combinations of distress type, severity, and extent.

The methodology is based on the underlying premise that there is a *threshold value (TH)*, below which pavement condition is considered to be unacceptable. If an agency is using a 0 to 100 scale for its pavement condition index, the threshold value is usually set at a rating of between 40 to 60 depending on the type of facility and the overall maintenance policies of the agency (FHWA 1990). The methodology also assumes that agencies are collecting pavement distress severity and extent information in the field. The methodology requires the following steps (FHWA 1990):

1. Establish the threshold value, which differentiates between acceptable and unacceptable pavement condition. Most agencies using a 0 to 100 scale use a value between 40 and 60 as the threshold value.
2. For a single distress type and each of its severity levels, identify the maximum amount of distress (at that severity level) that would equate to a condition level equal to the threshold value. This value is referred to as the maximum allowable extent (MAE) of distress. The *MAE* represents the relative amount of damage contributed by each severity of distress since a lower *MAE* will be set for more damaging distress than will be set for a less damaging distress type or severity.
3. Calculate the condition index using Eq. 4-3:

Index = 100 – {[(100-*TH*)/*MAE*1]*Actual extent of 1} - {[(100-*TH*)/*MAE*2]*Actual extent of 2} - … {[(100-*TH*)/*MAE*n]*Actual extent of *n*} *(4-3)*

where

*TH* = threshold value, and

*MAE* = maximum allowable distress for distress severity/extent combination 1 to *n*.

The actual extent of 1 to *n* = the amount of distress at that severity level identified during the survey.

The use of this approach is illustrated by the following example, which shows the application of the methodology for a single distress type (e.g., fatigue cracking). However, the methodology can be used for composite indices comprised of multiple distress types by extending the equation appropriately.

For the purposes of the illustration, assume an agency is interested in developing a Fatigue Cracking Index using a 0 to 100 scale, with 100 representing a pavement section with no fatigue cracking present. Fatigue cracking is measured at three severity levels (low, medium, and high), and it is measured as a percent of the effected pavement area. The agency has set the Threshold Value (TH) at 40.

Based on its experience, the agency has set the following *MAE* values for each severity level:

- Low severity fatigue cracking: MAE = 33 percent
- Medium severity fatigue cracking: MAE = 10 percent
- High severity fatigue cracking: MAE = 1 percent

In other words, the agency has determined that the *TH* would be met if either 33 percent of the section had low severity fatigue or if 10 percent of the section had medium severity fatigue cracking or if 1 percent of the section had high severity fatigue cracking.

The Fatigue Cracking Index is calculated from Eq. 4-3 as follows:

Index = 100 – {[(100-40)/33] * actual amount of low severity fatigue cracking} – {[(100-40)/10] * actual amount of medium severity fatigue cracking} – {[(100-40)/1] * actual amount of high severity fatigue cracking}, or

Index = 100 – (1.818 * actual amount of low severity fatigue cracking) – (6 * actual amount of medium severity fatigue cracking) – (60 * actual amount of high severity fatigue cracking).

The validity of the equation can be checked by inserting the MAE for each severity level into the equation in isolation. The resulting index for each severity level should be equal to the threshold value. If the combination of low, medium, and high severity cracking results in an index lower than zero, the index is rounded to zero.

### 4.11.2 Individual Indices

Some agencies prefer to calculate individual indices for each pavement section to assist in identifying the most appropriate type of maintenance and repair activity. For example, by using a structural distress index, a non-structural distress index, and a roughness index, pavement managers can quickly determine whether a section requires a structural repair or whether a functional improvement would be more appropriate. Agencies that use individual indices typically use them in combination with a composite index. The composite index is then primarily used to report the overall condition rating of a section to decision makers (often in terms of *good*, *fair*, and *poor* rather than to report the index), but it also provides a means of comparing the condition of sections, which can be difficult to do when a section is described using multiple individual indices. It is strongly recommended that if a composite index is used in conjunction with individual indices, predicted conditions are computed by first predicting the condition of individual indices using the agency's performance models and then calculating the composite index. The alternate approach is for an agency to develop a performance model for the composite index as well as the individual indices to predict future conditions. Because of the potential discrepancy between the predicted composite index and the predicted individual indices, the latter approach is not recommended.

The calculation of an individual index is based on the same concepts discussed earlier, including the use of deduct points that are subtracted from a perfect score to describe the current condition. Most indices are all assigned the same scale (e.g., 0 to 100), although there are exceptions to this rule. For instance, some agencies use IRI values as a roughness index rather than convert the IRI to a 0 to 100 scale. Either approach can be used successfully; therefore, the agency must decide which approach best meets its particular needs.

In a recent study conducted for the Pennsylvania Department of Transportation, a survey of state practice was conducted (APTech 2009). The results indicate that approximately half of the responding agencies use multiple individual indices for their distress data, and approximately 75 percent of the responding agencies use at least one individual index and a roughness index. The most commonly reported individual indices include the following (APTech 2009):

- Roughness index
- Rutting index
- Structural/fatigue index
- Non-structural cracking index
- Patch index

Although the use of two or more individual indices is useful for estimating treatment needs, this practice adds a level of complexity to the pavement management system that must be considered. This additional complexity arises because treatment rules and performance models must be developed for each index. Even an agency with just three surface types and three individual indices, must develop at least nine different performance models (three times three) and treatment rules that cover each index. In addition, impact rules that define the conditions after a treatment is applied have to be defined for each of the indices. Treatment and impact rules are discussed in more detail in Section 6.4.

## 4.12 OTHER FACTORS INFLUENCING PAVEMENT CONDITION SURVEYS

Many agencies have well established procedures in place for evaluating pavement conditions that date back 10 to 20 years. Some agencies have modified their original pavement condition survey procedures to reflect changes in technology, most notably the change from manual to automated surveys. However, it is probable that additional changes may be required to accommodate some of the recent changes taking place in pavement management. A brief summary of some of the more significant changes that are impacting pavement management is provided in this section.

### 4.12.1 The Use of Preventive Maintenance Treatments

Many agencies have adopted pavement preservation programs that include the use of preventive maintenance treatments on roads in relatively good condition. These programs are cost effective because of the use of low-cost interventions that keep the road in good condition longer, thus deferring the need for more costly rehabilitation treatments. As discussed further in Section 6.4.4, preventive maintenance treatments are primarily focused on addressing functional forms of deterioration, such as deficiencies caused by poor ride, poor pavement surface characteristics, hardening of the asphalt, or minor cracking. A key to the successful use of preventive maintenance treatments is early intervention, before excessive deterioration is present.

However, most pavement management condition survey procedures were developed to identify and prioritize rehabilitation treatments. Therefore, they have not typically been designed to include the types of triggers normally needed to identify appropriate preventive maintenance treatments, such as those listed below (Zimmerman and Peshkin 2004):

- Sealed versus unsealed cracks or fine cracks
- Raveling or weathering
- Flushing
- Oxidation

As a result, some agencies are considering changes to their data collection procedures to incorporate these forms of pavement deterioration. Even without making changes to the data collection procedures, there are ways to incorporate preventive maintenance treatments into a pavement management system.

For instance, the results of a pavement management analysis could be used to identify candidate sections for preventive maintenance based on existing measures (e.g., pavement sections in good condition with little structural deterioration), without trying to determine the most appropriate type of treatment to apply. After candidate sections are identified using the pavement management system, treatment selection could be determined by Maintenance and Operations personnel who are in the field and more familiar with the particular needs of the candidate sections.

Pavement management systems can also be used to document the performance of preventive maintenance treatments over time. This information provides valuable information to verify the cost-effectiveness of preventive maintenance treatments, but also provides feedback to further improve the models used to trigger candidate sections for pavement preservation activities.

### 4.12.2 Increased Use of Performance Measures

Another change that is occurring nationally is the increased use of strategic performance measures as a quantifiable indicator of service provided to the traveling public. The use of performance measures helps improve communication among stakeholders by providing a basis for communicating impacts of funding decisions and providing a degree of transparency in the agency's decision making. By linking performance targets to funding allocations, agencies are better prepared to achieve their stated objectives.

Changes in the types of performance measures used at the upper levels of transportation agencies are likely to occur over the next few years. These changes could impact the types of performance metrics collected by field personnel since it is important that tactical performance measures are aligned with strategic performance measures. For instance, if safety is considered to be an important performance measure for strategic purposes, it will be important that pavement management is able to report the impact of different funding scenarios and treatment programs on safety-related performance measures. Similarly, with the increased focus on sustainability, pavement management will have to identify and begin monitoring measurements of sustainability for the treatments included in the analysis.

### 4.12.3 New HPMS Requirements

Beginning in 2010, new requirements went into effect for the HPMS that changed the types of data reported by state DOTs for the NHS (FHWA 2008b). HPMS data are used at the national level for funding apportionment, performance measures, highway statistics, condition reporting, and for FHWA's transportation planning and policy studies. Since states are responsible for reporting HPMS information to the FHWA, the HPMS requirements impact the type and frequency of data collected.

With regard to pavement condition data, the new HPMS requirements specify annual reporting of IRI data and the addition of cracking, rutting, and faulting. Other data requirements include the date of last overlay, date of last reconstruction, and thickness of the latest overlay. Therefore, agencies that have not incorporated this information into their pavement management system will have to modify their data collection approaches to meet these requirements.

### 4.12.4 MEPDG Model Calibration Requirements

The MEPDG includes models that have been calibrated and validated using data from the FHWA's LTPP program (AASHTO 2008). Although the LTPP database represents data from locations representing a variety of geography, climatic conditions, construction materials, construction practices, traffic compositions and volumes, and other pavement design variables, agencies implementing the MEPDG are advised to calibrate the models using local field data to achieve more reliable performance predictions for their conditions as shown in the *Guide for the Local Calibration of the Mechanistic-Empirical Pavement Design Guide* (AASHTO 2010). Pavement management is a logical resource to provide the data, but studies have shown that the required data are not currently found in most pavement management databases (APTech 2010). However, pavement management databases could be enhanced to address this need.

The MEPDG considers both structural and functional pavement performance characteristics in its estimates of predicted pavement damage. The IRI is used to forecast pavement smoothness using the initial as-constructed IRI and changes in smoothness due to the propagation of distress, site factors (such as subgrade), and maintenance activities. For flexible pavements, smoothness is based on the amount of load-related fatigue cracking (including both bottom-up and top-down fatigue cracking), thermal cracking, and permanent deformation (rutting) (AASHTO 2008). The distress considered in rigid pavements includes faulting and transverse cracking, and punchouts on continuously reinforced concrete pavement (CRCP) (AASHTO 2008). These models have been incorporated into the new AASHTOWare DARWin-ME pavement design software, which builds upon the MEPDG. To calibrate the models in DARWin-ME using local data, condition data on each of these distresses must be available. Therefore, in the absence of the information as part of a network-level pavement condition survey, special condition surveys for the purposes of calibration efforts will be required.

## 4.13 CHAPTER SUMMARY

There are many ways to assess the structural and functional condition of a pavement. At the state DOT level, ride is the most frequently used pavement condition metric, although pavement distress information is also commonly used to provide more information about the type of deterioration that is occurring. The results of pavement condition surveys are used to determine one or more pavement condition indices, which provide a means of identifying and prioritizing treatment needs. While many agencies have been using their data collection procedures for years, there are a number of industry changes that may influence the type of data collected and the frequency with which it is collected. For instance, new HPMS reporting requirements include cracking, rutting, and faulting for the NHS. The new mechanistic-empirical design procedures that have recently been developed require calibration of the performance models using pavement management data. Additionally, new technology is being developed that may influence an agency's ability to assess pavement structural condition at a network level. These, and other types of changes, are forcing agencies to periodically revisit their data collection activities to determine whether adjustments are needed to continue to meet changing agency demands.

CHAPTER FIVE

# Pavement Performance Modeling

## 5.1 INTRODUCTION

Pavement prediction models serve several important roles in the pavement management process. For instance, they play a part in the following activities:

- Estimating future pavement conditions.
- Identifying the appropriate timing for pavement maintenance and rehabilitation actions.
- Identifying the most cost-effective treatment strategy for pavements in the network.
- Estimating statewide pavement needs required to address agency-specified goals, objectives, and constraints.
- Demonstrating the consequences of different pavement investment strategies.
- Establishing performance criteria for performance specifications and warranty contracts.

In addition, performance models can be used to provide feedback on pavement designs or on the effectiveness of different maintenance strategies. Given the contribution of the models to these pavement management functions, their accuracy is important to prevent agencies from incorrectly estimating the year in which rehabilitation is needed, the level of repair needed, or the future condition of the network. Therefore, the more closely the performance models reflect agency-specific deterioration patterns, the less likely it is that there will be misrepresentations of future condition levels or treatment needs. This correlation places a high degree of importance on the quality of the pavement condition data used to develop the models.

In the field of pavement management, various terms are used to describe pavement performance models, including *deterioration models* or *prediction curves*. In essence, each of these terms describes the equation in which the changes in pavement condition over time are represented.

## 5.2 DATA REQUIREMENTS FOR PAVEMENT PERFORMANCE MODELING

The literature details the data requirements that must be satisfied to develop reliable performance models (Darter 1980, Lytton 1987). Based on the previous work, the following factors should be considered in selecting the modeling approach and determining the availability of sufficient data for the development process (Darter 1980):

- **An adequate source of data**—Different types of models require different types of data, so it is important that the availability of adequate data is considered before beginning the modeling process. Each variable used in modeling must be available for each of the pavement sections included in the pavement management system. Further, the data must be maintained over time so the models continue to predict reasonable values.
- **Consideration of the most significant variables influencing pavement performance**—There are many variables that can have an impact on how pavements perform over time, including climate, traffic, layer thicknesses, and material properties. While an agency may want to incorporate all of these variables into its pavement performance models, it is often impractical to do so because most pavement management databases do not have adequate records to support the use of multiple independent variables. The family modeling approach discussed in Section 5.4.1 provides a means of indirectly accounting for important variables in the modeling process when the data are not available (or reliable enough) to be used directly in model development. If an agency does elect to use multiple independent variables in the development of its models, statistics programs can help to determine the degree of influence of each variable on pavement performance.
- **A functional form that fits the data**—Pavement performance models describe, using equations, the expected change in pavement condition performance over time. The change in condition can take a number of different forms (or shapes), depending on the type of equation used. The modeling form selected should fit the data and should reflect the typical deterioration patterns for the agency.
- **Satisfaction of criteria for precision and accuracy**—As discussed, pavement performance models are used extensively in a pavement management system. Therefore, it is important that the models provide reasonable estimates of changes in condition with time. As discussed in Section 5.5, there are several statistical methods available to evaluate the reliability of a performance model, including the coefficient of determination ($R^2$).

Lytton (1987) goes on to add that the principles and limitations associated with each model should be well understood to help ensure that the models are not being used outside of their intended purpose.

## 5.3 PERFORMANCE MODELING APPROACHES

When developing pavement performance models, the first step is to consider what the models are going to predict. Typically, pavement management systems predict changes in one of the following indices representing pavement condition over time:

- **Distress severity and extent**—Including changes in the amount and severity of a particular distress, such as fatigue cracking, rutting, or faulting.
- **Individual pavement condition indices**—Including changes in a structural crack index, roughness index, etc.
- **Composite indices**—Including changes in a composite index such as the PCI discussed in Section 4.11.1

There are advantages and disadvantages to each method of predicting pavement condition, as shown in Table 5-1. For instance, it can be difficult to accurately predict changes in a composite index because of the subjectivity in the index and the number of combinations of distress that can result in the same index. For example, a pavement section that has a composite index of 80 (on a scale of 0 to 100) might exhibit early fatigue cracking (a form of structural deterioration) or the rating might have resulted from block cracking (an environmental form of deterioration). Although both pavement sections have the same condition index and the same age, the section with the fatigue cracking would be expected to deteriorate much faster than the section with block cracking. However, since a single composite index model does not necessarily differentiate between the distress combinations that resulted in the rating, it is unlikely that the performance model will be able to predict different rates of deterioration for the two sections. This concern might be addressed by predicting the rate of deterioration for individual pavement condition indices, but the number of performance models that must be developed increases based on the number of indices considered.

Perhaps the most complex approach is predicting changes in distress severity and extent, such as predicting the progression of fatigue cracking over time as it changes from low severity to high severity. Models that predict distress severity and extent involve determining the point at which the distress is first seen as well as the propagation of the distress with time once it appears. Because of the complexity in modeling individual distress, an agency may elect to combine distress severities for a particular distress type to avoid modeling the progression of distress from one severity to another. For instance, all longitudinal crack severities would be combined and the total amount of cracking that will occur over time is predicted. It would be much more difficult to try to predict the progression of a crack from low severity to high severity.

**Table 5-1.** Advantages and Disadvantages of Predicting Different Types of Pavement Condition Variables

| Predicted Variable | Advantages | Disadvantages |
|---|---|---|
| Distress severity and extent | • Provides specific estimates of future distress quantities.<br>• Predictions are provided in a format that is closely related to the manner in which data are collected. | • Requires both the initiation of distress and the amount of distress over time to be modeled.<br>• May be difficult to incorporate into the pavement management software. |
| Individual indices | • In general, indices are easier to model than distress severity and extent.<br>• The predicted conditions relate to factors that trigger treatments. | • Models must be developed for each index.<br>• Update requirements can be onerous because of the number of models.<br>• If a composite index is used in conjunction with individual indices, there may be discrepancies between the predicted conditions using the individual index models and those used to predict the composite index (Note: this issue is eliminated if the individual indices are modeled and the composite index is calculated from the predicted indices, as discussed in Section 4.11.1). |
| Composite index | • This is likely the simplest approach, which results in the fewest number of models.<br>• Because of the limited number of models, updating the models is relatively simple. | • Different rates of deterioration associated with different distress types are masked.<br>• May not satisfy the needs of some stakeholders who want more detailed models. |

Once it is determined what the models should predict, the type of model must be selected. In pavement management, four types of models are commonly used to predict future pavement conditions: deterministic, probabilistic, Bayesian, and subjective (or expert-based) models. Each of the four approaches is summarized here and described further in the subsequent sections:

- **Deterministic models—**These models predict a single dependent value (such as the condition of a pavement) from one or more independent variables (such as the age of the pavement, past cumulative traffic, environment, and pavement construction characteristics). The models are typically developed based on the results of a statistical analysis.
- **Probabilistic models—**These models predict a range of values for the dependent variable, such as the likelihood that a pavement will change from each of the various condition states to another in a single reporting cycle.

- **Bayesian models**—These models combine both objective and subjective data. Each of the variables used in the model is described in terms of a probability distribution.
- **Subjective (or expert-based) models**—These models are similar to deterministic models, except that the relationships between an independent and dependent variable are based on expert opinion rather than historical data.

Depending on the variables used, the models can be further classified as mechanistic, mechanistic-empirical, or empirical. Mechanistic models are based on fundamental principles of pavement behavior, while empirical models are based on the results of experiments or experience. Mechanistic-empirical models include portions of both approaches and relate the predicted condition to measured deterioration, such as distress or roughness, through regression equations (FHWA 1998). Therefore, mechanistic-empirical models are commonly used in pavement management.

### 5.3.1 Deterministic Models

Deterministic models are often used by agencies that have historical pavement condition information or sufficient survey results that they can identify statistically-significant pavement deterioration trends. These models are developed from a regression analysis in which a statistical relationship between two or more variables is established. The statistical relationships in these models are not exact and include some amount of variability. The magnitude of the variability is based on factors such as the quality of the data, the appropriateness of the independent variables to predict the dependent variables, and the range of data in the data set.

Because the correlation between the independent variables and the dependent variables is not exact, an approach for determining the best statistical fit of the data must be used. A common approach in pavement management applications is to use the least squares regression technique, which minimizes the sum of the squared differences between the line generated by the regression equation and the actual data points.

Deterministic models may take many forms (e.g., shapes) depending on the type of equation used (e.g., linear, quadratic, or sigmoid). It is common in pavement management to use a single independent variable to predict the dependent variable (e.g., pavement condition). Pavement age (e.g., years since last major rehabilitation) or traffic volumes are commonly used independent variables.

The use of only one independent variable simplifies the development of the models and overcomes the issues that arise when a database does not contain complete or accurate records for all of the variables included in the equation. For instance, if traffic volume is a variable in the equation, but traffic counts have not been conducted for 15 years, the model will have to use the data that are available; however, the accuracy of the predictions would be suspect. Similarly, if pavement thickness is included as one of the variables, but the database does not contain complete records with this information, the validity of the predictions could also be questioned. This concept is discussed in Section 5.4.

### 5.3.2 Probabilistic Models

Probabilistic models differ from deterministic models in that instead of predicting a single value for pavement condition, the likelihood of a pavement being in one of several condition states (or categories) is predicted. Probabilistic models are not used as commonly as deterministic models in pavement management, likely because most pavement management software programs are not equipped to input these types of models without converting them to one of the deterministic model forms. However, they represent a direct way of accounting for pavement variability, which may be attractive to some agencies. For pavement management purposes, the literature discusses the use of Markov and Semi-Markov transition probabilities (FHWA 1998, Lytton 1987, Shahin 2005, Haas et al. 1994). The Markov probabilistic approach is based on the current pavement condition and assumes that the probability of changing from one condition state to another is independent of time. Since the models depend only on the current condition state, there is no opportunity to include other variables (such as traffic loading or environmental factors) that often contribute to performance and that are often changing over time, unless families are created and separate transition matrices are developed for each family. The semi-Markov approach is designed to overcome the independence of time assumption used when changing from one pavement condition state to another pavement condition state. Semi-Markov models allow transition probability matrixes to be created and used together to provide piecewise increments of time. According to Shahin (2005), probabilistic modeling is particularly useful for predicting individual distress information.

### 5.3.3 Bayesian Models

Bayesian statistical decision theory is emerging as a modeling technique for pavement management. While this methodology typically uses both objective and subjective data to predict performance, models can be developed using only subjective data. Regression analysis is used to develop the models, but each of the variables is assumed to be random and to have an associated probability distribution.

Because subjective data can be used to supplement objective data, Bayesian regression can be useful for agencies that have recently begun the implementation of pavement management, that have changed their pavement condition rating procedures (e.g., no historical data are available), or that have introduced new designs or materials into their network. It also provides a way to override the influence of poor quality data or to supplement expert models with field data as they become available. An example of the development of pavement performance models using Bayesian regression is provided in *MDOT Pavement Management System: Prediction Models and Feedback System* (George 2000).

### 5.3.4 Subjective or Expert-Based Models

Another, less formal way of incorporating subjective opinions into pavement performance models is to develop subjective, or expert-based, models. As with Bayesian models, this approach is useful when historical condition data are not available, when new practices or materials are being used, or when the agency has little confidence in its condition data.

The process used to develop subjective performance models may be informal or formal. In an informal process, an individual (or a group of individuals) develops an equation that describes the rate of deterioration for a particular set of conditions. For example, assuming an average rate of deterioration of 3 points per year (on a 100-point scale) is a type of subjective model.

In a formal process, a panel of experts typically identify ages at which certain events take place. These age/condition combinations are either plotted manually on a graph or they are input into a regression analysis and an equation is developed. For instance, if an agency uses a pavement condition rating between 0 and 100, the panel might be asked to describe the condition at which reconstruction is needed. A follow-up question would determine the number of years at which reconstruction would be expected. Then, a line is drawn connecting the point set by the experts with the point at which the pavement is constructed (with age of 0 and a perfect condition). The shape of the line can be drawn to reflect either a linear model or a curved model, depending on the experts' opinions. Intermediary points could also be added to help shape the curve.

## 5.4 FAMILY MODELING AND SITE-SPECIFIC MODELS

The modeling approaches discussed in the previous section can be used to develop deterioration rates for a pavement family, in which one model is used to represent the rate of deterioration for a group of pavement sections with similar characteristics; or site-specific models, in which the predicted conditions are based on the unique characteristics of a particular pavement section. A description of each approach is provided.

### 5.4.1 Family Models

Since pavement management databases rarely include all of the variables considered to be important for modeling pavement performance and there are frequently data variability or completeness issues that further limit the availability of data for modeling purposes, the family modeling approach was developed. This method simplifies the modeling process by reducing the number of independent variables in the performance model to a single independent variable (usually pavement age or traffic) that is used to predict future pavement conditions. The equation can be reduced to one independent variable by using other variables to group pavement sections into *families* that have similar characteristics and performance patterns. The pavement performance model developed for the family is used in the pavement management system to represent the rate of deterioration for all of the pavement sections that meet the family definition. As one would expect, the definition of pavement families must be comprehensive enough that each pavement section in the pavement management database falls into one, and only one, pavement family.

A family modeling approach might be used to divide asphalt- and concrete-surfaced pavements, for example, to reflect the differences in their deterioration rates. To reflect differences in performance based on traffic characteristics, the asphalt-surfaced family may be further separated into families for asphalt-surfaced interstate highways and asphalt-surfaced non-interstate highways. This subsequent separation for interstate and non-interstate highways provides a way to take differences in traffic into account without requiring the availability of accurate traffic counts in the database. A similar approach could be used by establishing families based on "heavy" traffic volumes or "light" traffic volumes.

Pavement managers may also use the family modeling approach to establish the deterioration rate for a portion of the entire network, such as a sub-network. These sub-networks could be established very simply, using factors such as surface type; or they could be more complex, using a combination of geographic location, surface type, functional classification, and freight volume. The key is to establish families that have similar performance characteristics so the family model is representative of the rate of deterioration for each section included in the family.

The degree of sophistication of the factors used in creating the families depends on the quality and the degree of sophistication of the pavement management database. Therefore, a major advantage of the family modeling approach is the use of certain performance variables to *classify* pavement sections into families, rather than relying on the accuracy of the values for *predicting* future performance.

Performance models are created for each pavement family by plotting the condition and inspection age of the sections (e.g., the number of years since major rehabilitation at the time the inspection is performed) for each pavement section that meets the family definition. Regression techniques are then applied to predict the behavior of the data based on the age of the pavement, as discussed in Section 5.3.

Pavement families can be very simple or quite complex. Since performance models have to be developed for each family and each condition index, the number of families generated has a significant impact on the complexity of the pavement management system. For example, an agency that has three pavement types, three condition indices for each pavement type, and three traffic levels will have to develop and maintain twenty-seven different performance models (e.g., 3 * 3 * 3). Therefore, agencies should use some restraint in defining families in too much detail. In general, a family model should be comprised of data representing a range of pavement conditions and pavement ages. If a family does not have a full range of data available, it may be temporarily combined with a family displaying similar deterioration characteristics until more data become available.

When using the family modeling approach with historical condition data, it is important to store the family characteristics with the historical condition ratings so that each inspection point can be grouped with the correct family as models are being developed. If this step is not taken, the historical data could be pulled into the wrong family if a treatment has been applied at some point. For instance, if a concrete road is overlaid with hot-mix asphalt at some point in time, it is important that the data associated with the concrete ratings are kept with the concrete pavement families and those associated with the composite pavement are grouped with the composite families.

### 5.4.2 Site-Specific Models

Some agencies prefer using the unique characteristics of each pavement section to predict future conditions. Multiple variable regression equations are an example of site-specific models in which the predicted performance is based on the specific data stored in the database for that section. The predictions are considered to be site-specific because two pavement sections with identical condition information will not be expected to deteriorate at the same rate if other variables used in the model are different (e.g., climate, pavement thickness, or traffic).

Most agencies that use site-specific models require that at least three to five data points be available for the pavement section or an alternate model must be used. For example, the Colorado Department of Transportation requires at least five inspection points after a rehabilitation treatment has been applied before a site-specific model can be used (Keleman et al. 2003) while the Minnesota Department of Transportation requires that three inspection points exist and that agency-established rules for a reasonable rate of deterioration are satisfied before its site-specific models are used (FHWA 2008c). For instance, if overlays are expected to perform adequately for 5 to 10 years, a site-specific curve will be used if the predicted conditions fall within that range, otherwise the default family model will be used.

### 5.4.3 Colorado DOT Example of Site-Specific and Family Models

The Colorado Department of Transportation (CDOT) uses both individual and family models. Currently, they use raw distress data (IRI, rut, fatigue cracking, block cracking, transverse cracking, longitudinal cracking, and corner breaks) to create index values on a 1 to 100 scale for each distress type. Site-specific deterministic performance curves are then created for a project section if a) at least 5 years of performance data is available since last rehabilitation, b) the data has a standard deviation less than 10, and c) if a minimum coefficient of regression ($R^2 = 0.50$) is obtained. If a site-specific curve cannot be developed for a project section, the next option is the development of a family curve followed by the use of a default curve.

When the development of family curves is a necessity, curves are created using the criteria of pavement type (asphalt, asphalt over concrete, concrete, and concrete over asphalt), traffic (low; medium; high; very high; and very, very high), climate (very cool, cool, moderate, and hot), and pavement thickness (asphalt: 0 to 4 inches, 4 to 6 inches, and greater than 6 inches; concrete: less than 8 inches and greater than 8 inches). When less than nine data points exist for a given family curve, an expert-based model is used as a default model (Keleman et al. 2003).

## 5.5 EVALUATING MODEL RELIABILITY

For models that are developed using regression, statistical methods are used to explain how well the predicted model fits the data. Perhaps the most common statistical parameter used to explain the "goodness of fit", or the degree to which the model fits the data, is the coefficient of determination ($R^2$). The coefficient of determination represents the amount of variability that can be explained by the model and provides an estimate of how well future conditions can be predicted by the model. The coefficient of determination is the ratio of the sum of squares due to regression divided by the sum of squares about the mean, as represented in the following equation.

$$R^2 = 1 - (SS_{err}/SS_{tot}) \qquad (5\text{-}1)$$

where

$R^2$ = coefficient of determination,

$SS_{err}$ = the sum of squares of residuals, and

$SS_{tot}$ = the total sum of squares.

The coefficient of determination is reported as a value between 0 and 1.0 (or in percentages between 0 and 100 percent). Therefore, a higher value is an indication of a better fit of the model to the given dataset compared to lower values. However, there are situations in which a model with a lower $R^2$ value may be used if the agency determines that it provides a more reasonable representation of pavement deterioration.

There are also situations in which the $R^2$ calculation can be deceiving. For example, if a statistical analysis tool is used to create the models and the endpoint of the model is constrained (e.g., forcing the curve to intersect the x-axis to arrive at a finite end point for the model), the calculated $R^2$ value can be artificially inflated. As a result, the calculated $R^2$ values of models created under artificially constrained models should not be directly compared when determining which model provides the best $R^2$ value for an unconstrained model.

One method of improving the reliability of a model is to remove outliers, or data points that appear to be erroneous or that do not make sense logically. For instance, a pavement section with a perfect condition score that is 20 years old could be considered an outlier. Further investigation into the section is warranted to determine whether the section is, in fact, an outlier or whether it is a legitimate data point. Most likely, a section with a high condition index at an age greater than 10 years has an erroneous pavement age.

There are other statistical methods of evaluating the reliability, or goodness-of-fit, of a performance model along with the reliability of predictive variables of the model, including the following:

- **Standard Error of Estimate**—This is a measure of the accuracy of a prediction. It is the square root of the sum of the square deviations of prediction (also called the sum of the squares error) divided by the number of pairs of scores used to develop the equation, as shown in the following equation.

  $$SE_x = s / (\sqrt{n}) \qquad (5\text{-}2)$$

  where

  $SE_x$ = Standard Error of Estimate,

  $s$ = sample standard deviation, and

  $n$ = number of observations or sample size.

- **Residual plots**—Some individuals create plots that show the residuals (e.g., the difference between the equation and the median data points) at different points in time. It provides a good indication of the relationship between the model and the independent variable. These plots are useful for showing whether the model accurately represents the data over all of the limits of the variable. A reasonable residual plot shows an even balance of data points above and below the zero residual line along all ages, as shown in Figure 5-1. An example of a model that generally over-predicts the values is shown in Figure 5-2. The development of residual plots that result in unbalanced data around the zero residual line can lead the model developer to examine parameters of the given model or other model forms.
- **Root mean square error (RMSE)**—This is the standard deviation of the predicted "y" values for a specific value of "x."
- **T-test**—For small samples, the t-test (or t-distribution) may be used in Bayesian analysis to determine the statistical significance between two sample means.
- **F-test**—This test is used with a least squared regression analysis to compare statistical models and to determine which one best fits the data.

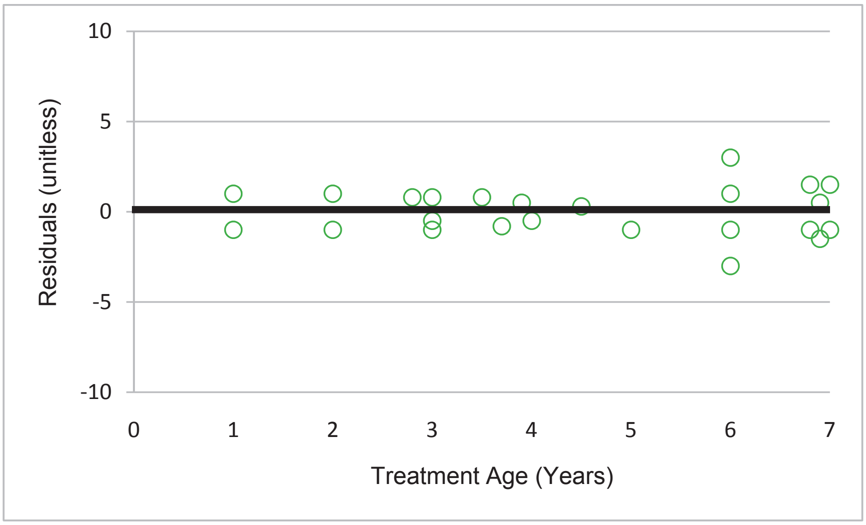



**Figure 5-1. Sample Residual Plot Showing a Reasonable Balance of Data Points**

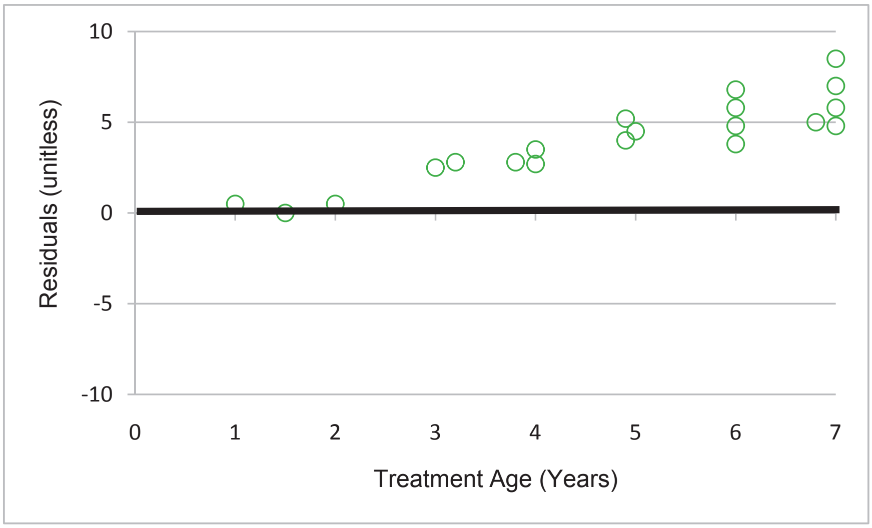



**Figure 5-2. Sample Residual Plot Showing Over-Prediction by the Model**

There are undoubtedly other statistical tests that may be useful during the development of performance models. Therefore, individuals working in this area are advised to confer with statisticians and use available references, such as the text written by Ott and Longnecker (2010).

Model reliability can also be assessed using extracted data from the model data set for use in verifying the robustness of the developed models. Within statistics, there is no standard for splitting data for model development and validation (Ott 1993). Therefore, a random percentage of the data can be removed from the original data set prior to model development. Other studies have reserved five percent of the data for validation of the models, building the models using the remaining 95 percent of the data (Sadek et al. 1997).

## 5.6 SHIFTING THE CURVE

When family models are used to predict pavement conditions, a single model is used to represent the rate at which each pavement condition index changes over time for all sections that fit the family definition. As a result, a single family could have several pavement performance curves if several pavement condition indices (or distress types) are being modeled. Since the resulting models represent average rates of change for whatever dependent variable is being predicted, it is highly likely that many of the actual inspection points for the sections within the family will not fall directly on the family model, as shown in Figure 5-3. In this example, which is meant to represent a generic condition index, the pavement section represented by the data point is deteriorating at a faster rate than is typical for the pavement family.

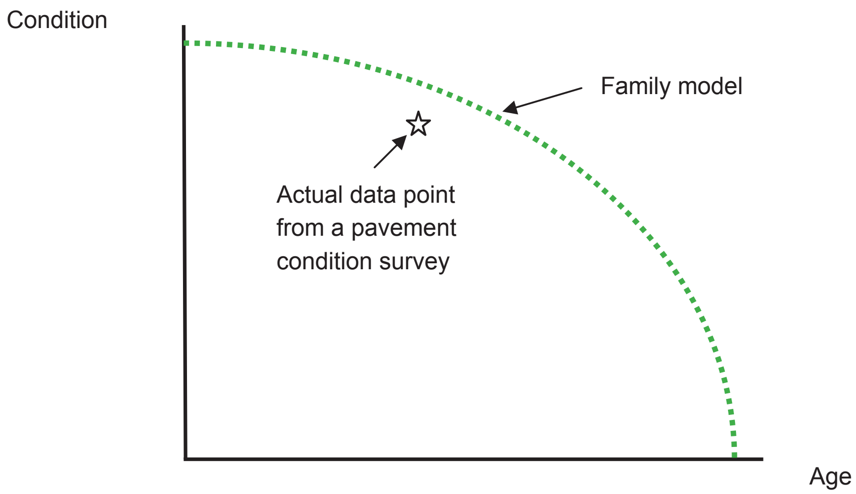



**Figure 5-3. Example of an Actual Data Point Compared to a Family Model**

For the pavement management system to reasonably predict the condition of the section, the performance model must be "shifted" over to intersect the data point. This feature, which is typically referred to as "shifting the curve," creates a way for the pavement management system to use the general shape of the family model, but customizes its use for each individual section. While this approach may not be as accurate as if a site-specific curve was developed for each section, it provides a reasonable approach to predicting the condition of pavement sections as long as the family model is representative and the data point is included in the right family.

The manner in which the performance model is shifted is reflected in Figure 5-4. In this example, and for modeling purposes only (e.g., no changes are made to the database), the portion of the model that extends beyond the apparent age (e.g., the age at which the family model reaches the condition index observed in the field) is used to predict future conditions from the actual age and condition obtained from the latest survey.

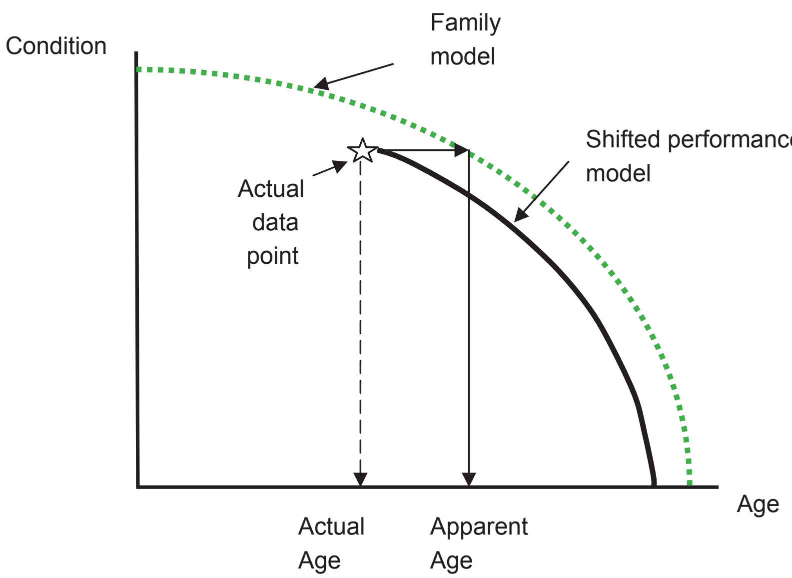



**Figure 5-4. Example of Shifting the Family Model to Predict Conditions**

## 5.7 UPDATE REQUIREMENTS

Because of the importance of the pavement performance models to pavement management recommendations, the models should be reviewed periodically to help ensure that they continue to reflect actual deterioration patterns. Generally, performance models are reviewed more frequently when a pavement management system is first being implemented and the initial models are finalized. Once models are verified and used to report predicted conditions to outside stakeholders, minor adjustments to the models may be made, but rarely are dramatic changes made unless simultaneous changes to the condition rating procedures or condition indices are made. Frequent, dramatic changes to the performance models should be avoided so that stakeholders can build confidence in the system over time. Establishing confidence among stakeholders is an important part of increasing agency accountability and establishing higher levels of transparency in the decision process.

Since most initial pavement performance models are built using expert opinion to some degree, it is important to incorporate the results of pavement condition surveys into the models as the data become available. A Bayesian approach may be appropriate for incorporating field data into an expert model, as discussed in Section 5.3.3. Another approach is to replace the expert models with models based on historical conditions once a sufficient number of surveys have taken place. This link between field conditions and predicted conditions illustrates the importance of feedback to continually improve the pavement management system.

For example, after being mandated by the state legislature to implement pavement management, the Oklahoma Department of Transportation quickly moved forward with the development of new condition indices and performance models based on expert opinion (APTech 2009). The original expert equations were developed based on a family modeling approach for various individual indices. Once a sufficient amount of pavement condition data had been collected around the state, the pavement performance models were updated to evaluate how they compared to the expert curves. For many pavement families, the models developed using measured data better reflected pavement deterioration trends than the expert models. Therefore, the expert models were replaced with models based on measured field data.

## 5.8 SPECIAL USES OF PERFORMANCE MODELS

Pavement management data provides the means to assess the performance of pavement sections for a variety of engineering applications such as:

- Evaluating the performance of different pavement designs or mixes.
- Modeling the performance of preventive maintenance treatments.
- Conducting forensic studies.
- Calculating remaining service life.
- Calibrating MEPDG models.

The development of models for this variety of applications requires the adaptation of current network-level models as described in the following sections. It should be emphasized that the availability of reliable information is critical to the success of each of these applications.

### 5.8.1 Evaluating the Performance of Different Pavement Designs or Mixes

Network-level performance models can be used to evaluate the performance of different pavement designs or mixes in a variety of ways. For example, one approach is to compare the rate of deterioration for pavement sections with a particular mix design or pavement design with family models developed for more traditional pavement designs and mixes. Another approach is to develop separate family models for the various characteristics to be evaluated. For instance, if the performance of a particular pavement design in different regions of the state is desired, then different pavement families can be created and differences in performance can be compared using tests to determine the statistical significance in the differences. The results could be used to determine which region of the state is getting the best performance from that particular design and the reasons for the differences can be investigated further.

The Illinois Department of Transportation recently evaluated the typical performance of its hot-mix asphalt overlays in different geographic regions of the state (Wolters, Hoerner, Smith 2008). The study used pavement performance information from the Illinois Roadway Information System (IRIS) and compared the resulting performance models with the estimated service life being used in the state's design policies. As a result of the study, modifications to the design policies were considered. This type of study would also be useful for estimating treatment intervals in a life-cycle cost analysis.

### 5.8.2 Modeling the Performance of Preventive Maintenance Treatments

The ability to model the performance of preventive maintenance treatments within the pavement management system is influenced by the ability to track the maintenance activities that have occurred on each section in the pavement network. A record of treatment applications is important for agencies to document any benefits associated with the use of preventive maintenance treatments and to explain variations in pavement condition indices that might be related to the application of maintenance treatments. As discussed in Section 3.2, linking maintenance data with pavement management requires that the same referencing system is used to store the data in both systems.

To be able to use the pavement management system to recommend candidates for treatment, agencies must be able to model treatment performance. When using a family modeling approach, inventory flags can be incorporated into databases to provide a means of differentiating performance characteristics of pavements that have received preventive maintenance treatments versus those that have not. A regression analysis can then be conducted on the flagged sections to determine the performance of pavement sections that have had preventive maintenance treatments applied. By comparing these models to the control models (with no preventive maintenance), the benefit associated with preventive maintenance can be determined in terms of the additional area between the original pavement performance curve and the preventive maintenance curve. This concept is illustrated in Figure 5-5.

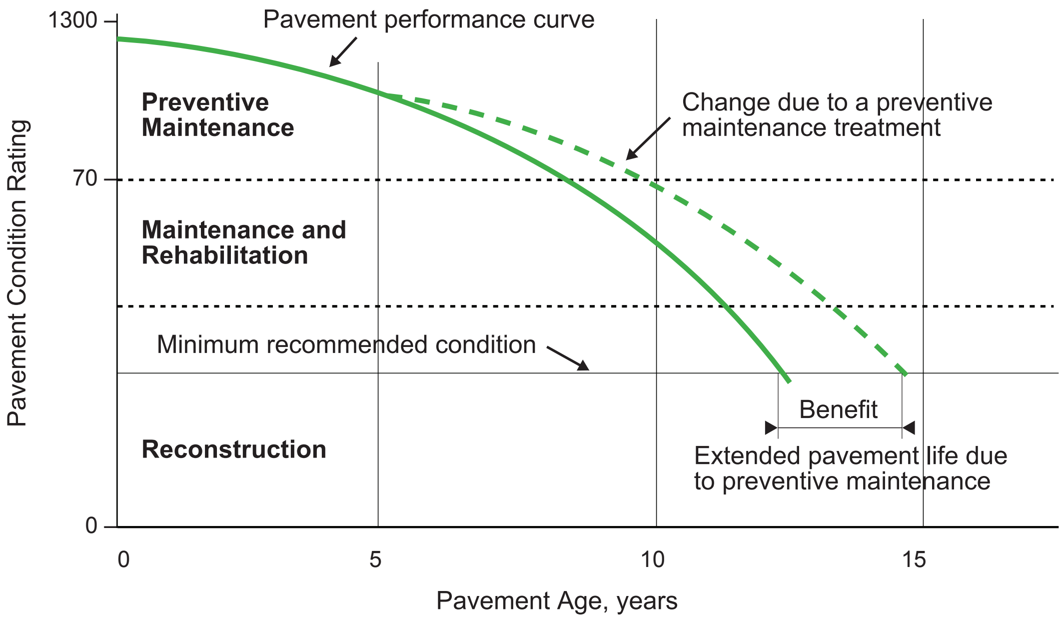



**Figure 5-5. Pavement Performance Models for Pavement Sections Receiving Preventive Maintenance Treatments (Hein 2008)**

### 5.8.3 Conducting Forensic Studies

Forensic studies are often conducted on pavement sections that have failed prematurely to determine the factors that have contributed to the unusual performance and whether changes to existing design or construction practices might be required. Since a forensic study is typically conducted on an isolated pavement section, very detailed project-level pavement evaluation techniques are normally included as part of the study. These techniques may include a detailed pavement condition survey, nondestructive testing, coring, and material testing. Performance modeling at this level is typically more site-specific and may utilize pavement design software to determine performance under different loading conditions and differences in performance if certain characteristics had been changed.

Forensic studies may also be conducted to investigate differences in performance between the same treatment applied in different geographic regions or with different material properties. For example, a study might compare the differences in performance between two sections on the same road that had similar treatments applied. The forensic study might investigate the reasons for any differences in performance, and might also determine if (and why) the performance of these sections differs from the performance of similar sections in other regions using the family model. This type of study helps to drive changes in treatment selection, in material specifications, or in construction practices.

### 5.8.4 Calculating Remaining Service Life

Performance models can be used to estimate the Remaining Service Life (RSL) of a section, as shown in Figure 5-6. In this example, the known performance of the pavement section is shown by the solid portion of the performance curve and the predicted performance is represented by the dashed line. The number of years until an agency-defined minimum service level, or threshold level, is reported as the RSL for that particular pavement section. If multiple condition indices are used, the performance of each index is projected individually, and the shortest RSL is reported as the Remaining Service Life for the section. Therefore, a pavement section with an RSL of 0 is a representative of a pavement that has reached the minimum service level, indicating that reconstruction, or some other type of major rehabilitation, is required.

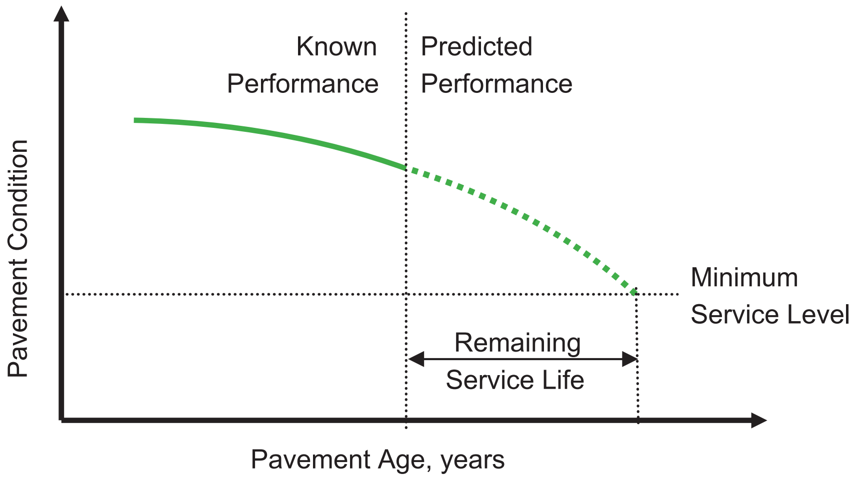



**Figure 5-6. Determining RSL Using Pavement Performance Models**

There are several advantages to the use of the RSL for reporting pavement conditions. Perhaps its greatest benefit is its ability to represent a metric that can be applied to most transportation assets, which provides a means of comparing pavement conditions on a somewhat equivalent basis. It is also a metric that may be more meaningful to stakeholders than a 0 to 100 condition scale because non-technical individuals understand the implications associated with a pavement section that has little remaining life.

On the other hand, the RSL terminology can be confusing when pavement sections have been at an RSL value of 0 for several years and the road is still carrying traffic. This situation seems in contrast to the implied condition that once the minimum service level is reached, the facility should be improved or closed. Since this is not what typically happens in real life, the credibility of the index can suffer.

### 5.8.5 Calibrating MEPDG Models

The MEPDG significantly changed the methodology used for the design of pavement structures (AASHTO 2009). Implementation of the MEPDG is expected to improve the efficiency of pavement designs and to enhance the abilities of state transportation departments to predict pavement performance, which will thereby improve their ability to assess maintenance and rehabilitation needs over the life of the pavement structure. The models developed under the MEPDG have been incorporated into the DARWin-ME pavement design software provided through AASHTOWare.

Before the DARWin-ME software can be fully implemented at a level other than the Level 3 default values, it must be calibrated using actual pavement design input and field properties to ensure its validity and accuracy. As part of an initial calibration effort, the MEPDG performance models were calibrated and validated primarily using data from the FHWA Long-Term Pavement Performance (LTPP) program. Although the LTPP database represents a valuable resource, the variability between the states in terms of geography, climatic conditions, construction materials, construction practices, traffic compositions and volumes, and numerous other pavement design variables make it desirable to calibrate the MEPDG at the local level using local field pavement data. This is not a simple task and requires a great deal of effort to evaluate the inputs needed to accurately reflect the individual state's unique pavement needs. Of the three levels of input for MEPDG, the site specific materials, climatic, and traffic data (Level 1 data) most accurately reflects the local situation; the estimated regional data (Level 2 data) are more regionally based but less accurate; and the default data (Level 3 data) are for situations where more specific information is simply not available. The advantage of providing these three levels of input is that the MEPDG can still be used to design pavement structures with acceptable results even if specific Level 1 or Level 2 data are not available. Theoretically, the most accurate pavement design would be the one that was calibrated using Level 1 data and used as many Level 1 and Level 2 data inputs as possible.

As state DOTs move forward with the adoption of the MEPDG through the use of DARWin-ME, there will be increased interest in calibrating the DARWin-ME performance models to local conditions. Because of the number of inputs involved, the data collection and analysis activities associated with calibrating the models could be expensive, time consuming, and resource intensive. Therefore, the use of existing data sources, such as pavement management, could significantly reduce the resource demands associated with the calibration efforts. The FHWA recently completed a project demonstrating the use of pavement management data to calibrate the MEPDG performance models (FHWA 2010c). The study developed and demonstrated a framework for calibrating the models, using actual data from the NC DOT pavement management system.

The MEPDG performance models are based on the distress types and measurements shown in Table 5-2. In most instances, the distress types and measurement approaches do not match identically with the types of condition measures normally included as part of a network-level pavement management survey. For instance, network-level pavement management surveys do not differentiate between top down and bottom up longitudinal cracking. Therefore, unless special test sections are established for calibration purposes, the default model for top down cracking will be used (since fatigue cracking is assumed to start at the bottom of a pavement layer and work its way up). Other differences include the lack of any severity levels in the MEPDG models and the use of a 500-foot inspection sample for monitoring distress information in the LTPP procedure. However, even with these differences, the FHWA study demonstrated how existing pavement management data could be used to calibrate the models. As relevant data are added to the database, the models can be further enhanced.

**Table 5-2.** MEPDG Required Distresses for Local Calibration (Pierce et al. 2011)

| MEPDG Required Distresses for Local Calibration | | | | | |
|---|---|---|---|---|---|
| HMA Distress Data | | Jointed Plain Concrete Pavement (JPCP) Distress Data | | Continuously Reinforced Concrete Pavement (CRCP). Distress Data | |
| IRI[1] | in/mile | IRI[1] | in/mile | IRI[1] | in/mile |
| Asphalt top/down (longitudinal) cracking | ft/mile | Transverse cracking | ft/mile | Number of punchouts | per/mile |
| Asphalt bottom/up (alligator) cracking | % cracked per section length | % slab cracked per section | | Maximum crack width | in |
| Low temperature thermal cracking (transverse) | ft/mile | Mean joint faulting[2] | inches | Minimum crack load transfer (transverse) | LTE% |
| Asphalt rutting[2] (permanent deformation) | inches | | | Minimum crack spacing | ft |
| | | | | Maximum crack spacing | ft |

1 International Roughness Index, typically measured every tenth of a mile.
2 Average, standard deviation, COV, maximum, minimum

## 5.9 CHAPTER SUMMARY

A pavement management system uses predicted pavement conditions to demonstrate the impact of different funding scenarios, to determine the best use of available funds, and to estimate changes in resource needs to address pavement deficiencies. Several methods of developing pavement performance methods were introduced, including deterministic, probabilistic, Bayesian, and subjective approaches. Methods of evaluating the reliability of the models were also provided.

In an effort to simplify pavement performance modeling at the network level, some agencies use a family modeling approach in which condition data for pavement sections with similar characteristics are grouped together to determine a representative model to signify the typical deterioration pattern for the data set. The use of certain characteristics to group pavements into families reduces the number of variables used directly in the model (e.g., reduced to a single variable) and reduces the specificity required of the data. For instance, instead of needing to know exact traffic counts, a surrogate, such as functional classification, can be used to differentiate families based on traffic. A method of shifting the family performance model to predict the condition of an individual section was also described.

The chapter concludes with a discussion of the use of performance models beyond the traditional applications of pavement management. This section of the guide discussed the use of performance models to evaluate new designs and mixes, to determine the benefit of using preventive maintenance treatments, to support a forensic analysis, to estimate remaining service life, and to calibrate MEPDG models.

CHAPTER SIX

# Project and Treatment Selection

## 6.1 INTRODUCTION

A common use of a pavement management system is to develop recommendations for projects and treatments that make the best use out of the available resources. This chapter first introduces the types of treatments normally included in a pavement management system and the types of rules that are created to help determine candidates for maintenance, rehabilitation, or reconstruction; and then discusses the methods used to develop project and treatment recommendations and to determine the long-term consequences associated with the suggested program. The chapter also includes guidance for incorporating new designs and materials into the project and treatment selection process, as well as for coordinating pavement preservation activities with maintenance personnel.

## 6.2 DEFINITIONS

Pavements are designed to provide a smooth, safe wearing surface for a period of 20 to 40 years (or more) for moving people and goods from one location to another. The actual duration over which a pavement remains serviceable is measured using the various performance criteria identified in Chapter 4, and is influenced by factors such as traffic levels, material selection, climatic conditions, and construction quality, some of which were addressed in Chapter 3. However, the importance an agency places on maintaining that pavement and the funding available for restorative activities can also play a significant role in the cost and duration of a pavement's life cycle.

When originally developed, pavement management systems were focused primarily on the identification and prioritization of pavement rehabilitation and reconstruction projects (Zimmerman and ERES Consultants 1995). In more recent years, agencies have recognized that allowing an asset to deteriorate to a point where only rehabilitation or reconstruction activities are feasible is a very expensive method of maintaining a pavement network. As a result, many agencies have implemented pavement preservation programs that include the use of preventive maintenance treatments early in a pavement life cycle to defer the need for future rehabilitation activities. Because pavement preservation activities may be paid for with federal funding, and because they offer a low-cost way of preserving pavement conditions, they have become an important approach for extending a pavement's life cycle.

While most agencies agree in concept that pavement preservation is an effective strategy for extending pavement life, there is general confusion in the industry as to what treatments are considered preservation activities and what are considered to be rehabilitation or reconstruction activities. Although there is no single definition in place to address these issues, there have been several initiatives aimed at reducing or eliminating any confusion over these terms.

For instance, a FHWA Memorandum attempted to differentiate between various types of pavement repair, by providing the following definitions (Geiger 2005):

- **Rehabilitation** "consists of structural enhancements that extend the service life of an existing pavement or improve its load-carrying capability, or both. Rehabilitation activities are considered to be examples of *minor rehabilitation* when non-structural enhancements are made to existing pavement sections." According to the memo, "*major rehabilitation* has been defined by the AASHTO Highway Subcommittee on Maintenance as structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability."
- **Preventive Maintenance** is defined as "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)." It is generally applied to pavements in good condition without extensive amounts of deterioration.
- **Routine Maintenance**, on the other hand, 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."
- **Corrective Maintenance** includes activities that are "performed in response to the development of a deficiency or deficiencies that negatively impact the safe, efficient operations of the facility and the future integrity of the pavement section." These types of activities are generally reactive in nature.
- **Pavement Preservation** is defined as "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."

Although not defined in the FHWA Memorandum, pavement reconstruction is generally considered to be the replacement of an existing pavement structure by the equivalent of a new structure. It usually involves the complete removal and replacement of the existing pavement structure, and may include either new or recycled materials.

The general relationship between each of these activities is illustrated in Figure 6-1. As shown in the figure, pavement preservation activities include both preventive maintenance and minor rehabilitation activities. As defined above, these activities focus on restoring the functional characteristics of a pavement, rather than the structural condition of a pavement, which is more appropriately addressed through rehabilitation and reconstruction activities. Routine and corrective maintenance activities may be performed at any time during a pavement's life cycle.

An alternative view of the differences in these activities is presented in Table 6-1, which summarizes the primary purpose of each activity. The three shaded rows in the table (e.g., minor (light) rehabilitation, preventive maintenance, and routine maintenance) represent the types of treatments normally referred to as pavement preservation, again illustrating that it is comprised of preventive maintenance, some forms of minor (non-structural) rehabilitation, and some forms of routine maintenance (Geiger 2005). Pavement preservation is intended to apply preventive (actions intended to prevent, stop, or slow down deterioration), restorative (actions intended to improve conditions or restore conditions to acceptable levels), or limited corrective (actions intended to fix defects or re-establish structure integrity) treatments, or some combination thereof, to pavements that are in relatively good condition and have little or no structural deterioration. Application of the right treatment at the right time and in the right manner can help prolong the service life of the pavement. Examples of preventive maintenance treatments include seal coats, micro-surfacing, and crack/joint filling.

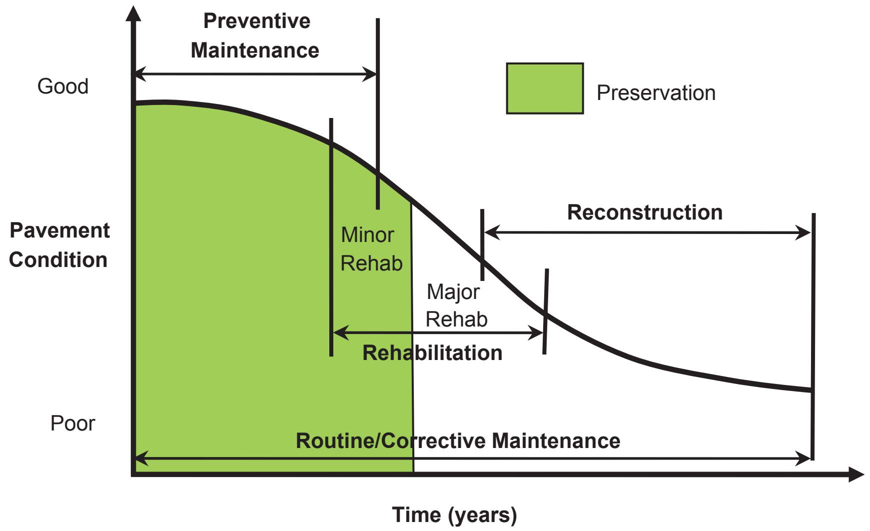



**Figure 6-1. Relationship Between Pavement Condition and Different Categories of Pavement Treatment (Adapted from Peshkin *et al.* 2007)**

**Table 6-1.** Classification of Pavement Activities by Purpose (Adapted from Geiger 2005)

| Type of Activity | Purpose of Activity | | | | |
|---|---|---|---|---|---|
| | Increase Capacity | Increase Strength | Slow Aging | Restore Surface Characteristics | Improve or Restore Functionality |
| New Construction | X | X | X | X | X |
| Reconstruction | X | X | X | X | X |
| Major (Heavy) Rehabilitation | | X | X | X | X |
| Structural Overlay | | X | X | X | X |
| Minor (Light) Rehabilitation | | | X | X | X |
| Preventive Maintenance | | | X | X | X |
| Routine Maintenance | | | | | X |
| Corrective (Reactive) Maintenance | | | | | X |
| Catastrophic Maintenance | | | | | X |

When a pavement has deteriorated to a point that more extensive cracking and other distresses are present, the use of preventive maintenance is no longer appropriate, but it could be too soon to trigger major rehabilitation. Pavements at this condition level receive minor rehabilitation treatments, such as thin overlays or surface recycling, that restore functional qualities and, to a limited extent, structural integrity.

The use of preventive maintenance treatments and minor rehabilitation techniques along with routine maintenance are good options for a pavement that is still in relatively good condition.

If preventive maintenance or minor rehabilitation is not used during the life of the pavement, the pavement will deteriorate to the point at which major rehabilitation (structural restoration, such as full-depth repairs, thick overlays, or even reconstruction) is necessary. When a pavement develops significant levels of distress, preservation activities are no longer viable treatment options for extending pavement life.

## 6.3 PAVEMENT PRESERVATION STRATEGIES

The practice of using pavement preservation activities to extend pavement service life is becoming increasingly popular among transportation agencies. In recent years, a number of state DOTs (such as California, Indiana, North Carolina, Missouri, Minnesota, South Carolina, and Louisiana) have created, or formalized, pavement preservation programs. Other agencies that have been practicing pavement preservation for an extended period of time (such as Texas and Washington State) have expanded their programs to include a larger proportion of their pavement network than in previous years.

The benefits associated with pavement preservation have been difficult to demonstrate, largely because of the lack of historical performance data and the inconsistencies in treatment definitions and applications. However, most agencies agree in concept that by maintaining pavements in good condition at a relatively low cost, the need for more costly rehabilitation activities is deferred. In other words, it is more cost-effective to preserve existing assets than it is to allow them to deteriorate until the only viable strategy is a costly treatment, such as rehabilitation or reconstruction. This concept is illustrated in Figure 6-2, which shows the higher costs associated with rehabilitation and the lower costs associated with the use of preventive maintenance treatments. Although the figure does not include numerical differences in costs between treatments, some agencies have reported rehabilitation costs of eight to nine times as much as a preventive maintenance treatment (Peshkin et al. 1999). The greater the difference in treatment costs, the greater the benefit associated with the use of pavement preservation activities.

It is possible that some pavement preservation treatments provide negative benefits to the agency, depending on how benefits are calculated. For example, crack sealing may result in a rougher pavement, so IRI values may increase immediately after the treatment is applied. If IRI is used as the performance measure, a negative benefit may result from the use of the treatment. However, if instead of using IRI, a more general representation of pavement condition is used, the treatment may show benefits in terms of extended performance at a higher condition level than if the road had been left untreated.

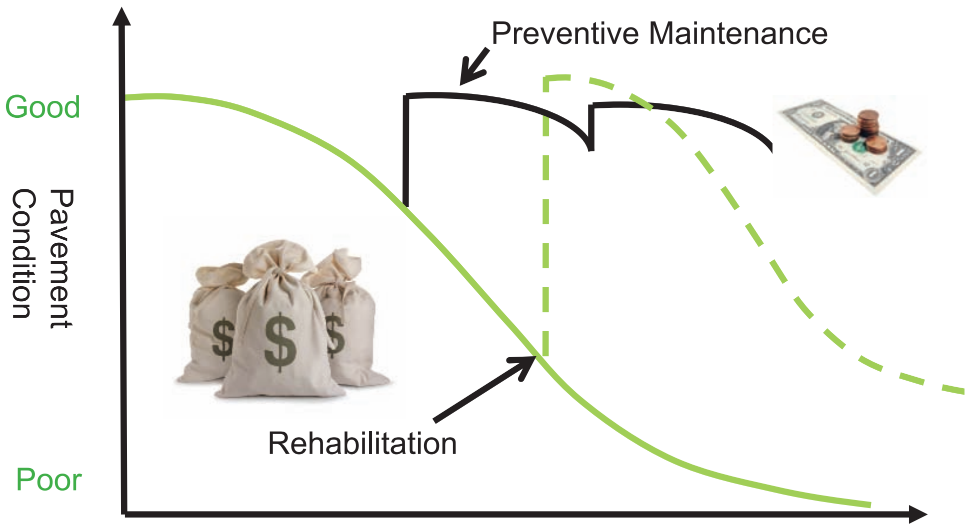



**Figure 6-2. Pavement Condition as a Function of Time (FHWA 2010f)**

## 6.4 IDENTIFYING TREATMENT NEEDS

One of the primary uses for a pavement management system is the identification of improvements needed to address the deficiencies identified during the pavement condition surveys. By projecting pavement conditions (using the performance models discussed in Chapter 5), a pavement management system is a useful tool for evaluating both current and future pavement preservation needs and the impacts of different treatment choices on long-term network conditions. To determine either current or future treatment needs, the following components must be defined:

- The types of treatments or treatment categories to be considered in the analysis.
- The conditions under which each of the treatments is considered viable.

These components are addressed in Section 6.4.1. Then, Section 6.4.2 addresses the development of impact rules, which are used in pavement management software to define the change in conditions and future performance associated with each of the treatments considered in the analysis. Impact rules are necessary to predict the long-term impacts of each treatment strategy or funding option.

### 6.4.1 Defining Treatments or Treatment Categories

One of the first steps in determining treatment needs is identifying the types of treatments to be considered for addressing various forms of pavement deterioration. In general, agencies define specific treatments, categories of repair, or some combination of the two approaches. Specific treatments might include the types of treatment shown in Table 6-2.

**Table 6-2.** Types of Treatments Included in a Pavement Management System (Zimmerman and ERES Consultants 1995)

| Asphalt-Surfaced Pavements | Portland Cement Concrete Pavements |
|---|---|
| Routine maintenance | Slab grinding |
| Surface seal coats | Microsurface overlay |
| Milling and inlays | Full- and partial-depth repairs |
| Thin overlays | Crack and seal |
| Thick overlays | Thin-bonded overlays |
| Mill and overlay | Unbonded overlays |
| Reconstruction | Slab replacement |
| | Reconstruction |

There are several advantages and disadvantages associated with this approach. Major disadvantages are the complexity of the modeling and the increased data requirements. A pavement management system must have performance models, treatment rules, and treatment impact rules for each of the treatments considered in the analysis and for each of the condition indices being used. Therefore, the more treatments included in the analysis, the more modeling required to establish the pavement management software. This approach typically requires more data than a system in which treatment categories are used, primarily because of the number of factors that are required to differentiate between the use of each treatment. For example, to differentiate between the selection of a thick overlay and a mill and overlay, information on bridge clearances might need to be known.

However, agencies that use this approach tend to believe that the increased data demands and modeling requirements associated with this approach are justified due to the specificity of the treatment cost estimates and the condition predictions. To some degree, this approach combines network- and project-level decisions.

Alternatively, an agency may choose to determine needs based on categories of repair rather than specific treatment types. Many pavement management systems available in the public domain use this approach to determine needs because it is relatively easy to set up and it produces reasonable results at the network level. Treatment categories that might be included in a pavement management analysis include the following:

- Preventive maintenance
- Surface seal coats
- Minor rehabilitation
- Major rehabilitation
- HMA reconstruction
- PCC reconstruction

There are numerous reasons for using treatment categories rather than listing specific treatments in the pavement management system, including the following:

- The use of treatment categories limits the number of treatments considered in the analysis, which simplifies the number of performance models and treatment rules that must be defined.
- Unavailability of performance data that allows rates of deterioration for different types of treatments to be differentiated. The use of a treatment category allows the agency to model the performance of all treatments that fall within that category in the same way.
- Limited data in the pavement management system to allow identification of the specific treatment that is needed. For example, in an urban environment the data available in the pavement management system may not be sufficient to indicate whether milling is needed due to curb height restrictions. Similarly, the condition data may not be specific enough to indicate whether existing pavement deterioration is due to load-related distress or non-load-related distress, so it would be difficult to determine the appropriate overlay thickness to recommend.
- Use of pavement management information only as a network-level tool, to determine the level of repair necessary. Once the level of repair is determined, project-level investigations are performed to design the appropriate treatment. This separation of network- and project-level activities allows for the consideration of localized factors that influence the final selection of a treatment.

There are some disadvantages to the use of treatment categories that should be considered before using this approach. Since a single treatment category represents several different treatments, average costs and rates of deterioration are used to model scenarios in the pavement management system. This level of granularity may not be sufficient to achieve more precision in the analysis results.

The final approach is to use a combination of these two methods. For example, an agency may elect to include specific treatments in its pavement management system for rehabilitation activities for which the agency has demonstrated a good record of performance data (e.g., thin HMA overlays, mill and fill). Other treatments, such as preventive maintenance treatments, for which historical performance data are not available, may be represented by a single category of treatment (e.g., preventive maintenance). This approach capitalizes on the benefits associated with the use of specific treatments and minimizes the disadvantages associated with the use of treatment categories.

### 6.4.2 Setting Treatment Trigger Rules

For each treatment included in the pavement management system, trigger rules must be established to define the set of circumstances that describe conditions under which the treatment is considered to be viable. Treatment trigger rules range from very simplistic to very complex, depending on the types of data available in the pavement management system. At the simplest level, treatment rules generally include:

- Information about the surface type (e.g., HMA, PCC).
- Pavement condition ratings for each of the condition indices reported as a result of the pavement condition surveys.
- A representation of traffic, such as functional classification, system, or traffic volumes.

Additional information, such as truck volumes, specific distress quantities, pavement structure layer and thickness data, and previous treatment histories, can be very helpful in determining the most appropriate treatment for a given pavement section. In general, the more factors that are included in the trigger rules, the more complex the process becomes.

For example, the pavement management system used by the South Dakota Department of Transportation (SDDOT) considers the thirteen surface types shown in Table 6-3. Combined with the six condition indices for flexible pavements and seven condition indices for rigid pavements, this has led to the development of 168 different performance models in their system (SDDOT 2010). The SDDOT has also defined more than fifty treatments that are considered in the analysis, and treatment rules have been established for each using variables such as distress index values, roadway width and designation, and pavement type. Examples of the types of rules used by the SDDOT are shown in Figure 6-3. These examples describe the conditions for using microsurfacing, asphalt overlays, and mill and overlays on thin, flexible rural pavements that fall into the TONS (thin on strong) and TONW (thin on weak) categories shown in Table 6-3. The codes for the condition indices used in the treatment rules can be found in Table 6-4.

**Table 6-3.** Surface Types Considered in the SDDOT Pavement Management System (SDDOT 2010)

| | Code | Type | Description |
|---|---|---|---|
| FLEXIBLE | AONC | ACP on PCCP | Asphalt overlay on top of PCCP |
| | BLOT | Blotter | Blotter treatment without any AC mat |
| | FD | Full Depth | ≥ 10 in. Asphalt Concrete |
| | THK | Thick | ≥ 5 < 10 in. Asphalt Concrete |
| | TONS | Thin on Strong | < 5 in. Asphalt Concrete and ≥ 8 in. granular base |
| | TONW | Thin on Weak | < 5 in. Asphalt Concrete and < 8 in. granular base |
| RIGID | CRCP | Continuously Reinforced | Continuous reinforced PCCP |
| | MESH | Mesh Reinforced | Mesh reinforced |
| | TKSJ | Thick Short Jointed | ≥ 8 in and ≤ 20 ft. joint spacing without dowels |
| | TKSJD | Thick Short Jointed w/dowels | ≥ 8 in.and ≤ 20 ft. joint spacing with dowels |
| | TNSJ | Thin Short Jointed | < 8 in and ≤ 20 ft. joint spacing without dowels |
| GRAVEL | GRAV | Gravel | Gravel Surfacing |
| OTHER | OTHR | Other Surfacing | Other (Bridges, etc.) |

**RURAL THIN ASPHALT PAVEMENT TREATMENT TRIGGERS**
**(INCLUDES TONS & TONW)**

**Microsurfacing**
**SURFACE AGE < 12 ONLY**
**RECONFLAG<>1**

RUT ≤ 3.0

**AC Overlay**
**Milled and Overlaid or Original Pavement (Only)**

TRCR ≤ 2.6 and RUT ≥ 1.0 and FTCR ≥ 2.0 and PTCH ≥ 2.0 and BLCR ≥ 2.0

FTCR ≥ 2.0 ≤ 3.5 and RUT ≥ 1.0 and PTCH ≥ 2.0 and BLCR ≥ 2.0

PTCH ≥ 2.0 ≤ 3.5 and RUT ≥ 1.0 and FTCR ≥ 2.0 and BLCR ≥ 2.0

BLCR ≥ 2.0 ≤ 3.4 and RUT ≥ 1.0 and FTCR ≥ 2.0 and PTCH ≥ 2.0

RUFF < 2.9 and RUT ≥ 1.0 and FTCR ≥ 2.0 and PTCH ≥ 2.0 and BLCR ≥ 2.0

**Mill and AC Overlay**

TRCR ≤ 2.5 and FTCR ≥ 2.0 and PTCH ≥ 2.0 and BLCR ≥ 2.0

FTCR ≥ 2.0 ≤ 3.5 and PTCH ≥ 2.0 and BLCR ≥ 2.0

RUT ≤ 3.0 and FTCR ≥ 2.0 and PTCH ≥ 2.0 and BLCR ≥ 2.0

PTCH ≥ 2.0 ≤ 3.5 and FTCR ≥ 2.0 and BLCR ≥ 2.0

BLCR ≥ 2.0 ≤ 3.4 and FTCR ≥ 2.0 and PTCH ≥ 2.0

RUFF ≤ 2.8 and FTCR ≥ 2.0 and PTCH ≥ 2.0 and BLCR ≥ 2.0

**Figure 6-3. Sample Treatment Triggers Used by the SDDOT (SDDOT 2010) (See Table 6-4 for codes used in this figure)**

In general, the trigger values used in the pavement management system should reflect the types of conditions under which pavement improvements are normally considered. Therefore, as trigger values are being established, it is important to involve those individuals who have experience with project and treatment selection in the process. One approach for developing trigger values is to establish a committee or task force with responsibility for setting and updating the treatment rules. In addition to including pavement management personnel, the committee should include a broad representation of agency personnel, including personnel from design, maintenance, and field offices. The knowledge and expertise of the members of the committee serve as the basis for establishing the treatment rules. By querying these individuals about the types of factors that differentiate the use of one treatment over another, valuable information about setting treatment rules can be gleaned.

#### 6.4.2.1 Decision Trees

To help ensure that rules are established for all possible combinations of events, some agencies prefer to develop their treatment trigger rules as decision trees or tables, or both, to help visualize the process. To make it easier for the users, some pavement management software programs use a decision tree format for entering the treatment trigger rules into the pavement management system. The same types of information described earlier are used to create decision trees, so the only difference is in the format used to display or enter the information, or both. An example of a decision tree used by the Ministry of

Transportation in Ontario (MTO) is provided in Figure 6-4. The MTO establishes separate decision trees for each combination of pavement type and functional classification. Once the appropriate decision tree is identified, variables such as overall pavement condition index (PCI), pavement age, and the presence of particular distress types are considered in determining the viability of different treatments.

**Table 6-4.** Condition Index Codes Used by the SDDOT (SDDOT 2010)

| Flexible Pavements | | Rigid Pavements | |
|---|---|---|---|
| **Deficiency** | **Code** | **Deficiency** | **Code** |
| Transverse Cracking | TRCR | D Cracking and ASR | DASR |
| Fatigue Cracking | FTCR | Joint Spalling | JTSP |
| Patching/Patch deterioration | PTCH | Corner Cracking | CRCR |
| Block Cracking | BLCR | Faulting | FLTG |
| Rutting | RUT | Joint Seal Damage | JTSL |
| Roughness | RUFF | Roughness | RUFF |
| | | Punchouts | POUT |

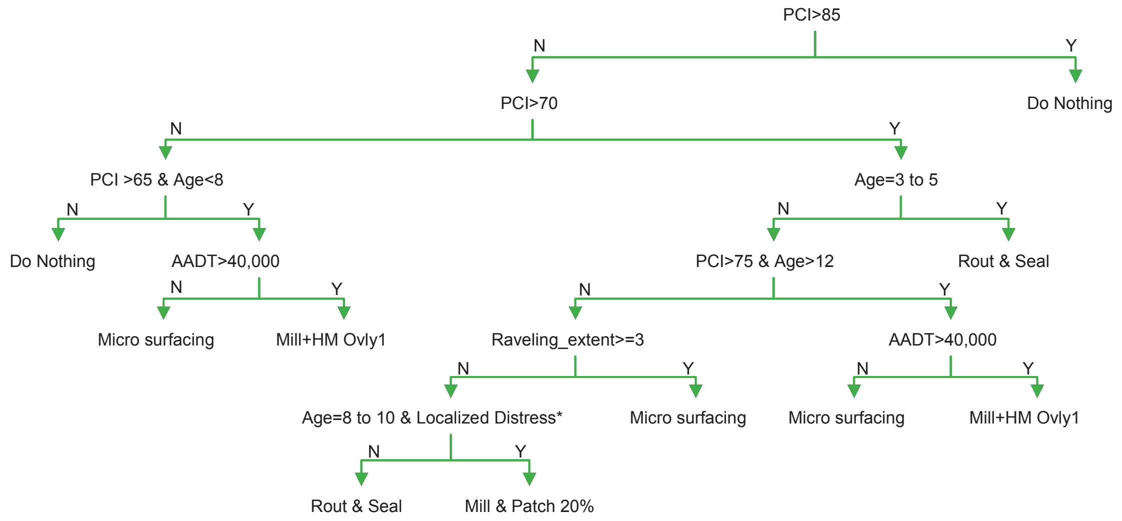



**Figure 6-4. Sample Decision Tree Used by the MTO for a Particular Combination of Pavement Type and Functional Classification (Bekheet et al. 2005)**

Decision trees are fairly easy to use and offer the user flexibility to modify the rules as an agency's policies and practices change. They are also fairly easy to explain to stakeholders, and they can easily be incorporated into most pavement management software programs.

### 6.4.2.2 Establishing Trigger Values

If historical information about the conditions under which different types of treatments have been applied is available, it can be helpful in establishing trigger values for each treatment to be considered in the pavement management analysis. By extracting pavement condition data, traffic information, pavement structure records, and other relevant information from the database for each section that received a treatment, patterns in the data can be used to set initial treatment rules.

In the absence of historical pavement condition information, it is generally easiest to keep the treatment rules simple and to ask several experts for guidance as to the number of years before certain treatments are needed on different types of pavements. For instance, asking how many years typically pass before a new HMA pavement needs an overlay will provide a timeframe that can be superimposed on a pavement performance model to determine the condition rating at which that treatment should be triggered. Following up with similar types of questions for each surface type and treatment type will typically provide a good round of treatment triggers to start with.

A study conducted for the Indiana Department of Transportation evaluated the development of treatment triggers for pavement preservation treatments using two approaches: one in which historical data were used to set the treatment triggers and another in which expert opinion was used (Ong et al. 2010a). The study found that both methods were effective at setting treatment triggers, but the expert approach was favored when developing triggers for new and innovative materials and treatments.

It is important to avoid trying to be too exact in developing treatment triggers, especially when a pavement management system is first implemented. The most successful agencies keep their treatment triggers relatively simple until they have a degree of comfort with the models. This usually involves several iterations before a reasonable set of treatment triggers are developed. Additional guidance on the development of treatment triggers include the following:

- If the pavement management software allows it, consider storing multiple sets of treatment triggers so you can easily compare different scenarios. For instance, one set of treatment triggers may represent the types of treatments that are normally used by the agency. A second set might include more proactive applications of treatments, representing the "desirable" use of treatments. The availability of both sets of treatment rules means that an agency can quickly compare the long-term impacts of either scenario to determine whether one is more effective than another.
- To test the reasonableness of the treatment triggers, run an analysis on a subset of the network using the treatment rules. Then, conduct field visits to the various sites to determine whether the recommended treatment is appropriate, or whether changes to the treatment rules are needed.

#### 6.4.2.3 Updating and Calibrating Treatment Triggers

It is important that the treatment triggers used in the pavement management analysis continue to reflect the types of treatments being used by the agency and the conditions under which they are considered viable. Therefore, the list of treatments and the rules being used for triggering treatments should be reviewed regularly. A two- to three-year cycle should normally be sufficient. However, if substantial changes are made to the types of treatments that are being used, or if new policies are established that influence the types of pavement improvements being made, a more frequent update cycle might be considered.

The Minnesota Department of Transportation (Mn/DOT) regularly calibrates its pavement management treatment trigger rules using input provided by field personnel (FHWA 2008c). Every two to three years, representatives from the Mn/DOT Pavement Management Unit spend a day in the field with the District Materials Engineer to review the types of treatments that are appropriate for randomly-selected sites. The results are then compared to the rules used in the pavement management software in an effort to calibrate the treatment rules to actual practice. The process also helps to build credibility of the pavement management system, which has led to better acceptance of the recommendations among district personnel.

### 6.4.3 Impact Rules (or Reset Values)

During an analysis run, a pavement management system identifies feasible maintenance and rehabilitation treatments, and their associated costs, in each year of the analysis. Another component to the analysis is the prediction of future conditions after each of the viable treatments is included in the improvement program recommendations. This aspect of the analysis is essential for comparing the long-term impacts of one program with another so the most cost-effective strategy can be identified. Therefore, in addition to defining treatment triggers and cost models, an additional set of rules must be defined to describe the conditions after a particular treatment has been selected in the analysis. These rules are commonly referred to as impact rules or reset values. They are used only for a pavement management analysis, and they do nothing to change the data in the pavement management database. At the most basic level, impact rules must be developed for both surface type and condition.

#### 6.4.3.1 Surface Type Resets

One type of reset rule is for the surface type, to indicate whether the pavement surface stays the same after a treatment is applied, or whether it changes. Often, if the pavement type changes due to a treatment, it changes the pavement family that is used for predicting future conditions, too. For example, if a concrete pavement is overlaid with hot-mix asphalt, the pavement surface type would change from a concrete pavement to an asphalt-over-concrete pavement (or an asphalt-surfaced overlaid pavement, depending on the surface types included in the database). The change in surface type will help ensure that the concrete pavement performance model is not used to predict the performance of the overlay. Instead, the performance model associated with the new surface type will be used. However, the change in surface type is only applicable for the analysis—it is not changed automatically in the database. Changing the surface type in the database is done manually, once the appropriate treatment has been constructed.

#### 6.4.3.2 Condition Resets

Reset values are also often needed to update the condition indices used in the database so the impacts of a treatment scenario can be determined. These condition resets indicate whether the treatment brings the condition of the pavement section back to perfect condition, or whether it increases one or more condition indices by a certain number of points. The reset values for most rehabilitation activities return all condition indices back to a perfect score (or remove the presence of any distress if indices are not used). However, it is more difficult to develop reset values for other treatments, such as preventive maintenance, because these treatments may or may not return each index back to a perfect score. Depending on the capabilities of the pavement management software, there may be special features for handling these types of treatments. For instance, the reset value for a chip seal may increase a functional index by a certain number of points (e.g., 10 points out of 100) but may have no impact on a roughness index.

At Mn/DOT, the type of treatment dictates the approach used to reset conditions (FHWA 2008c). For example, an equation that resets indices to a perfect score can be used for reconstruction projects, where the original performance of the pavement has little impact on the performance of the treatment. However, for preventive maintenance treatments, where the pre-existing condition is very important, a relative improvement is used. For example, crack sealing retains the existing condition of a pavement section in

Mn/DOT's pavement management system for a period of years (FHWA 2008c). Once the hold period is over, the pavement then reverts back to the original rate of deterioration. The distress reduction option is also used with localized maintenance treatments, such as patching.

### 6.4.4 Considerations for Preventive Maintenance Treatments

One of the challenges with developing treatment rules for preventive maintenance activities is that the factors that often trigger the use of these treatments are not always incorporated into the traditional network-level pavement condition surveys. For instance, some preventive maintenance treatments are effective at restoring surface texture characteristics. While many state DOTs collect friction information, it is not normally conducted as part of a network-wide survey or the test results are not accessible in the pavement management system. Similarly, some state DOTs use composite indices to identify when maintenance and rehabilitation treatments are needed. However, since preventive maintenance treatments are more typically triggered by or limited by individual distress information, some agencies have had to modify the way they approach treatment rules for preventive maintenance treatments.

Results of the study conducted by the Indiana Department of Transportation led to the development of treatment triggers for pavement preservation treatments, including preventive maintenance treatments (Ong et al. 2010a). The study investigated the development of treatment triggers using both historical data and the opinions of approximately fifty department of transportation employees with experience in the use of these treatments. The study found the feedback from the experts to be most applicable in developing treatment rules, largely because the triggers were expected to model preferred practices, rather than historical practices. The study reported the following observations in developing the treatment triggers (Ong et al. 2010a):

- Rut depth, crack quantities, and roughness all impacted whether pavement preservation treatments were appropriate for asphalt pavements. The type of crack (e.g. load- or non-load-related cracks) did not have an impact on the preferred treatment. Pavements with poor friction values were good candidates for pavement preservation activities, unless the pavement also had significant structural damage.
- For jointed and jointed-reinforced concrete pavements, pavement preservation activities were preferred on pavements with poor friction characteristics.
- In all instances, trigger values for non-interstate pavements were lower than trigger values for interstate pavements.

The resulting treatment triggers for pavement preservation treatments from the study are presented in Tables 6-5 and 6-6, for asphalt and concrete pavements, respectively. Table 6-5 shows that:

- Crack seals were the preferred treatment on pavements with a fair IRI, low rut severity, and no more than medium crack severity.
- Chip seals are only used on non-interstate pavements needing improvement to surface texture characteristics.
- Thin overlays are used when cracking and rutting is moderate and IRI values are fair. If a pavement section has poor IRI, a thin overlay is not used unless crack and rut severities are low. When used to address poor friction characteristics, the pavement should not have a significant amount of structural deterioration.

Table 6-6 reflects the following guidelines for jointed (or jointed-reinforced) concrete pavements:

- Crack seals were recommended on pavements with a fair IRI, low faulting, and no more than medium crack severity.
- To address moderate severity faulting, joint repair, load transfer retrofitting, and diamond grinding may be considered. However, diamond grinding is preferred if surface texture characteristics are poor.
- If moderate faulting and crack severities are present, partial- and full-depth repairs may be considered feasible treatments.

**Table 6-5.** Pavement Preservation Treatment Triggers for Asphalt Pavements in Indiana (Adapted from Ong et al. 2010a)

| Conditions | | | Interstates | | | | | | Non Interstates | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Excellent IRI | | Fair IRI | | Poor IRI | | Excellent IRI | | Fair IRI | | Poor IRI | |
| | | | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN |
| Load Associated Cracks | No Crack | No Rut | DN | TOL | DN | TOL | TOL | TOL | DN | CHP | DN | CHP | DN | TOL |
| | | LS Rut | DN | TOL | DN | TOL | TOL | TOL | DN | CHP | DN | CHP | CRX | TOL |
| | | MS Rut | CRX | TOL | CRX | TOL | TOL | TOL | DN | CRX | CRX | CRX | CRX | TOL |
| | | SS Rut | CRX | TOL | CRX | TOL | TOL | TOL | CRX | CRX | CRX | TOL | TOL | TOL |
| | LS | No Rut | DN | TOL | CRX | TOL | TOL | TOL | DN | CHP | CRX | CHP | CRX | TOL |
| | | LS Rut | CRX | TOL | CRX | TOL | TOL | TOL | DN | CHP | CRX | CHP | CRX | TOL |
| | | MS Rut | CRX | TOL | CRX | TOL | TOL | TOL | CRX | CRX | CRX | CRX | TOL | TOL |
| | | SS Rut | CRX | TOL | TOL | TOL | TOL | TOL | CRX | TOL | CRX | TOL | TOL | TOL |
| | MS | No Rut | CRX | TOL | CRX | TOL | TOL | TOL | CRX | CHP | CRX | CHP | TOL | TOL |
| | | LS Rut | CRX | TOL | CRX | TOL | TOL | TOL | CRX | CHP | CRX | CHP | TOL | TOL |
| | | MS Rut | CRX | TOL | TOL | TOL | SOL | SOL | CRX | CRX | TOL | TOL | TOL | TOL |
| | | SS Rut | TOL | TOL | FOL | FOL | SOL | SOL | TOL | TOL | FOL | FOL | SOL | SOL |
| | SS | No Rut | CRX | TOL | TOL | TOL | FOL | FOL | CRX | TOL | TOL | TOL | FOL | FOL |
| | | LS Rut | TOL | TOL | FOL | FOL | SOL | SOL | TOL | TOL | FOL | FOL | FOL | FOL |
| | | MS Rut | FOL | TOL | SOL | SOL | ARP | ARP | FOL | FOL | SOL | SOL | SOL | SOL |
| | | SS Rut | SOL | SOL | ARP | ARP | ARP | ARP | SOL | SOL | ARP | ARP | ARP | ARP |

**Notes:**
IRI = International Roughness Index, $SN_{40}$ = Skid Number at 40 mph. LS = Low Severity, MS = Medium Severity, HS = High Severity. DN = Do Nothing, CRX = Crack Seal, CHP = Chip Seal, TOL = Thin Preventive Maintenance Overlay, FOL = Functional Overlay, SOL = Structural Overlay, ARP = Asphalt Pavement Replacement.
Only the best treatment is shown in this table. A combination of treatments can be used in addition to the one shown in the table.

**Table 6-6.** Pavement Preservation Treatment Triggers for Concrete Pavements in Indiana (Adapted from Ong et al. 2010a)

| Conditions | | | Interstates | | | | | | Non Interstates | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Excellent IRI | | Fair IRI | | Poor IRI | | Excellent IRI | | Fair IRI | | Poor IRI | |
| | | | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN | Good FN | Poor FN |
| Load Associated Cracks | No Crack | No Fault | DN | GRD | N.A. | N.A | N.A. | N.A. | DN | GRD | N.A. | N.A | N.A. | N.A. |
| | | LS Fault | DN | GRD | GRD | GRD | N.A. | N.A. | DN | GRD | GRD | GRD | N.A. | N.A. |
| | | MS Fault | GRD | GRD | GRD | GRD | PFD | PFD | DN | GRD | GRD | GRD | GRD | GRD |
| | | SS Fault | N.A. | N.A. | GRD | GRD | PFD | PFD | N.A. | N.A. | GRD | GRD | PFD | PFD |
| | LS | No Fault | DN | GRD | N.A. | N.A. | N.A. | N.A. | DN | GRD | N.A. | N.A. | N.A. | N.A. |
| | | LS Fault | CRX | GRD | CRX | GRD | N.A. | N.A. | CRX | GRD | CRX | GRD | N.A. | N.A. |
| | | MS Fault | GRD | GRD | GRD | GRD | PFD | PFD | GRD | GRD | GRD | GRD | PFD | PFD |
| | | SS Fault | N.A. | N.A. | GRD | GRD | SLR | SLR | N.A. | N.A. | GRD | GRD | SLR | SLR |
| | MS | No Fault | CRX | GRD | N.A. | N.A. | N.A. | N.A. | CRX | GRD | N.A. | N.A. | N.A. | N.A. |
| | | LS Fault | CRX | GRD | PFD | PFD | N.A. | N.A. | CRX | GRD | PFD | PFD | N.A. | N.A. |
| | | MS Fault | GRD | GRD | PFD | PFD | C&S | C&S | GRD | GRD | PFD | PFD | SLR | SLR |
| | | SS Fault | N.A. | N.A. | SLR | SLR | CRP | CRP | N.A. | N.A. | C&S | C&S | CRP | CRP |
| | SS | No Fault | CRX | GRD | N.A. | N.A. | N.A. | N.A. | CRX | GRD | N.A. | N.A. | N.A. | N.A. |
| | | LS Fault | CRX | GRD | SOL | SOL | C&S | C&S | CRX | GRD | SOL | SOL | SLR | SLR |
| | | MS Fault | N.A. | N.A. | SLR | SLR | CRP | CRP | N.A. | N.A. | SLR | SLR | CRP | CRP |
| | | SS Fault | N.A. | N.A. | N.A. | N.A. | CRP | CRP | N.A. | N.A. | N.A. | N.A. | CRP | CRP |

**Notes:**
IRI = International Roughness Index, $SN_{40}$ = Skid Number at 40 mph. LS = Low Severity, MS = Medium Severity, HS = High Severity.
N.A. refers to infeasible combination of pavement conditions, DN = Do Nothing, CRX = Crack Seal, GRD = Diamond Grinding and Grooving, LTR = Joint Bump Repair and Load Transfer Retrofitting, PFD = Partial or Full Depth Repair, SOL = Structural Overlay, SLR = Slab Reduction Techniques, CRP = Concrete Pavement Replacement
Only the best treatment is shown in this table. A combination of treatments can be used in addition to the one shown in the table.

Other agencies have integrated preventive maintenance treatments into their pavement management systems to varying degrees. For instance, the SDDOT treatment triggers (discussed in Section 6.4.2) included treatment rules for microsurfacing. The Utah Department of Transportation (UDOT) has also developed treatment rules for three different types of seal coats and for thin overlays as part of their pavement preservation program. The appropriate treatment is selected based on project location (e.g., urban or rural), pavement condition, functional class, and traffic volume, under the following general conditions (FHWA 2008c):

- Seal coats are considered on sections with a pavement condition between 70 and 100. In general, low seals (such as chip seals or slurry seals) are considered when traffic volumes are less than 7,000 vehicles per day, medium seals (such as microsurfacing or a hot-applied chip seal) are considered when traffic volumes are between 7,000 and 15,000 vehicles per day, and high seals (such as thin, open-graded or dense-graded overlays) are considered when traffic volumes are in excess of 15,000 vehicles per day.
- Minor rehabilitation activities (including mill and replace or a thin overlay) are considered on sections with pavement conditions between 50 and 70.

The decision tree used in the UDOT pavement management system for selecting the most appropriate seal is provided as Figure 6-5.

A separate study of the pavement preservation programs in eight state DOTs identified several other additional agencies with treatment rules in place to support their pavement preservation programs (Adams and Kang 2006). The report includes the treatment thresholds for pavement preservation treatments used by the Michigan Department of Transportation (MDOT), which are shown in Table 6-7. These treatment rules consider Remaining Service Life (RSL), Distress Index (DI), Road Quality Index (RQI), and rut depth in determining the appropriate pavement preservation treatment.

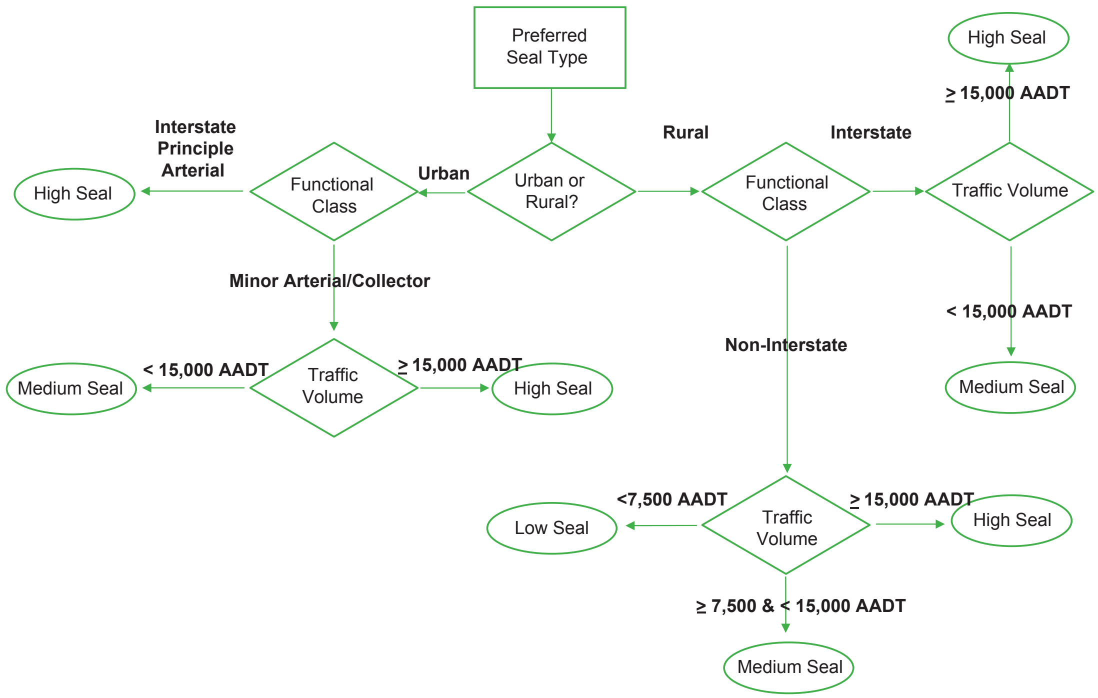



**Figure 6-5. Utah DOT Decision Tree for Seal Selection (FHWA 2008c)**

**Table 6-7.** Treatment Thresholds for MDOT (Adams and Kang 2006)

| Pavement Type | Strategy | Standards | |
|---|---|---|---|
| **Flexible** | Thin Overlays | RSL ≥ 3 yrs<br>DI < 40<br>RQI < 70<br>Rut Depth < 12 mm | |
| | Micro-Surfacing | Multiple Courses<br>RSL ≥ 5 yrs<br>DI < 30 | Single Course<br>RSL ≥ 10 yrs<br>DI < 15 |
| | | RQI < 53<br>Rut Depth < 25 mm | |
| | Crack Seal/Crack Treatment | RSL ≥ 10 yrs<br>DI < 15<br>RQI < 54<br>Rut Depth < 3 mm | |
| | Chip Seal | Double<br>RSL ≥ 5 yrs<br>DI < 30 | Single<br>RSL ≥ 6 yrs<br>DI < 25 |
| | | RQI < 54<br>Rut Depth < 3 mm | |
| | Mill and Overlay | RSL ≥ 3 yrs<br>DI < 40<br>RQI < 80<br>Rut Depth < 25 mm | |
| **Rigid** | Crack Sealing | RSL ≥ 10 yrs<br>DI < 15<br>RQI < 54 | |
| | Diamond Grinding | RSL ≥ 12 yrs<br>DI < 10<br>RQI > 4 | |
| | Clean and Seal Joint | RSL ≥ 10 yrs<br>DI < 15<br>RQI < 54 | |
| | Dowel Bar Retrofit | RSL ≥ 10 yrs<br>DI < 15<br>RQI < 54 | |
| | Concrete Pavement Restoration | RSL ≥ 3 yrs<br>DI < 40<br>RQI < 80 | |
| | Patching | Damage < 50–75 mm<br>(2–3") deep<br>Area < 1 $m^2$ (10.8 $ft^2$) | |

**Note:**
RSL = Remaining Service Life
DI = Distress Index
RQI = Ride Quality Index

## 6.5 TECHNIQUES FOR PROJECT AND TREATMENT SELECTION

The treatment rules discussed in Section 6.4 are useful in identifying the feasible treatment options for addressing pavement needs within the network. In an ideal situation, an agency would have sufficient funding to address all of its pavement needs. However, in reality few agencies have adequate funding to address their needs. As a result, many agencies rely on their pavement management systems to help ensure that the funding available is used as wisely as possible. There are several different approaches that may be used to determine the most cost-effective use of available funding, each of which is discussed in more detail in Sections 6.5.1 through 6.5.3. First is an explanation of some of the common terms that are used when discussing project and treatment selection activities:

- **Ranking**: One of the easiest and most common approaches to prioritizing needs is by listing needs in accordance with a set of rules that rank projects from highest priority to lowest priority. The most common approach to ranking is to place the highest priority on the roads in worst condition. Although this is a popular method of managing a pavement network, it is typically not a cost-effective strategy.

- **Optimization**: In mathematical terms, optimization refers to the use of a mathematical model that defines both objectives and constraints using mathematical terms. Common methods of optimization include linear programming, non-linear programming, and dynamic programming. There are some pavement management systems that perform true optimization analysis to develop improvement program recommendations, although they are not widely used by state DOTs. Even so, it is common for people to refer to their project and treatment selection process as an "optimization analysis" even if it does not fit the true definition of an optimization analysis. There is an easy test to determine whether a pavement management system is performing an optimization analysis in its truest sense: if the results of the analysis provide a summary of the number of miles of roads that need to be moved from one condition to another (rather than specific projects and treatments), then it is highly likely that the pavement management system is conducting a true optimization analysis. Otherwise, it is probably conducting a heuristic analysis, which is defined below.

- **Heuristic Analysis**: There are a number of analytical approaches used in pavement management that result in near optimal solutions. These types of analyses are commonly referred to as heuristic analysis techniques. Examples of heuristic analysis techniques used in pavement management are incremental benefit-cost and marginal cost-effectiveness analyses (which are described further in Section 6.5.2).

- **Single-Year Versus Multi-Year Analysis**: In a single-year analysis (also known as an annual analysis), the project and treatment selection process for each year is performed independently of any other year. For instance, an agency may have $5 million for Year 1 and $5 million for Year 2. If the set of projects and treatments for the first year are identified before considering the projects and treatments that will be incorporated into the Year 2 program, this agency is considered to be developing two single-year programs, as illustrated in Figure 6-6. Alternatively, a pavement management system may perform a multi-year analysis. Under this type of analysis, viable project and treatment strategies in each of the analysis years are considered together so that the optimal strategies for each year can be developed. For instance, in a multi-year analysis, an agency would be able to determine whether it is better to improve a particular pavement section in Year 1, or to let it deteriorate further and improve it in Year 3 (for example). These types of comparisons are not typically performed in a single-year analysis. Therefore, a multi-year analysis is generally preferred over a single-year analysis. Figure 6-7 illustrates a multi-year analysis.

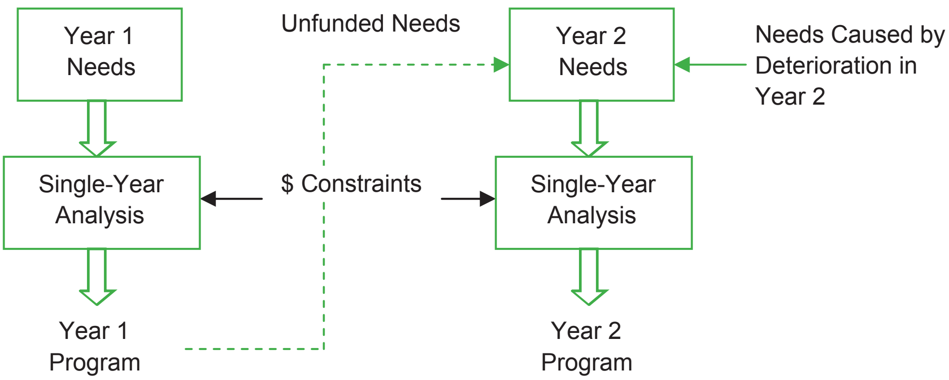



**Figure 6-6. Program Development Using Single-Year Analysis**

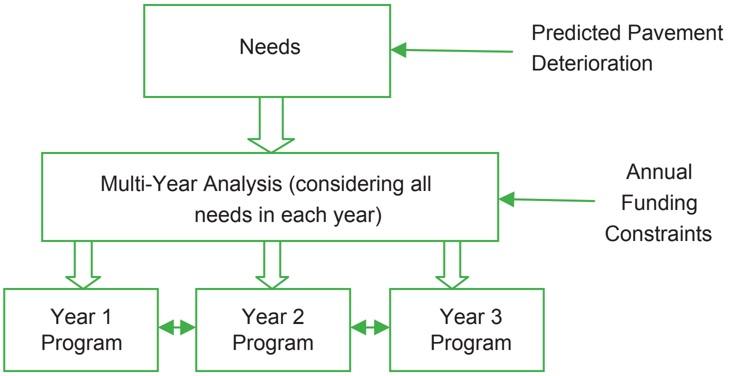



**Figure 6-7. Illustration of a Multi-Year Analysis**

- **Life-Cycle Cost Analysis**: A life-cycle cost analysis (LCCA) is a well-accepted method of comparing the cost-effectiveness of a number of different strategies by considering all costs that can be expected to be incurred over a given analysis period. In transportation agencies, an LCCA is primarily used to compare the cost-effectiveness of various pavement design strategies to determine if one strategy has a lower cost over the analysis period when all costs associated with each strategy are taken into consideration, but it may also be used in the development of models for alternate bid contracts. This analysis may consider both the real costs to the agency over the analysis period, such as the costs associated with construction, maintenance, and rehabilitation of the pavement, as well as costs borne by the users of the facility, commonly referred to as user costs. User costs typically represent expenses that are not directly incurred by the agency, but instead reflect the costs to the users of the facilities as they incur construction delays or additional wear on their vehicles. Since maintenance and rehabilitation costs can be expected to occur at various times throughout the life of the pavement, the costs are converted to an equivalent basis for comparison. This conversion allows an agency to compare one strategy that might have high initial costs and low annual maintenance costs with another that might have a lower initial construction cost but higher maintenance and rehabilitation costs. In order to compare strategies with costs incurred at different times throughout the analysis period, the costs are normally brought back to a baseline period, such as the year in which the project will be constructed. Various techniques are available to convert future costs to a present value.

  A true LCCA can be a very complex analysis, taking into account differences in future maintenance and rehabilitation schedules. If user costs are considered in the analysis, it becomes even more complex, since very detailed information about traffic patterns during the construction period, for example, are used to quantify user delay costs.

There are essentially three approaches that may be used in pavement management for project and treatment selection under fiscally constrained situations: ranking, prioritization (e.g., incremental benefit cost), and optimization. Each of these three analysis approaches provides a method for identifying an optimal strategy for preserving the condition of the network, given any constraints that may exist (such as funding). It is worth noting that the optimal solution recommended from a network optimization scenario, may or may not include the highest ranking project or the best solution for each section if they were considered individually. Instead, the results reflect the best solution for the network as a whole, when all of the needs and constraints are considered collectively.

A general comparison of these approaches can be found in Table 6-8. A more detailed description of each approach follows.

**Table 6-8.** Comparison of Prioritization Methods (Adapted from Haas et al. 1994)

| | Class of Method | Advantages and Disadvantages |
|---|---|---|
| Ranking | Simple, subjective ranking of projects based on judgment, overall condition index, or decreasing first year cost (single- or multi-year) | Quick, simple; subject to bias and inconsistency; may be far from optimal |
| | Ranking based on condition parameters, such as serviceability or distress; can be weighted by traffic (single- or multi-year) | Simple, easy to use; may be far from optimal, particularly if traffic weighting is not used |
| | Ranking based on condition parameters and traffic, with economic analysis including decreasing present worth-cost or benefit-cost ratio (single- or multi-year) | Reasonably simple, may be closer to optimal |
| Prioritization | Near-optimization using heuristic approaches including incremental benefit-cost ratio and marginal cost-effectiveness (maintenance, rehabilitation, and reconstruction timing taken into account); usually conducted as a multi-year analysis | Reasonably simple; suitable for microcomputer environment; close to optimal results |
| Optimization | Annual optimization by mathematical programming model for year-by-year basis over analysis period | Less simple; may be closer to optimal; effects of timing not considered |
| | Comprehensive optimization by mathematical programming models taking into account the effects of maintenance, rehabilitation, and reconstruction timing | Most complex and computationally demanding; can give optimal program (maximization of benefits or cost-effectiveness) |

### 6.5.1 Ranking

One of the easiest methods of selecting projects is to rank needs based on some type of agency priority, such as pavement condition or traffic levels, or both. Agencies that use ranking approaches typically evaluate the project needs in each year independently, and rarely consider alternate strategies for preserving the pavement network. Since a ranking technique does not consider the cost effectiveness of different preservation options, it does not provide the information necessary to optimize the use of available funding. Therefore, it is not recommended as a long-term strategy for managing a pavement network.

A common method of ranking needs is to list road sections in sequential order by pavement condition rating, and to fund the projects with the worst pavement condition until the available funding limits have been met. This approach is commonly referred to as a worst-first strategy in which the pavements in the worst condition are the highest priority for funding.

Some agencies have developed formulas for ranking their pavement needs, which take into account pavement condition, traffic levels, and other considerations. The most common ranking criteria include the following (Zimmerman and ERES 1995):

- Condition
- Initial cost
- Cost and timing
- Life-cycle cost
- Benefit-to-cost ratio

The ranking technique generally requires the following steps:

1. Assess the needs for a given year by identifying all pavement sections that are not in good condition.
2. Calculate treatment costs by multiplying the cost of the appropriate treatment for each level of repair times the project area.
3. Sort the needs in priority order using the ranking methodology established by the agency. For a worst-first strategy, the road sections in worst condition would be the highest priority.
4. Select projects in accordance with the prioritized listing until there is no funding left for that year.
5. Consider any remaining unfunded needs in the next year and repeat the process.

### 6.5.2 Multi-Year Prioritization Using Incremental Benefit-Cost or Marginal Cost-Effectiveness

The next level of sophistication in project and treatment selection is a prioritization process, in which needs in one or more years are considered simultaneously and the most cost-effective use of available funding over the analysis period is identified. This approach is preferred over a ranking approach because multiple treatments are considered, consequences of delaying or accelerating a treatment are evaluated, and the cost-effectiveness of a treatment is taken into account in developing the program recommendations. Pavement management systems that conduct a multi-year prioritization analysis use current and projected pavement conditions, along with the types of treatment rules discussed earlier, to determine feasible projects and treatments in each year of the analysis period. Since various treatment timing options are evaluated over a multi-year period, this approach provides agencies the opportunity to determine whether it is more beneficial to apply a treatment while the pavement is still in relatively good condition or to let that pavement section deteriorate further so other sections can be addressed. The results of a prioritization analysis typically present forecasted network conditions, so the long-term impacts of different treatment approaches or funding levels, or both, can be quickly compared. According to a survey of state practice published in 1995, ranking was the predominant method used in project and treatment selection (Zimmerman and ERES 1995). However, a more recent survey conducted by FHWA indicates that the number of agencies that are using prioritization approaches rather than ranking approaches has increased slightly (FHWA 2004).

One of the keys to the use of a multi-year prioritization method is having a way to estimate the benefit, or effectiveness, of each treatment that is considered viable. In many pavement management applications, the benefit of a treatment is represented by the additional performance provided by the treatment, as shown in Figure 6-8. The benefit is calculated as the area under the performance curve for the treatment being considered, so a treatment that has a large impact on performance will have a greater benefit than a treatment with a marginal increase in performance. The benefit is usually represented as a unit-less number and is typically compared to the normal performance model for the section, representing the "do nothing" condition in which no treatment is applied. Many agencies elect to multiply the benefit area associated with the feasible treatment by an agency-defined traffic factor so the benefit associated with projects on high-volume facilities is greater than the benefit associated with the same treatment applied to a pavement with similar conditions but lower traffic volumes. The use of a traffic factor to modify the area calculation allows agencies to take user considerations into account in the analysis. The use of a weighting factor is optional and its impact on project and treatment recommendations should be considered carefully since it may skew funding away from low-volume pavements.

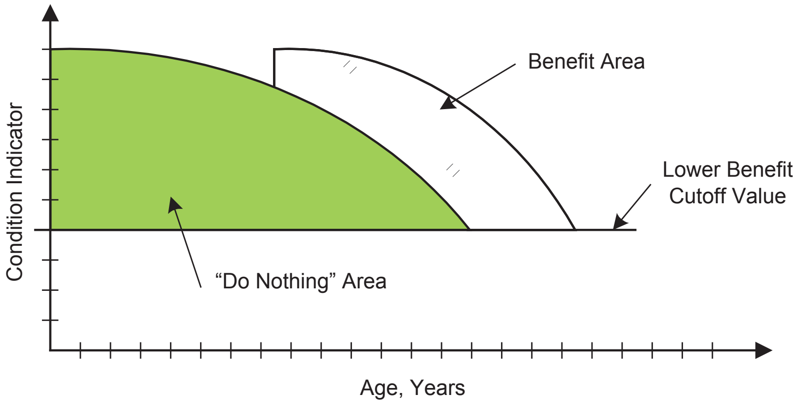



**Figure 6-8. Illustration of Benefit Calculation Using Increased Pavement Performance**

Another component to the calculation of cost effectiveness is the cost of the treatment being considered. By dividing the treatment benefit by the treatment cost, a benefit to cost ratio (or cost-effectiveness ratio) can be calculated.

### 6.5.2.1 Incremental Benefit-Cost or Marginal Cost-Effectiveness

Although some agencies use a benefit-cost ratio to rank projects in each year of the analysis, the more sophisticated programs use an incremental benefit-cost or marginal cost-effectiveness approach to conduct multi-year prioritization, which provides a means of comparing treatment options over multiple years. Very simply, an incremental benefit-cost analysis evaluates whether additional benefits can be realized for incremental increases of investment. A marginal cost-effectiveness approach does essentially the same thing, instead focusing on the cost-effectiveness of additional investments (rather than benefit). For instance, an incremental benefit-cost or marginal cost-effectiveness analysis will consider each feasible treatment option for each pavement section in each year of the analysis. They also consider marginal improvements in treatment strategies that can be considered when funding is available. As a result, the analysis compares the trade-offs associated with accelerating or postponing treatments, and different treatment options for a single section can be evaluated while taking all the other network needs into consideration.

Both an incremental benefit-cost and a marginal cost-effectiveness analysis are examples of a heuristic method of determining a near-optimal solution to a fiscally constrained analysis. Both methods enable an agency to determine the most cost-effective set of projects over an analysis period for a given level of funding. The analysis can also be used to show the impact of different funding levels on long-term network conditions. As a result, these types of analyses are effective tools for communicating the consequences of different investment levels or program strategies, or both, with decision makers. They enable agencies to determine (FHWA 1998):

- The pavement sections that should be improved in each year of the analysis.
- The most cost-effective treatment to be applied.
- The most effective time to apply the treatment.

Therefore, these types of analyses produce results that enable an agency to demonstrate the benefit of a pavement preservation program over a worst-first strategy, to convey the impact of a budget cut on future network conditions, and to illustrate the consequences associated with politically-driven projects rather than projects driven by pavement need.

In the strict economic sense, there are likely differences in how incremental benefit-cost and marginal cost-effectiveness analyses are conducted; however, in pavement management the terms are essentially used interchangeably as methods of evaluating the cost-effectiveness of different combinations of projects and treatment options. A difference between the two methods is that one refers to the benefit associated with the application of a treatment and the other refers to its effectiveness. These may or may not be defined in economic terms but are more commonly described in terms of pavement performance when used in pavement management applications. As mentioned earlier, the area under the pavement performance model is typically used to determine benefit (or effectiveness) and the area calculation may or may not be multiplied by a traffic factor.

The following steps are outlined in this guide for conducting a marginal cost-effectiveness analysis (based on FHWA 1998):

1. Identify the feasible treatments for each section over the entire analysis period using condition information, performance models, and treatment rules.
2. Calculate the effectiveness (E) of each combination of strategies using a technique such as the area under the performance curve.
3. Calculate the cost (C) of each combination in net present value terms.
4. Calculate the cost-effectiveness (CE) of each strategy by dividing C into E, where the highest value is the best.
5. Select the treatment strategy and timing for the section with the highest CE.
6. Calculate the marginal cost-effectiveness of all the other strategies for all sections as follows:

$$\text{Marginal cost-effectiveness (MCE)} = (E_r - E_s)/(C_r - C_s) \qquad (6\text{-}1)$$

where

$E_s$ = effectiveness of the strategy selected in step 5,

$E_r$ = effectiveness of the strategy for comparison,

$C_s$ = cost of the strategy selected in step 5, and

$C_r$ = cost of the strategy for comparison.

7. If the MCE is negative, or if $E_r$ is less than $E_s$, the comparative strategy is eliminated from further consideration; if not, it replaces the strategy selected in step 5.
8. This process is repeated until no further selections can be made in any year of the analysis period due to funding constraints or the elimination of all feasible strategies.

Because of the number of possible combinations of project sections and treatment options that must be considered in this type of analysis, steps have been taken to reduce the computational effort required. For instance, *Pavement Management Systems* (FHWA 1998) illustrates the use of an efficiency frontier as a way to eliminate project and treatment alternatives that provide no incremental benefit over other choices. An example of an efficiency frontier is shown in Figure 6-9. It is created by plotting the cost and benefit associated with each of the viable alternatives being considered. Starting at the do-nothing point represented by the intersection of no costs and no benefits, points are connected by a line so that a) no points exist above the line, and b) no line segment has a steeper slope than the previous line segment (FHWA 1998). The slope of the lines represents the incremental benefit cost of going from one strategy to another. Strategies which fall on the line segment represent the most cost-effective strategies for that particular section and all other strategies can be eliminated from consideration in the analysis. As a result, the computational requirements for the multi-year prioritization analysis can be significantly reduced.

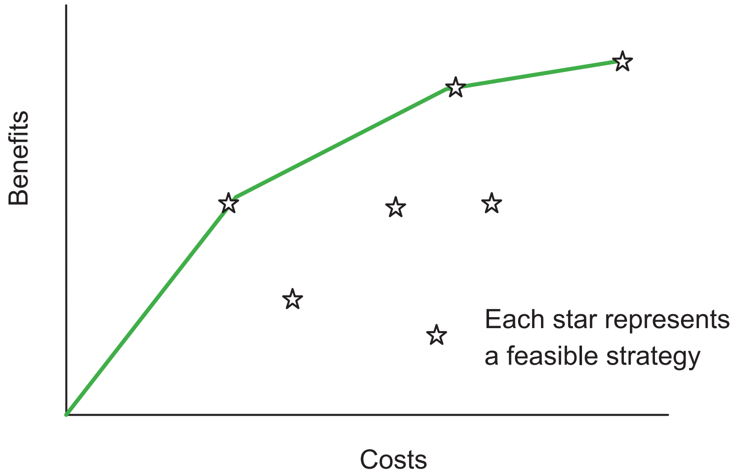



**Figure 6-9. Example of an Efficiency Frontier (from FHWA 1998)**

### 6.5.3 Optimization

A true optimization analysis is a more complex analysis to determine how to efficiently allocate resources so that network conditions are maximized (the objective function) and costs are minimized (the constraints). In some cases, agencies add additional constraints to help meet agency objectives. For example, an additional constraint that prevents any interstate pavement from dropping below a particular condition level may be included as an analysis parameter.

Several mathematical models have been used in optimization, including linear, non-linear, integer, and dynamic programming (Zimmerman and ERES 1995). The objective of these programming methods is to determine the optimal solution to achieve the objective function given certain constraints. An appropriate mathematical programming method is "a function of the type of variables in the analysis (whether they are continuous or not), the form of the objective function, and whether the decisions must be made in sequence" (Zimmerman and ERES 1995). Since constraints place an artificial limit on an optimization problem, the results of an optimization analysis may identify a sub-optimal solution. For that reason, research into the use of multi-variable optimization methods is emerging and warrants further consideration in the future.

According to Haas, Hudson, and Zaniewski (1994), linear programming is useful for conducting a multi-year prioritization analysis because it can model the trade-offs between different project timings and the impacts on pavement performance. The general form of a linear programming model is shown below.

$$\begin{gathered} \Sigma\Sigma\Sigma \quad x_{ijt} \times B_{ijt} \\ Subject \ \ to \ \Sigma\Sigma x_{ijt} \Leftarrow 1 \, for \ \ i = 1, \, 2, \, \ldots n \\ \Sigma\Sigma x_{ijt} D_{ijtt'} \Leftarrow B_t \ \ for \ \ t = 1, \, 2, \, \ldots \, n \\ X_{ijt} \Rightarrow 0 \end{gathered} \tag{6-2}$$

where

$X_{ijt}$ = Section *i* (of *n* total sections) with alternative *j* (of *k* total treatment alternatives) in year *t* of the analysis period,

$B_{ijt}$ = Present value of annual benefits of section *i*, with alternative *j*, built in year *t*, all discounted to a base year at a selected discount rate,

$D_{ijtt'}$ = The actual construction or maintenance cost, or both of section *I*, with alternative *j*, built in year *t*, incurred in year *t'*, *and*

$B_t$ = Budget for year *t*.

An advantage of the optimization analysis is the ability to incorporate risk into the analysis. Risk can be considered through the use of transition probability matrices (TPMs), such as the one shown in Table 6-9. TPMs describe the likelihood that pavement conditions will move from one condition state to another. For example, in Table 6-9, the pavement network is divided into four condition states, with a condition state of 1 being the highest condition. The columns labeled "Future Condition States" identify the probability that a pavement that is currently in one of the four condition states will move to another condition state over the analysis period (typically defined as one year). The information in Table 6-9 indicates that there is a 20 percent likelihood that a pavement that is currently in condition State 1 will remain in that condition state, a 40 percent chance that it will drop to condition State 2, a 30 percent chance that it will drop to condition State 3, and a 10 percent chance that it will drop to condition State 4. The variability associated with pavement condition surveys can be reflected in a TPM, as shown by the 10 percent probability that a pavement in condition State 3 will be reported in condition State 2 in the next year.

**Table 6-9.** Example Transition Probability Matrix

| Current Condition State | Future Condition States | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| 1 | 0.2 | 0.4 | 0.3 | 0.1 |
| 2 | | 0.2 | 0.6 | 0.2 |
| 3 | | 0.1 | 0.3 | 0.6 |
| 4 | | | 0.1 | 0.9 |

TPMs can be developed using either historical data or input from experienced practitioners, as in the development of pavement performance models. Using matrix multiplication techniques, they can also be converted to a deterministic performance model if needed to comply with the capabilities of a particular pavement management software program.

One of the challenges associated with the use of pure optimization is the difficulty in linking network-level results with project-level results. At the network level, the results of an optimization analysis typically provide the percentage of the road network that should be moved from one condition state to another through maintenance or rehabilitation actions. For example, a network analysis might indicate that 10 percent of the network should be moved from condition State 4 to condition State 1, representing the need for reconstruction or major rehabilitation activities. Similarly, a recommendation to improve a pavement from condition State 2 to condition State 1 might be addressed through a lower cost, preventive maintenance treatment. Therefore, to conduct this type of analysis, an agency must have assigned treatments and costs associated with each possible condition state improvement.

However, since mileages are recommended at the network level rather than specific projects and treatments, a second analysis must be conducted to identify specific locations and appropriate treatment options that will satisfy the network-level recommendations. Therefore, an optimization analysis is a two-step process in comparison to the heuristic approaches discussed earlier.

The use of the optimization approach has not been widely adopted, although some agencies, such as the Kansas Department of Transportation, have implemented it into their pavement management systems.

## 6.6 COORDINATING WITH MAINTENANCE

When pavement management systems were first being developed and used, the analysis focused on the identification and prioritization of pavement rehabilitation and reconstruction projects. Therefore, the recommendations from a pavement management analysis were often made independently of the actions of maintenance and operations personnel. However, as transportation agencies have shifted their focus from expansion to preservation of the network, the number and size of pavement preservation programs has grown. As a result, it has become increasingly important to coordinate pavement management and pavement preventive maintenance activities.

There are both technical and organizational issues that must be addressed to establish stronger links between pavement management and maintenance personnel. From a technical point of view, there may be differences in the types of information used in making decisions and the planning horizon being considered. For instance, maintenance personnel are usually focused on activities that will be conducted within one to two years, while capital improvements are often planned three to five years in the future. Traditional pavement management systems have also developed pavement condition survey procedures designed to identify rehabilitation and reconstruction needs, so some of the triggers for preventive maintenance treatments (such as friction or bleeding) are not routinely collected during the survey process.

In the past, there have also been data challenges that have had to be overcome to coordinate capital and maintenance activities. For many years, maintenance activities had been reported in a manner that was not useful for pavement management purposes. For instance, reporting that "X" tons of patching material were used over a 20-mile segment provides no indication of whether all sections received an equal amount of patching, or whether certain pavement management sections required more patching than others. To a large degree, these types of issues are being addressed now that many agencies have GIS for integrating data records. Other agencies have overcome this issue by integrating their maintenance management systems with their pavement management system.

The organizational issues that need to be addressed can arise because of the organizational hierarchies that have traditionally separated agency divisions working on pavement management and those working on maintenance and operations activities. Agencies have overcome these challenges through informal relationships between managers, or through the creation of coordinating positions that more formally establish these links. For instance, state DOTs in North Carolina, Indiana, California, Louisiana, and Minnesota have established Pavement Preservation Engineer positions (or an equivalent position) to facilitate the coordination between activities conducted by maintenance personnel and the capital improvements recommended by the pavement management system (Zimmerman and Peshkin 2008). The Montana Department of Transportation has also established pavement preservation nominating guidelines in its pavement management system that have significantly improved the match between the recommended preservation treatments and those that are constructed (FHWA 2010b).

In an FHWA-sponsored peer exchange meeting, participating agencies identified the following strategies for improving the links between pavement management and those responsible for implementing pavement preservation programs (FHWA 2010d):

- Improving the quality of data reported in a maintenance management system.
- Automating the process of sharing data within separate management programs.
- Improving the tracking of treatments being applied so that an accurate construction history can be compiled.
- Decreasing the discrepancies between planned and actual maintenance activities.
- Strengthening the interpersonal relationships between personnel.
- Providing reliable information about the performance of maintenance activities for use in pavement performance models so the cost-effectiveness of treatments can be determined.

As agencies continue to shift their focus from the expansion of the pavement network to its preservation, it will become increasingly important for interfaces to be developed between the organizational units responsible for pavement management and those responsible for applying maintenance activities.

## 6.7 EXAMPLES OF TREATMENT RULES

### 6.7.1 Oklahoma Department of Transportation

The Oklahoma Department of Transportation (OkDOT) participated in a Pavement Management Peer Exchange sponsored by the FHWA and hosted in Nashville, Tennessee. The Peer Exchange report includes the following information (FHWA 2010d).

#### 6.7.1.1 Treatment Types

OkDOT's treatment rules consider factors such as pavement type, traffic level, and pavement condition. The types of treatments recommended in the pavement management system include the following:

- Armor coat (a type of seal coat)
- Microsurfacing
- Grinding (with and without dowel-bar retrofit)
- Slab replacement
- Thin overlay (with and without milling) (2 in.)
- Medium overlay (with and without milling)
- Thick overlay (with milling) (5 to 6 in.)
- Bonded or unbonded overlays on PCC pavements
- Replacement (either asphalt or dowelled jointed concrete pavement)

#### 6.7.1.2 Pavement Preservation Treatment Rules

OkDOT has a formal Pavement Preservation Program (3P) that has been approved by the FHWA (FHWA 2010d). The program is intended to extend the pavement life of non-NHS highways at least five years, NHS highways at least seven years, and interstates at least 10 years. This program may not be used for projects with major safety or crash issues, pavement management condition data must be used to determine eligibility, and other guidelines must be met.

A set of 3P flow charts have been accepted by both the FHWA and OkDOT to determine appropriate treatments that can be funded using federal capital dollars. These flowcharts can be used by the OkDOT Division offices to select 3P treatments for qualifying pavement management sections. An example of the flowchart for asphalt-surfaced pavements with moderate traffic is provided as Figure 6-10.

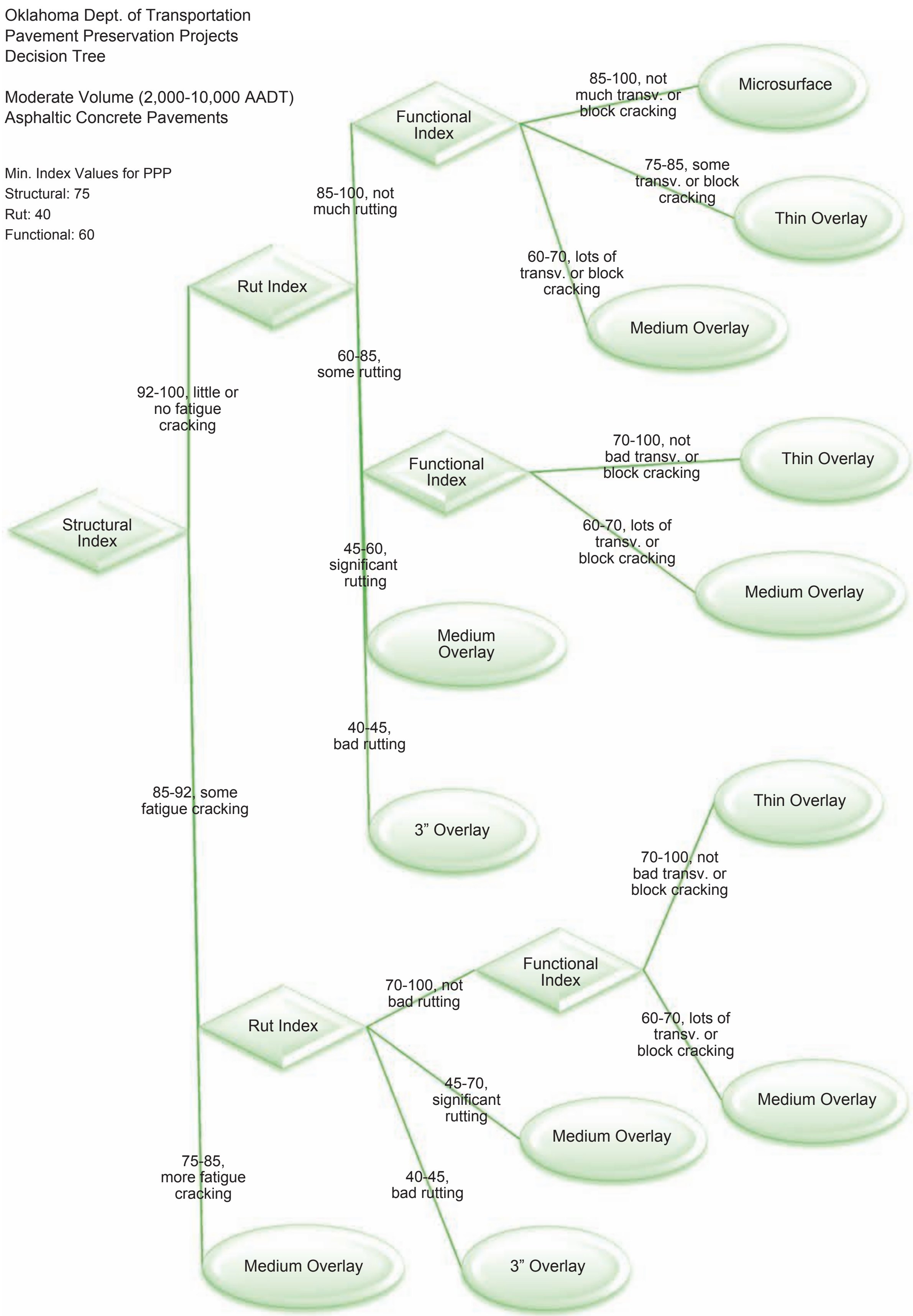



**Figure 6-10. Example of a 3P Flowchart for the Oklahoma DOT (Adapted from FHWA 2010d)**

## 6.7.2 Wyoming Department of Transportation

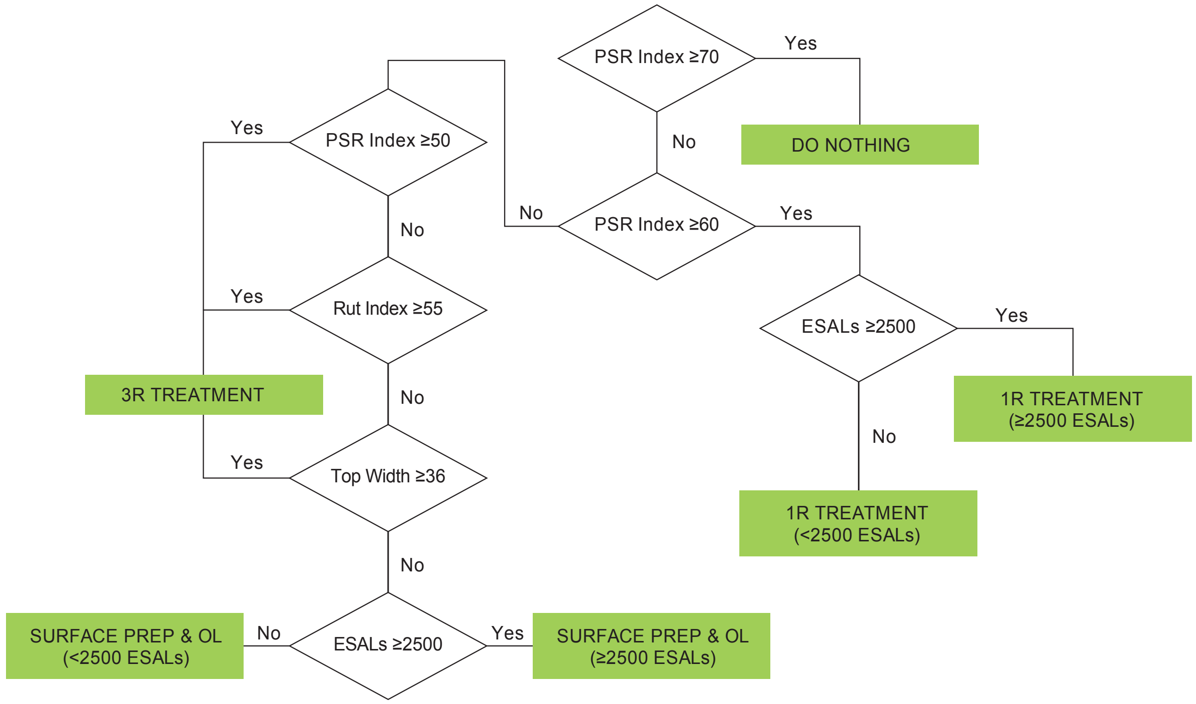
The Wyoming Department of Transportation (WYDOT) also participated in a Pavement Management Peer Exchange sponsored by the FHWA and hosted in Denver, Colorado. The Peer Exchange report includes information about WYDOT's pavement management decision trees (FHWA 2010b).

### 6.7.2.1 Treatment Rules

In the initial development of its pavement management software, WYDOT included treatments for maintenance (including treatments such as chip seals and crack sealing), for consideration in the 1R program (for preventive maintenance treatments such as thin overlays less than 2 in.), the 2R program (for minor rehabilitation treatments such as mill and overlay), and the 3R program (for major rehabilitation such as widening with an overlay). However, the initial decision trees were found to be too detailed. As a result, WYDOT revised its decision trees to recommend the category of repair needed, rather than the specific treatment recommended. Separate decision trees, a sample of which is illustrated in Figure 6-11, were developed for each pavement type and system. Reconstruction projects, which are administered under the 4R program, are not considered in the pavement management software since they are normally triggered by factors other than pavement condition.

### 6.7.2.2 Treatment Cost and Impact Rules

Treatment cost models and impact rules have also been developed for each set of treatments. The cost models represent all costs associated with projects, such as paving costs, mobilization, traffic control, and so on. In addition, impact rules were developed to describe the expected performance after a treatment is recommended within the pavement management analysis. For example, 1R treatments provide a prescribed improvement to the Pavement Surface Rating (PSR) and Ride Indices, but do not return either index to a perfect condition. More substantial treatments such as 2R and 3R treatments return all of the indices to a perfect condition. The impact rules also describe the expected performance after a treatment has been applied. For example, the 1R and 2R treatments deteriorate at a faster rate than the family performance curves. The 3R curves, on the other hand, follow the assigned family deterioration curves. Presumed maintenance activities are built into each of the performance models.




**Note:**
1R treatments include preventive maintenance activities
2R treatments include minor rehabilitation activities
3R treatments include major rehabilitation
Top width represents road width

**Figure 6-11. Sample WYDOT Decision Tree (modified from FHWA 2010b)**

## 6.8 CHAPTER SUMMARY

At its most basic level, a pavement management system is used to identify and prioritize pavement preservation and rehabilitation projects. This chapter introduced and illustrated methods used to develop both treatment and impact rules. The treatment rules used in pavement management describe the conditions under which a treatment is considered feasible and impact rules describe the pavement performance that might be expected following the application of a treatment. Special considerations for developing treatment rules for preventive maintenance treatments were also presented.

The chapter also introduced three common methods of project and treatment selection under constrained conditions: ranking, multi-year prioritization, and optimization. A multi-year prioritization approach, which includes incremental benefit-cost and marginal cost-effectiveness analyses, is currently the most commonly used approach for project and treatment selection at the state highway level.

The chapter concluded with a discussion of the importance of coordinating pavement management with maintenance and operations, especially as pavement preservation programs increase in popularity and size. Strategies for strengthening the links between pavement management and maintenance are also provided.

CHAPTER SEVEN

# Using and Presenting Pavement Management Results

## 7.1 INTRODUCTION

One of the primary purposes of a pavement management system is to provide the information needed to make decisions about investments in pavement maintenance and rehabilitation. Depending on the needs of the specific audience, pavement management information can be used to establish priorities among competing pavement needs, to identify cost-effective projects and treatments, and to convey the consequences of different investment strategies on future network conditions. These different objectives require information with varying degrees of technical detail to reach a decision. For instance, very detailed information about the type and extent of deterioration present in a pavement section and projections about future traffic levels are required to design a pavement rehabilitation treatment. However, much less detail is required to provide reports that quickly convey a message to elected officials. Therefore, it is important that pavement management practitioners consider the needs of their audience when processing and presenting pavement management results to various stakeholders. This chapter introduces some of the primary uses of pavement management information and illustrates some of the approaches used to present the information. It concludes with guidance on developing effective presentations and reports.

## 7.2 TYPICAL USES OF PAVEMENT MANAGEMENT INFORMATION

Pavement management addresses a variety of needs within a transportation agency and provides information needed by individuals designing, maintaining, or preserving the pavement network as well as individuals responsible for setting funding priorities and investment levels. This section discusses the following common uses of pavement management information:

- Determining needs
- Illustrating the impact of different strategies (“What if” analysis)
- Providing project and treatment recommendations
- Allocating funds
- Setting performance targets
- Long-term planning
- Communicating current network conditions

Each of these uses of pavement management information is described in more detail and several examples are provided to illustrate the types of reports that might be generated.

### 7.2.1 Determining Needs

Once an agency has collected pavement condition information for the network and has defined treatment rules that identify the level of maintenance and rehabilitation needed at different condition levels, current and future pavement maintenance and rehabilitation needs can be defined. This information is often used to illustrate whether available funding is sufficient for addressing needs, or to demonstrate that needs are quickly outpacing available funding. A growing backlog of needed treatments is an indication of the need for increased allocation of resources for preservation.

Conducting a needs assessment is relatively easy. It involves running a multi-year analysis in which a set of treatment rules are applied to current and projected pavement conditions under an unconstrained funding scenario. The needs, which represent all the treatments needed to satisfy the requirements defined in the treatment rules, represent the amount of money considered necessary for the agency to apply its preservation philosophy (assuming the philosophy is represented by the treatment rules). Some agencies run a needs report using more than one treatment strategy so they can compare a "preferred" strategy with another representing only the most critical treatment activities. This is done by running the same unconstrained report using two different sets of treatment strategies. The results of the comparison provide a good indication of the minimal level of funding needed in contrast to the desired level of funding. Knowing both of these numbers can be useful when working with individuals responsible for setting agency budgets.

The results of a needs analysis should provide the following (AASHTO 2001):

- A listing of pavement sections needing maintenance and rehabilitation.
- Projected pavement network conditions, both with and without the needed treatments.
- The total cost to apply the repairs identified in the needs analysis.
- A summary of the funding needed by treatment category (e.g., preventive maintenance, minor rehabilitation, and major rehabilitation), functional class (e.g., interstate and non-interstate), or by geographic region.

An example of a 20-year summary of the interstate reconstruction needs in Oklahoma, which was produced by the Oklahoma DOT using its pavement management data, is presented in Figure 7-1. It reflects an increasing need for reconstruction activities under current funding strategies.

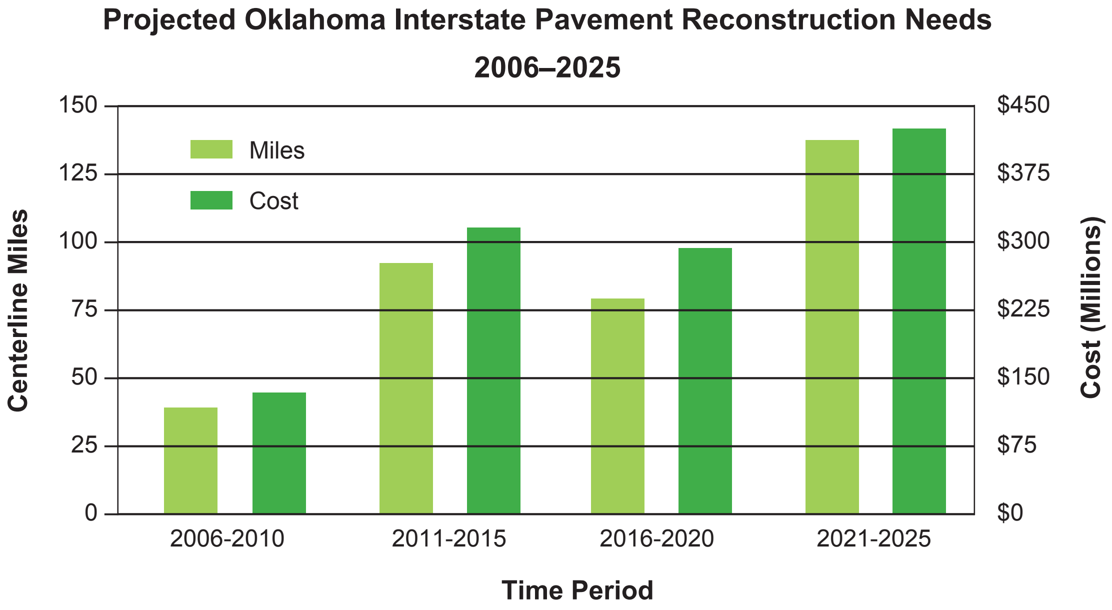



**Figure 7-1. Example of Pavement Reconstruction Needs Analysis Summary (OkDOT 2006)**

## 7.2.2 Illustrating the Impact of Different Scenarios ("What If" Analysis)

One of the most valuable outputs from a pavement management system is a summary of the impacts on pavement network condition associated with different funding levels or treatment strategies. Commonly referred to as a "what if" or "trade-off" analysis, these analyses help decision makers make informed decisions based on the consequences of each of the various options available. The consequences can be reported in a number of ways, such as overall network conditions, future costs, or progress towards an agency goal. The impacts are usually forecast at least five years into the future, enabling agencies to better understand the long-term impacts of decisions being made today.

### 7.2.2.1 Using Analysis Results to Compare Options

A number of agencies have used the results of an impact analysis to demonstrate the cost-effectiveness of pavement preservation programs over worst-first strategies. This type of analysis can be done by running two multi-year analyses, each with the same level of funding provided. One analysis is run using treatment strategies that promote the use of rehabilitation and reconstruction activities on roads in poor condition. The other analysis includes early intervention treatments, such as preventive maintenance activities, over the same analysis period. The results of the analyses, often conveyed in terms of average network conditions or percentage of the network in poor condition, typically demonstrate the cost-effectiveness of the preservation strategy. In some cases, it takes longer than five years for the benefits of a pavement preservation program to be realized, but that depends on the condition of the network and the funding levels available.

An example of an output showing the benefits of a pavement preservation program is provided in Figure 7-2. This analysis compares the percent of deficient miles associated with a do nothing strategy (e.g., no improvements are made) to two alternate strategies, both of which have the same total funding.

In Scenario 1, all funding goes to rehabilitation activities; and in Scenario 2, 95 percent of the funding is used for rehabilitation and 5 percent is spent on preventive maintenance. This example illustrates the differences in pavement conditions that can be achieved with a different set of treatments.

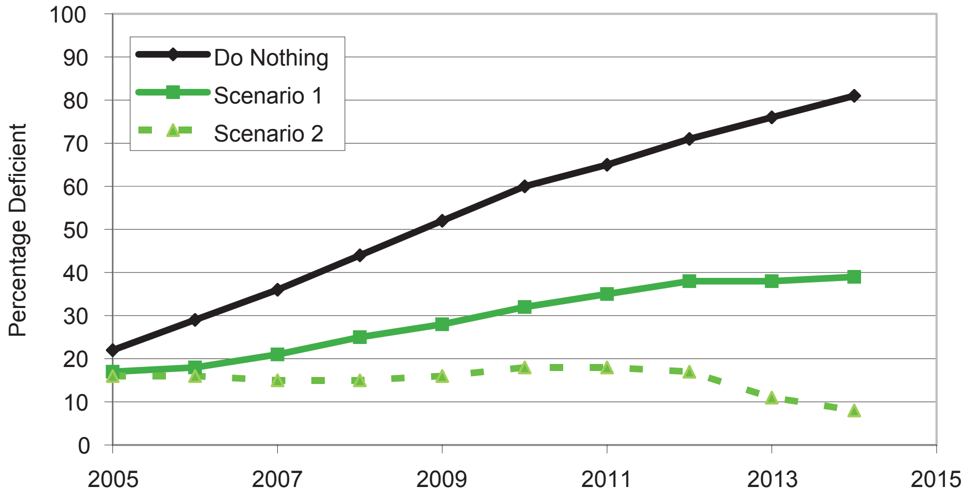



**Figure 7-2. Illustration of Deficient Pavements Under Different Treatment Strategies (Bekheet et al. 2005)**

Another example is provided as Figure 7-3 to show the use of an impact analysis to differentiate between both funding levels and treatment strategies. The figure illustrates the difference in the remaining service life extension (RSLE) for the entire network under both a proposed preservation program (e.g., "Proposed Framework") and a worst-first strategy. As evidenced by the figure, regardless of the size of the budget, the preservation strategy results in improved network conditions.

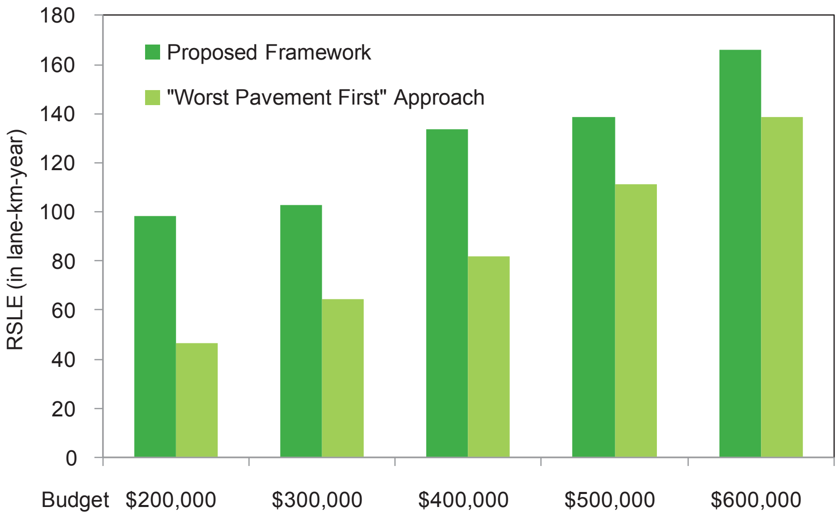



**Figure 7-3. Impact Analysis Showing the Benefits of a Pavement Preservation Program (Ong et al. 2010b)**

### 7.2.2.2 Using the Analysis Results to Determine Needed Funding Levels

The results of an impact analysis can also be used to determine the appropriate level of funding to be spent on the pavement network. This type of analysis often requires several iterations for the targeted conditions to be achieved. For instance, an initial funding limit may be input into the analysis to generate a summary of the resulting conditions. Depending on the results, a higher or lower funding level is then entered and another analysis is run. This process is then repeated until the targeted conditions are reached, or the desired impact is achieved. The final funding level that achieves the desired results represents the recommended funding level to meet the agency's targets.

An example of how the results of an impact analysis can be used to determine funding levels is shown in Figure 7-4. In this example, forecast conditions under expected revenue levels are shown in the top graph. Underneath it are graphs showing the anticipated costs to reach two different pavement condition targets: one to maintain the existing 53 percent of the network in Good/Fair condition and another to increase the percent of the pavement network in Good/Fair condition to 60 percent. This type of analysis can be used to determine funding levels needed for the entire road network, or for a subset of the network (e.g., functional class or region).

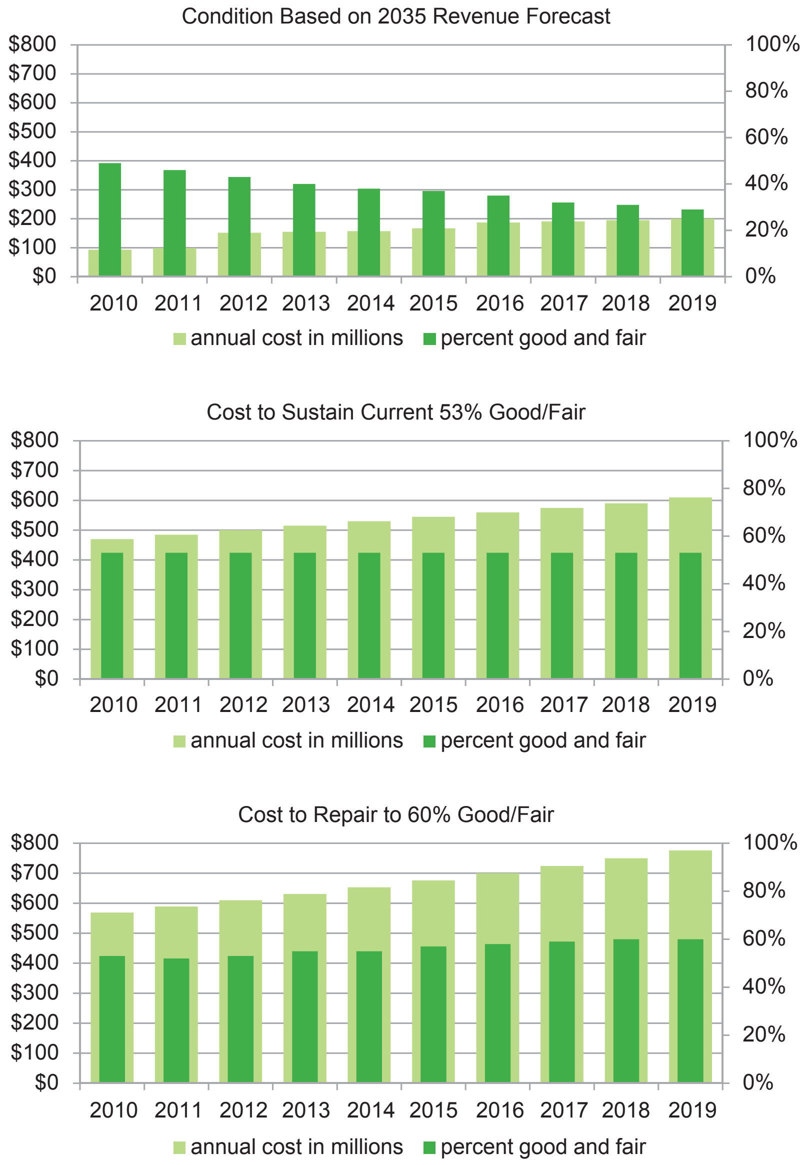



**Figure 7-4. Impact Analysis Showing Funding Needed to Meet Targeted Conditions (CDOT 2009)**

The types of reports that are produced to demonstrate the need for additional funding can vary dramatically. For example, Figure 7-5 illustrates the resulting pavement conditions in the San Francisco Bay area if the current funding level is provided, if adequate funding is provided to maintain the network conditions, and if improvements to network conditions are desired. The example illustrates that funding must be doubled to reduce the backlog to a reasonable level.

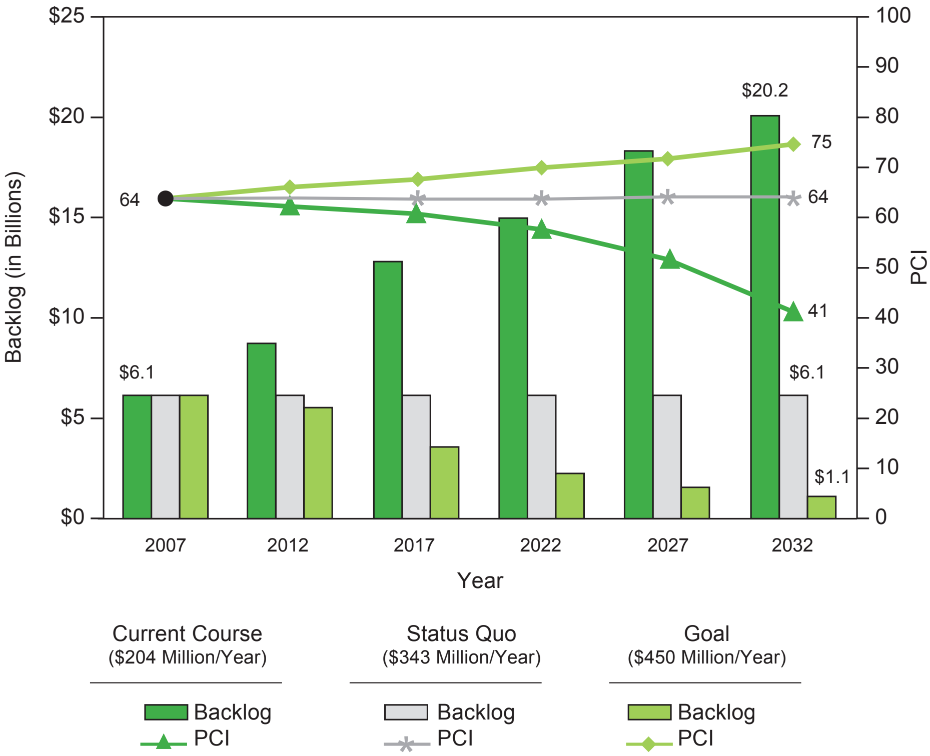



**Figure 7-5. California Regional Maintenance Backlog and PCI Over Time and Under Different Annual Funding Scenarios (Based on 2006 U.S. Dollar Values) (Romell and Tan 2010)**

A final example is provided in Table 7-1 and Figure 7-6. The City of Seattle's Department of Transportation used an impact analysis to generate pavement conditions under several different scenarios and compared the results to the projected conditions if the current annual maintenance expenditure of $7 million was continued. As illustrated in Table 7-1, the deferred maintenance backlog determined at the time of the analysis was projected to increase significantly under the current funding level. The consequences of alternative strategies are also presented in the table and in Figure 7-6.

**Table 7-1.** Consequences of Different Investment Scenarios (SDOT 2004)

| Annual Investment Level | 20-yr Annual Average Paving Accomplishment (12' lane-miles) | | Deferred Maintenance | | Description of Program |
|---|---|---|---|---|---|
| | Asphalt | Concrete | 2004 | 2023 | |
| $7 Million | 26 | 1 | $309 Million | $547 Million | At the $7M investment level, Seattle will continue at the current level of paving accomplishment. Most paving will be asphalt resurfacing on streets where condition allows. The amount of deferred maintenance will increase nearly 60% over the next 20 years. |
| $14 Million | 30 | 5 | $302 Million | $297 Million | At the $14M investment level, some funds are available for reconstruction efforts, but the net effect will be to maintain the street network at a deferred maintenance level comparable to the present. Initially, Seattle would not have adequate funds to prevent many streets from deteriorating to a level where major rehabilitation is required, so the deferred maintenance backlog would grow. However, asphalt resurfacing and other rehabilitation would stabilize the network condition and 5 additional lane-miles could be reconstructed each year, negating the initial increase in deferred maintenance backlog. At the end of 20 years, the deferred maintenance level would be approximately where it started. |
| $24 Million | 33 | 11 | $292 Million | Negligible | At the $24M investment level, funds are available to reconstruct streets in the worst condition and keep pace with other major maintenance needs. The deferred maintenance backlog is eliminated over the next 20 years. |

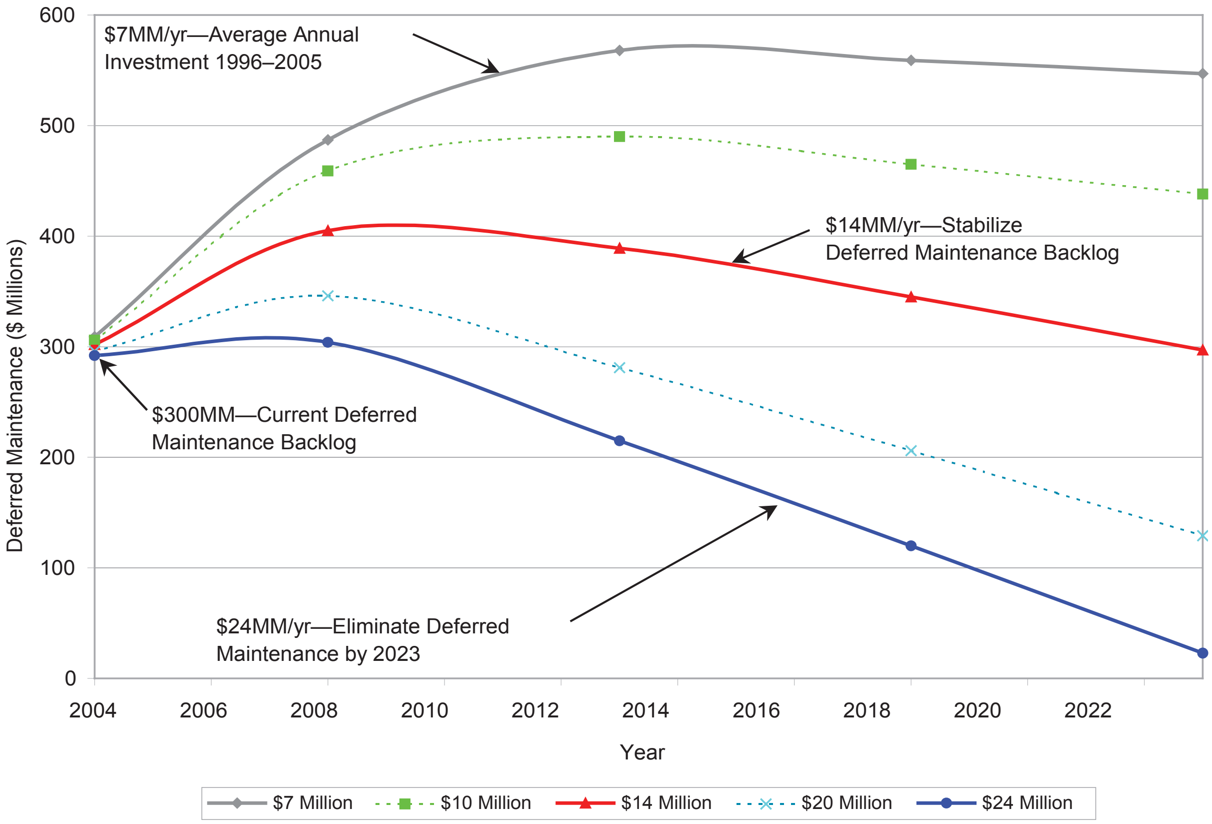



**Figure 7-6. Projected Deferred Maintenance Backlog by Funding Level (SDOT 2004)**

#### 7.2.2.3 Selecting Impact Measures

A key to the success of an impact analysis is conveying consequences to decision makers in a format that resonates with them by addressing their primary concerns. For instance, in an agency that places safety as its highest priority, reporting the impact of different strategies on smoothness may not have the desired effect. To be more effective, either a correlation has to be developed between smoothness and wet-weather crashes, or a different condition category should be selected. Therefore, selecting the right impact measure is very important to a pavement management practitioner.

The literature discusses the following impact measures and their use in pavement management (AASHTO 2001):

- **Network conditions**, in terms of overall pavement condition or a specific condition measure, such as smoothness. While these types of measures are common, an average condition value may not vary much from one option to another and the metric may have no meaning to a decision maker. For instance, they may not be able to recognize the difference between one strategy that results in an average condition of 65 and another that results in an average condition of 63.
- **Condition category**, such as *good, fair*, or *poor*, or by RSL category. Some agencies translate the network conditions into condition categories to enhance understanding by decision makers. In most instances, reporting that 25 percent of the network is in *poor* condition has more of an impact than an average condition of 55. Sometimes it is beneficial to present the conditions by functional class in addition to, or instead of, for the entire network. For instance, an agency might show the distribution of conditions for the interstate separately from the conditions for the non-interstate network. In local agencies, conditions for arterials and collectors may be presented separately from local roads.
- **Backlog of unfunded needs**, such as the funding needed to address all roads in poor condition or the number of miles needing reconstruction (or in poor condition). This metric is most useful when displayed as a trend, showing that the backlog of unfunded needs is either growing or shrinking, depending on the circumstances. If an agency is building the case for increased funding, the agency would use this metric to illustrate the growing backlog. However, if an agency received additional funding to address a large backlog, this metric would help document that the funding has been used wisely. An agency that has a steady backlog could demonstrate that they are maintaining their network conditions with the funding levels provided.
- **Cost of unplanned (or stop-gap) maintenance**, including maintenance costs required to keep roads in serviceable condition. If an agency spends a good deal of its budget on pothole repairs, or other types of emergency repair, then documenting the amount spent on these types of activities could be beneficial. The information could be used to illustrate trends in expenditures on stop-gap activities, or to compare the cost-effectiveness of funding repairs that have a longer life.
- **Impact to the user**, such as the number of vehicle miles traveled on roads in poor condition. As agencies become more customer-focused, it is likely that reporting measures that impact the traveling public will become more important as time goes by. Other forms of user impacts that could be reported are vehicle operating cost, crashes, or delays.

### 7.2.3 Providing Project and Treatment Recommendations

Perhaps the most common output from a pavement management system is a listing of recommended projects and treatments for the available funding levels. These reports can be sorted in a number of ways, summarizing the amount of work by treatment type or by geographic area. The detailed reports are typically more appropriate for technical personnel who will be using the information to finalize a capital improvement program, to design the treatment, or to prepare the bid package for construction. An excerpt from the recommended 5-year pavement program generated by the OkDOT is provided as Table 7-2.

**Table 7-2.** Example Report Showing Project and Treatment Recommendations (OkDOT 2007)

| DIVISION 7 RECOMMENDED 5 YEAR PAVEMENT PROGRAM | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Control Section | Route | Beg | End | Length (mi) | Pave Type | AADT | Deflection | Pavement Condition Indexes | | | | | | | | | Recommended Improvement | | |
| | | | | | | | | Year | Ride | Rut | Funct | Struc | Fault | Joint | Slab | PQI | Year | Treatment | Cost ($) |
| 26-06 | US 81 | 19.4 | 22.3 | 2.93 | JPCP | 7,771 | 5 | 2006 | 56 | | | | 94 | 96 | 92 | 79 | 2008 | Slab Repair<br>DBR & Diamond Grind | 500,000<br>878,718 |
| 26-08 | US 81 | 0 | 2.4 | 2.4 | JPCP | 10,995 | 9 | 2006 | 46 | | | | 83 | 93 | 75 | 67 | 2008 | DBR & Diamond Grind<br>Slab Repair | 849,728<br>499,840 |
| 26-08 | US 81 | 2.4 | 4.1 | 1.7 | JPCP | 15,176 | 7 | 2006 | 37 | | | | 83 | 85 | 72 | 62 | 2008 | Slab Repair<br>DBR & Diamond Grind | 375,713<br>638,712 |
| 26-12<br>26-12 | US 81 | 0<br>2.56 | 2.56<br>4 | 2.56<br>1.44 | AC<br>COMP | 3,976<br>4,100 | 8<br>7 | 2006<br>2006 | 88<br>92 | 93<br>82 | 81<br>74 | 93<br>87 | | | | 89<br>84 | 2009<br>2008 | Thin Overlay<br>Mill & Med Overlay | 352,518<br>296,626 |
| 26-12 | US 81 | 4 | 10.1 | 6.11 | COMP | 4,014 | 8 | 2006 | 76 | 80 | 64 | 80 | | | | 74 | 2008 | Medium Overlay | 1,126,440 |
| 26-12 | US 81 | 10.1 | 18.9 | 8.83 | COMP | 3,337 | 12 | 2006 | 85 | 84 | 77 | 85 | | | | 83 | 2010 | Mill & Med Overlay | 2,122,044 |
| 26-12 | US 81 | 18.9 | 20.2 | 1.26 | AC | 4,994 | 19 | 2006 | 57 | 77 | 44 | 88 | | | | 66 | 2008 | Reconstruct | 1,133,992 |
| 26-12 | US 81 | 20.2 | 21.7 | 1.52 | COMP | 5,662 | 11 | 2006 | 63 | 85 | 33 | 91 | | | | 61 | 2009 | Reconstruct | 1,367,990 |
| 34-06 | US 81 | 0 | 9.64 | 9.64 | AC | 1,907 | 12 | 2006 | 91 | 88 | 64 | 90 | | | | 86 | 2010 | Medium Overlay | 1,555,480 |
| 34-06 | US 81 | 9.64 | 10.8 | 1.13 | COMP | 2,499 | 8 | 2006 | 93 | 96 | 78 | 96 | | | | 90 | 2008 | Thin Overlay | 200,988 |
| 34-06 | US 81 | 10.8 | 13 | 2.23 | AC | 2,500 | 24 | 2006 | 93 | 95 | 80 | 97 | | | | 92 | | | |
| 34-06 | US 81 | 13 | 20.3 | 7.32 | COMP | 2,418 | 17 | 2006 | 94 | 97 | 80 | 95 | | | | 90 | | | |
| 34-08 | US 81 | 0 | 9.47 | 9.47 | AC | 2,767 | 15 | 2006 | 99 | 99 | 74 | 96 | | | | 95 | | | |
| 43-17<br>43-17 | I-35<br>I-35 | 0<br>3.02 | 3.02<br>8.37 | 3.02<br>5.35 | DJCP<br>DJCP | 26,298<br>23,997 | | 2006<br>2006 | 100<br>100 | | | | 100<br>100 | 100<br>100 | 100<br>100 | 100<br>100 | | | |
| 43-17 | I-35 | 8.37 | 11.5 | 3.13 | DJCP | 23,700 | | 2006 | 93 | | | | 100 | 99 | 100 | 97 | | | |
| 43-17 | I-35 | 11.5 | 17.9 | 6.35 | COMP | 23,637 | 3 | 2006 | 100 | 88 | 85 | 89 | | | | 90 | | | |
| 43-17 | I-35 | 17.9 | 24.5 | 6.62 | DJCP | 23,200 | | 2006 | 99 | | | | 100 | 100 | 100 | 100 | | | |
| 50-02 | US 77 | 9.75 | 10.2 | 0.41 | COMP | 10,900 | 7 | 2006 | 40 | 22 | 84 | 100 | | | | 60 | 2008 | Reconstruct | 1,578,534 |
| 50-06 | SH7 | 0 | 0.11 | 0.11 | AC | 2,600 | 6 | 2006 | 90 | 90 | 96 | 99 | | | | 92 | | | |
| 50-08 | SH7 | 0 | 1.89 | 1.89 | AC | 6,667 | 10 | 2006 | 72 | 68 | 50 | 68 | | | | 67 | 2008 | Mill & Thick Overlay | 983,018 |
| 50-08 | SH7 | 1.89 | 3.39 | 1.5 | AC | 5,532 | 10 | 2006 | 75 | 79 | 75 | 88 | | | | 78 | 2008 | Medium Overlay | 531,104 |
| 50-12 | SH7 | 0 | 1.64 | 1.64 | AC | 10,105 | 11 | 2006 | 68 | 76 | 74 | 92 | | | | 75 | 2009 | Mill & Med Overlay | 837,287 |
| 50-12 | SH7 | 1.64 | 6.21 | 4.57 | AC | 8,807 | 13 | 2006 | 85 | 68 | 73 | 91 | | | | 79 | 2009 | Medium Overlay | 1,617,648 |

Depending on how the information will be used, it is often helpful to include with the treatment recommendations available information about conditions before and after the treatment is applied, primary causes of deterioration (e.g., structural versus environmental), and the number of years before the project is projected to fall into the next lower treatment category. The latter piece of information helps decision makers determine whether a project can be accelerated or delayed to accommodate other needs. For instance, if a project is a candidate for minor rehabilitation, it is important to schedule that work before the pavement deterioration has reached the point at which major rehabilitation is needed and the project costs have increased dramatically.

### 7.2.4 Allocating Funds

The impact analysis examples illustrated the use of pavement management information to determine the level of funding needed to achieve an agency-specified goal or target. As discussed, an impact analysis can help an agency allocate funds among regions or districts, functional classifications, or different jurisdictions, or some combination thereof. In general, these funding allocations are made to ensure a distribution of work across an agency or to ensure that sufficient funding is available for high-priority roadways or agency initiatives. For example, an agency may first allocate funding to address its interstate needs before allocating funding to the remainder of its network. In a local agency, funding may be allocated to residential roads only after all other needs in the network are addressed. Regardless of how the information is used, the results of an impact analysis can convey the consequences of funding allocation decisions.

In recent years, one of the more common uses of pavement management information is at the Metropolitan Planning Organization (MPO) level to distribute funding among member agencies. MPOs are responsible for the planning, programming, and coordination of federal highway and transit investments in urbanized areas (with a population greater than 50,000) throughout the country. Because of their focus on collaboration between member organizations, MPOs help to ensure that federal funds are invested on region-wide priorities. Regional Planning Agencies (RPAs) are another example of multi-county regional planning bodies that may benefit from the use of pavement management information to support their regional planning and programming activities.

There are two primary roles for an MPO or RPA in supporting pavement management; fostering the implementation of pavement management concepts in local communities and using pavement management data in the planning process (Orloski 1994). There are several examples of MPOs that have promoted the implementation of pavement management concepts and have used pavement management results to improve the allocation of funding within the MPO. For example, the Metropolitan Transportation Commission (MTC) in the San Francisco Bay area has funded the development of pavement management software that can be used by member and non-member agencies. To qualify for federal funding, member agencies are required to keep the certification current. MPCS also provide support to member agencies through user meetings, technology training sessions, and by maintaining lists of trained consultants to collect data and implement the software.

In Michigan, Public Act 499 established a definition for asset management, created the Transportation Asset Management Council (TAMC), and defined the roles and responsibilities of the TAMC and local road agencies in implementing asset management principles (MI TAMC 2007). Since that time, the TAMC has promoted asset management concepts on roads and bridges within the state by surveying and reporting conditions, developing tools to analyze investment options, and providing education and training on the benefits of using pavement management and asset management principles (MI TAMC 2007). As a result, pavement management information for the entire federal-aid network is now available for use by the Michigan Department of Transportation in its long-term statewide planning activities. In its report, the use of consistent pavement management data on a statewide basis was found to be particularly effective in enhancing roadway management and for demonstrating the value of regional planning to local officials (MDOT 2006).

As evidenced by both the Michigan and the MTC examples, the use of common pavement condition measures and pavement management software has greatly enhanced the ability to plan and program at the regional level.

Agencies that use pavement management information for allocating funding should use caution when establishing their funding allocation formulas, to help ensure that the proper activities are being supported. For instance, an agency that uses pavement condition in a formula for allocating funding often distributes more money to regions or districts with the greatest number of road miles in poor condition. In other words, funding is distributed to address the worst pavement conditions. However, this approach may not present an optimum option. Therefore, the agency must investigate whether the available funds were used in an appropriate matter following pavement management principles, whether the road network deteriorates at a faster rate due to severe climatic conditions or unusually high traffic levels, or whether the issue is really just the inadequacy of the funding provided.

### 7.2.5 Setting Performance Targets

Performance measurement can be defined as follows (NCHRP 2006):

> *"Performance measurement is a way of monitoring progress toward a result or goal. It is also a process of gathering information to make well-informed decisions. Transportation agencies have used performance measures for many years to help track and forecast the impacts of transportation system investments, monitor the condition of highway features, and gauge the quality of services delivered by an agency."*

Most performance measures used for pavement management purposes relate to the preservation and maintenance of the asset, or to a measure of safety (such as wet weather crashes) (NCHRP 2006). Therefore, pavement management systems can provide the data required to establish pavement-related performance targets, to monitor progress towards achieving the performance goals and objectives, and to provide feedback on the effectiveness of different types of resource allocation decisions.

Figures 7-4, 7-5, and 7-6 each illustrated the use of pavement management results to identify the funding level required to meet a particular pavement condition target. Using the same type of approach, an agency can use the results of a pavement management analysis to help set strategic performance targets that identify the overall goals to be achieved, the resources required to meet these goals, and the consequences associated with an alternate strategy.

### 7.2.6 Long-Term Planning

Most state transportation agencies are responsible for the preparation of Long-Range Statewide Transportation Plans and a Statewide Transportation Improvement Program (STIP) as part of their transportation planning functions. The Long-Range Statewide Transportation Plan predicts the expected demand for transportation services over a 20-year period, and outlines plans for meeting the demand within expected funding constraints. The STIP, on the other hand, focuses on a much shorter timeframe (e.g., 4 years) and the more immediate demands on the system. Therefore, because of the forecasting capabilities of a pavement management system, pavement management information can have a significant contribution to the development of an agency's short- and long-term transportation plans.

The Minnesota Department of Transportation (Mn/DOT) has demonstrated success in using pavement management data for its long-term planning activities (FHWA 2008c). An overview of Mn/DOT's planning and programming process is provided in Figure 7-7. Both the 20-year and the 10-year plans (including the first 4 years of the plan, which are updated annually) use outputs from pavement management during their development. The strategic plans are used to establish investment levels that (1) safeguard what exists, (2) make the transportation network operate better, and (3) make Mn/DOT work better through improved efficiencies or better decisions (FHWA 2008c). For pavement preservation, the performance target is set so at least 70 percent of the principal arterials are in good condition, without lowering the condition of the remainder of the network below an acceptable level. Other performance measures are set to align with the Department's other strategic initiatives. Typically, the results of an impact analysis are used to support the development of these long-term plans.

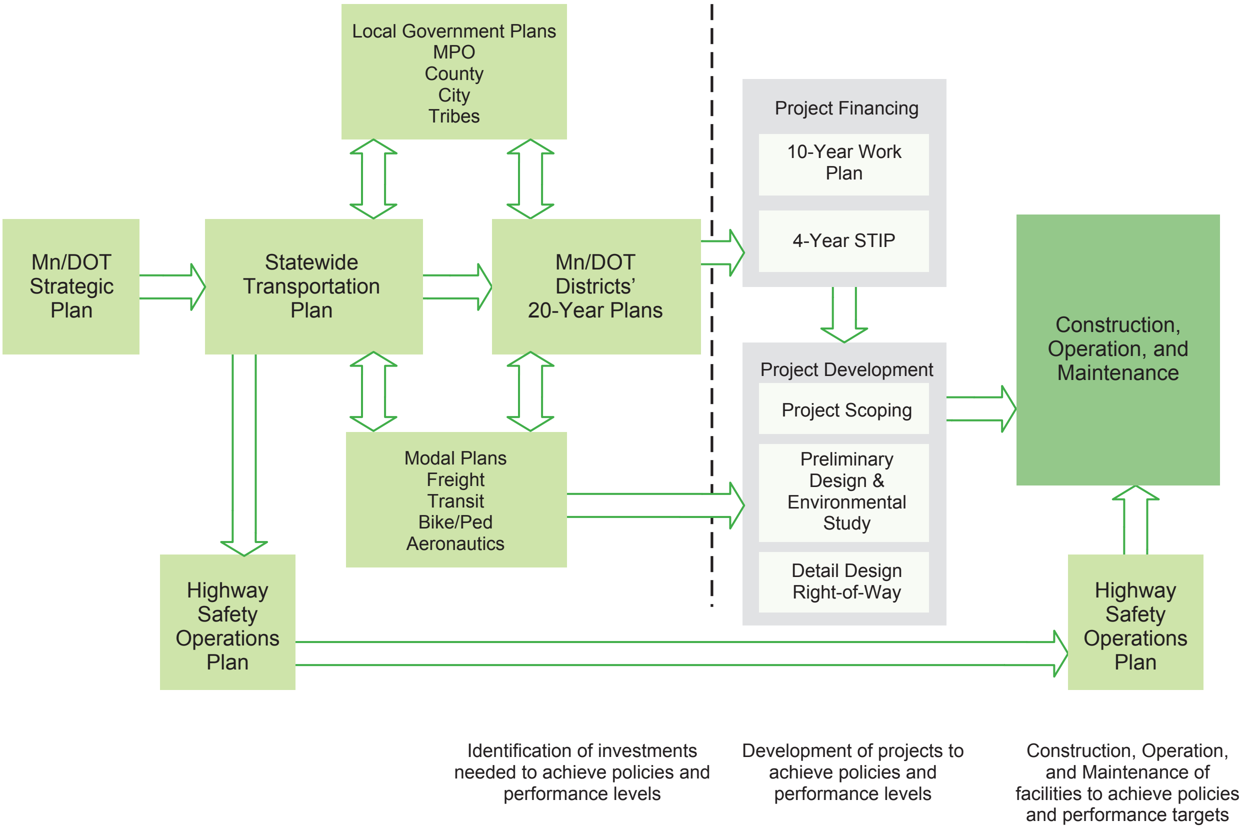



**Figure 7-7. Mn/DOT's Planning and Programming Process (FHWA 2008c)**

### 7.2.7 Access to Pavement Management Information

There are several ways in which pavement management information is provided to agency personnel. In the past, the traditional method of distributing information relied on published reports that documented pavement conditions after each round of condition surveys had been completed. In some cases, the pavement condition information was used to report statewide "needs."

There are many methods of communicating pavement management information to highway agency personnel. While many agencies continue to publish the traditional reports, other agencies have moved towards improving accessibility to pavement management information through agency tools, such as the geographic information systems (GIS) discussed in Section 3.2. Some agencies are moving towards the use of web-based programs that provide access to certain information at any time and from any location, as long as internet access is available.

Providing a high degree of accessibility to pavement management information is important to help ensure that the information is being used to support agency decisions. Regardless of whether the information is provided in a traditional print format, whether the pavement management staff generates outputs based on specific needs of agency personnel, or whether the information is provided electronically through the internet or GIS, pavement management staff should strive to ensure that the information addresses agency needs, that it is reliable, and that it is essentially complete.

## 7.3 USING PAVEMENT MANAGEMENT INFORMATION IN PRESENTATIONS AND REPORTS

Because stakeholders use pavement management information for different purposes, pavement managers are regularly asked to produce reports or to prepare and present information formally or informally. Therefore, it is important that pavement managers have good written and oral communication skills, and can respond to requests for information in a way that meets the stakeholders' needs.

One of the biggest challenges in reporting pavement management information is selecting a method of presenting the results that resonates with the audience. For instance, because elected officials rarely have the time to review large reports and they do not typically have a technical background, the information they receive has to be presented in a non-technical way. Some agencies have had success comparing pavement preservation to routine activities such as car or house maintenance to help the audience understand the need for low-cost activities that preserve the life of the asset and defer the need for more costly rehabilitation activities. Nevertheless, each agency must take responsibility for identifying the concerns of its stakeholders and developing presentations and other methods of communication that address those concerns.

Many public agencies have public relations personnel available to assist pavement managers in preparing formal presentations or outreach materials. These individuals can help identify the primary message that is being conveyed and can put together materials that make effective use of graphics to communicate the message quickly and effectively. Their input can be especially beneficial if an agency is campaigning for more funding or if a decision is being made that will not be popular with the public.

The following suggestions are provided to help practitioners prepare effective presentations.

- Assess your audience and their needs. It is important for the speaker to identify how well the audience understands the topic being discussed and to determine what information they will want to know, and need to know, about the subject. The presentation should remain focused on those items.
- Identify the message that is being conveyed and structure the presentation around that message. Frequently, presenters try to convey too much information in their presentations and the key message gets lost. As Voltaire said, "The secret of being a bore is to tell everything." Start the presentation with the message, build support for the message during the body of the presentation, and conclude by repeating the message.
- Recognize that the primary way an audience receives a message is based on how the material looks rather than what is said. Therefore, it is important that presentation materials look professional and convey information clearly.
- Make a good first impression that establishes why the audience should listen to the presentation. Grab the audience's attention by relating the material to their interests.
- Prepare well in advance and test the presentation with different audiences. Preparation is a key to understanding the message that will be conveyed and to delivering it effectively. If the

presentation doesn't make sense to the practice audience, chances are it will not make sense to your primary audience, either.

- Admit what you know and what you do not know. It is important that pavement management recommendations are based on sound, reliable data. However, forecasting pavement conditions into the future can be risky, especially if forecasts extend beyond five years. Therefore, explain the parameters upon which the recommendations are based and the factors that could alter the results. If the audience asks a question that cannot be answered immediately, promise to provide the answer at a specific point in time and do so.

## 7.4 CHAPTER SUMMARY

This chapter discussed methods of using and presenting pavement management information. First, it presented strategies for using pavement management results to determine pavement needs, to determine the consequences associated with different strategies, and to identify projects and treatments that make the best use of available funding. In addition, the chapter described the use of pavement management information for allocating funding, for establishing performance targets, and for long-term planning activities. The chapter concluded with suggestions for effective use of pavement management information in presentations.

CHAPTER EIGHT

# Implementation of Pavement Management Systems

## 8.1 INTRODUCTION

Pavement management systems vary dramatically in terms of complexity, flexibility, and cost. Therefore, each agency should consider its needs before investing in pavement management software. Considerations should take into account the sophistication of the agency's decision process, the resources available to support pavement management now and into the future, and the on-going requirements to keep the software updated with current information. This chapter provides guidance for selecting the appropriate software and for implementing a pavement management system within an agency. It also includes recommendations for identifying and addressing institution of issues that often hinder the system's success. Finally, the importance of transition planning to help ensure the continued use of the pavement management system is presented.

## 8.2 PAVEMENT MANAGEMENT SOFTWARE SELECTION

### 8.2.1 Types of Software

There are two different categories of pavement management software that are commonly available to transportation agencies: public-agency developed and proprietary. Public-agency applications include basic pavement management software that has been designed to meet the needs of a large number of public agencies. This type of software is usually developed by a public entity that retains ownership of the software and is responsible for any updates, modifications, or changes to the program. Public-agency software can usually be implemented at a fairly low cost and is limited in terms of the flexibility with which the program can be modified. For example, public-agency software programs often allow agencies to adjust the conditions under which treatments are selected and the rate at which pavements deteriorate, but they typically do not allow an agency to modify the scale of the pavement condition index or change the number of factors that are used in building treatment rules. This type of software is typically bundled as a complete package that includes both a database and analysis tools. Therefore, public-agency programs are most commonly used in smaller agencies that do not use other databases for storing pavement-related information. Examples of popular public-agency software programs include MicroPAVER™, developed by the U.S. Army Corps of Engineers and distributed through the American Public Works Administration

(APWA) at http://www2.apwa.net/about/sig/micropaver/ and StreetSaver™, developed by the Metropolitan Transportation Commission (MTC) in Oakland, CA at https://secure.streetsaveronline.com.

The other alternative is to implement proprietary software, which is developed and licensed to an agency by a private corporation. Proprietary systems generally provide a much greater degree of flexibility to an agency, but that flexibility usually comes at a higher cost than public domain systems. For example, these systems usually allow agencies to select a pavement condition rating process, to determine the types and number of treatments that can be analyzed, and to input a variety of different budget sources. Proprietary software vendors can often write programs to extract data from diverse data sources, so these are the programs that are most commonly used in large transportation agencies, such as state DOTs. Another advantage to proprietary software programs is that the developers are constantly upgrading and enhancing their software products so they remain competitive in the marketplace. As a result, new features are added regularly. However, because these programs are typically more complex than public domain software, they may require more training to effectively operate. The agency is also bound to the terms of a licensing agreement that may limit access to the program or restrict changes to the software code, or both.

In some cases, an agency may elect to build a system from scratch, so it is fully customized to meet the needs of the agency. Since the development of a comprehensive pavement management system is not a trivial activity, an agency should build sufficient amounts of time into its implementation process to thoroughly test a fully customized program to ensure it is working as expected.

### 8.2.2 Selecting the Appropriate Pavement Management Software

Before selecting pavement management software, an agency should conduct a business process review, or self-assessment, to determine its needs. This type of assessment examines both the business processes that currently exist to support pavement management and those that will need to be developed once the pavement management software is in place. It should also help determine the types and quality of the data available to support the decision processes, the types of questions that the software will address, and the availability of resources to support the implementation and operation of the system. The results of the needs assessment will define the requirements that must be addressed by the software and can often be incorporated into a Request for Proposals (RFP) if proprietary software will be used.

The following factors will have a significant impact on the type of software that the agency will select:

- **The type of condition survey procedure being used**. Most public domain software programs are based on a distress-based pavement condition survey procedure. If an agency must use its own pavement condition rating procedure for historical purposes, or if the pavement condition assessment is based on multiple indexes, the agency probably needs to use proprietary software. The manner of collecting the data (e.g., manual or automated surveys) does not typically influence the type of software to be used.
- **The method used for storing pavement inventory and condition data**. Most public domain systems store data in a hierarchical fashion, meaning that all data for a particular pavement section is linked to a unique ID. This is fine for small networks, for most city applications (with data stored on a block-by-block basis), or for agencies that store all their pavement inventory and condition data inside the pavement management database. However, if an agency

uses different segmenting approaches for different types of data, it will likely be easier to use a proprietary software program than to adapt to the hierarchical approach used in most public domain programs.

- **The frequency with which the pavement management software will be used**. If the pavement management software will only be used once a year to generate pavement improvement recommendations, then it is probably best to keep the system as simple as possible. It can be difficult to remember how to operate the more complex proprietary systems if they are not used on a regular basis.
- **The number of factors used to differentiate between treatments**. Most public domain systems provide users with the option of using common factors to identify feasible treatments, such as surface type, pavement condition, functional class (or the equivalent), and traffic level. Therefore, as long as an agency is not developing complex treatment rules, the capabilities of the public domain software are often adequate to determine pavement improvement needs.

## 8.3 IMPLEMENTATION STEPS

Once the decision has been made to implement a pavement management system, the literature includes guidance on the steps involved in its implementation (AASHTO 2001; WSDOT 1994). Most agencies should incorporate the following 10 steps into their implementation activities:

1. Form a steering committee
2. Assess agency needs and goals
3. Select the software
4. Collect data
5. Configure the software
6. Test the software
7. Conduct training
8. Fully implement the program
9. Document the implementation
10. Review and update the system regularly

These 10 steps are described in more detail in the remainder of this section. However, some agencies may be able to skip one or more of these steps as they move forward with the pavement management implementation.

### 8.3.1 Step 1: Form a Steering Committee

One of the most important steps in the implementation process is the selection of a steering committee to guide and oversee the activities that will be conducted. The steering committee should be made up of agency representatives who will both use data from the system and provide data to the system to help establish buy-in. Therefore, the steering committee should at least include individuals representing management, planning and programming, maintenance and operations, field offices, and engineering.

The steering committee's primary functions are to develop a work plan and to oversee the implementation of tasks as they are conducted. The committee should have sufficient authority to determine the following (WSDOT 1994):

- What data will be used in the pavement management system and how it will be obtained,
- Where pavement management will be housed,
- How the results of the pavement management analysis will be used,
- The timeframe for implementing the system, and
- Resource requirements needed to maintain the system data over time.

Periodically throughout the implementation, the steering committee should take steps to build buy-in among other potential stakeholders. These steps might involve presentations to upper management or elected officials, agency newsletters documenting the implementation activities, or informal discussions with agency personnel. Regardless of the approach used, the steering committee should remain proactive in reporting this information throughout the implementation.

To help ensure that the system continues to reflect agency policies and practices, many agencies keep the steering committee in place after the pavement management system is implemented to guide future updates and adjustments to the models.

### 8.3.2 Step 2: Assess Agency Needs and Goals

As discussed earlier in Section 8.2.2, it is important that the pavement management system closely match the agency's needs in terms of analysis and reporting capabilities, and resource requirements. This match often requires a frank assessment of the business processes currently used for pavement project and treatment selection and the potential changes that could take place once the pavement management system is in place. During this process, it helps to determine the following types of information (FHWA 2009A):

- The agency's organizational characteristics and the relationships between various groups,
- The business process and information systems that will be supported by the pavement management system and the user's requirements to support these processes,
- The data requirements and database management characteristics that must be met to obtain and store data, including location referencing methods,
- Any hardware and software requirements that must be met when implementing software, and
- The flow of data used to support pavement management, including the data source, data type and format, and use.

In addition, it is important to assess the resources that will be available to support the pavement management system, in terms of funding and personnel. The results of this type of analysis will help to define the requirements for data collection and software selection activities.

### 8.3.3 Step 3: Select the Software

Once the agency's needs are understood, the next step is selecting the pavement management software program that best satisfies those needs. In a very small agency, the most appropriate tool may be as simple as a spreadsheet. However, most agencies will look for a public domain or proprietary software tool to store the data or to conduct the analysis and reporting required, or both.

If the agency will be conducting the implementation itself, it can obtain a license for the software from the appropriate party. Otherwise, the agency might develop an RFP that outlines the software requirements and the implementation timeframe. Some agencies elect to shortlist the vendors with the highest rated proposals and ask them to demonstrate the software's capabilities as part of an interview. These presentations can help an agency better assess the complexity of the software program and the corresponding personnel requirements to operate the software effectively.

### 8.3.4 Step 4: Collect Data

Once the software has been selected and the data requirements have been defined, the agency can begin the data collection process (if the data collection activities have not already been conducted). There are two general types of data to collect and input into the pavement management system: inventory data (which includes location referencing information) and pavement condition information.

If the agency is totally new to pavement management and has no historical pavement condition data that will be used, the agency may elect to collect data on only a portion of the network as a pilot implementation (as discussed in Step 6). However, it is generally more cost-effective to collect data on the entire network at one time, especially if automated equipment has to mobilize to the area to collect data. Therefore, even if the software is being tested on only a portion of the network, most agencies make plans to collect all the data for the network at one time. Depending on the survey method used, it may be possible to collect data on the pilot area first so that the information is available for the software test in Step 6. That way, the remaining data collection efforts can continue while the software is being tested.

### 8.3.5 Step 5: Configure the Software

As discussed in Section 6.4, pavement management software is typically configured to reflect the agency's pavement deterioration rates as well as the types of treatments, treatment rules, and costs that the agency must consider in developing pavement preservation and improvement programs. During this step, the agency or the agency's contractor will develop pavement performance models and will configure the treatment rules and budget models. Depending on the complexity of the system, this may be a relatively simple step that takes only a few days to complete, or it could require several months in a large agency.

The most important point to consider during this process is that agencies rarely are satisfied with the first set of models that they develop, so this step often becomes an iterative process that is conducted in conjunction with Step 6. It is very important that the agency test the models to see that they provide reasonable results before considering the pavement management software implemented, as discussed in the next step.

### 8.3.6 Step 6: Test the Software

Once the software has been configured, it is important to test the models on at least a representative portion of the network to help ensure that the treatment recommendations make sense. There are several tests that can be performed to verify the reasonableness of the models, as discussed below.

#### 8.3.6.1 Testing the Pavement Performance Models

If historical pavement condition information is available, it can be used to test the reasonableness of the pavement performance models. This will be accomplished by selecting a set of historical data for a representative sample of the network that includes several different surface types and a range of pavement conditions and forecasting the predicted conditions 3, 5, and 10 years into the future using the proposed performance models. By comparing the predicted results to the actual conditions recorded during a pavement condition survey, an agency can assess the reasonableness of the forecasts at each point in time.

If no historical data are available, expert opinions can be used to evaluate the reasonableness of the models. A more detailed evaluation can take place in the future, once historical data have become available.

#### 8.3.6.2 Testing the Reasonableness of the Treatment Rules

To test the reasonableness of the treatment rules, the agency should generate an unconstrained list of recommended treatments for the pavement network. Assuming that the agency has pavements with different surface types and pavement conditions, this should give a good representation of the types of treatments that will be generated by the software. The agency could select a representative sample of the projects, drive over the sections to evaluate whether the treatment is reasonable, and make any adjustments to the treatment rules that may be needed. The agency should also check to make sure that all pavements that are at a condition level that should warrant a treatment have been assigned a treatment, to verify that there are no gaps in the rules. In some cases, the agency may decide that additional variables are required to differentiate between the selection of one treatment over another. In that case, steps need to be taken to ensure that the required data are available in the database before adding them to the treatment rules.

#### 8.3.6.3 Testing the Reasonableness of Treatment Costs

Perhaps the most straightforward way to evaluate the reasonableness of the treatment costs generated by the pavement management software is to compare the cost of the recommended projects from the trial to recent bid documents for similar projects. Depending on the results of the comparison, adjustments can be made to the costs stored in the pavement management system.

### 8.3.7 Step 7: Conduct Training

The final step in the formal implementation of pavement management software is to conduct the training required so the agency is capable of operating the software on its own. If the data collection techniques are also new to the agency, the training should include a review of the pavement condition survey methodology and reporting. As part of the training, it may also be important to conduct a class for all potential stakeholders who will be providing data to the pavement management system, or who will be using its outputs, so they understand the basic capabilities of the program. These individuals do not necessarily have to know how to operate the software, but they need to understand how recommendations are generated and the types of data that are used in developing those recommendations.

### 8.3.8 Step 8: Fully Implement the Program

Once the agency has confidence in the models and has completed its checks, it can move forward with the full implementation of the system. This may include collecting any additional data not collected earlier or running an analysis using the network data or both.

### 8.3.9 Step 9: Document the Implementation

The pavement management software should be documented by the agency so that, as agency personnel change positions, any new pavement managers can track the final decisions regarding data, model development, treatment costs, and reporting. It is strongly recommended that this documentation be maintained over time, to build a historical record of the models. This type of documentation, which is more than just a user's guide, should provide the information that an agency would need if it had to reconfigure the software system from scratch.

### 8.3.10 Step 10: Review and Update the System Regularly

The implementation of a pavement management system is never complete because the system requires regular updating with new data. In addition, the models may need to be adjusted to continue to reflect the agency's policies and practices. At a minimum, the following schedule is recommended for reviewing and updating a pavement management system:

- Review the pavement performance models after each round of pavement condition surveys, or at least every three to five years.
- Review treatment rules and costs annually before each analysis period.
- Update surface types and construction history each year after the construction season.

## 8.4 INSTITUTIONAL ISSUES

The success of pavement management can be negatively impacted by institutional issues, or barriers, which may be caused by a variety of factors, including people, the organizational structure and culture, or other factors. This section introduces some of the institutional issues that are common in pavement management and provides suggestions for overcoming them.

### 8.4.1 Institutional Issues Related to People

Some institutional issues are caused when agency personnel feel threatened in their positions, either because of changes to the way business will be conducted or because of fear that their position will lose its importance. There are a number of different ways that these issues manifest. For example, people who are resistant to change may erect barriers in an effort to keep the status quo. Alternatively, people who feel the need to protect their turf may try to resist sharing information that is needed to support pavement management decision processes. The same type of reaction may occur among people who feel that the new business processes will expose areas of weakness, or who do not understand the changes that are taking place.

Communication is important to address these types of issues. The more people understand the changes that are taking place, and the more buy-in they develop during the implementation process, the more likely they are to go along with and support the changes. Therefore, agencies might consider hosting training courses to introduce changes or communicating the changes through newsletters and other interagency communication channels, or both. Regardless of the communication approach selected, the information presented should have the following characteristics (AASHTO 2011):

- It should be clear and provide a sufficient level of detail.
- It must be presented in a way that is relevant to the recipient.
- It should be delivered in an acceptable format that is accessible to all relevant parties.
- It should provide an opportunity for the recipient to ask questions and get clarification on anything that is not clear.

Participation on the steering committee or involvement in some aspect of the pavement management implementation can help to alleviate people-related institutional issues.

The *AASHTO Transportation Asset Management Guide: A Focus on Implementation* (2011) includes an entire section on developing a change strategy, which can include a formal process if significant changes to business processes, roles, and activities are associated with the implementation of a pavement management system (or other management systems). The guide stresses the importance of leadership in driving the change and management in sustaining the changes within the organization.

### 8.4.2 Institutional Issues Related to Organizational Structure and Culture

Some of the issues that impact pavement management are related to the organizational structure of large transportation agencies. For instance, it is difficult within a large, decentralized organization to ensure that everyone is working towards a common goal or collecting data in a consistent manner. As a result, many transportation agencies tend to operate in "silos" that are responsible for the management of a particular asset (e.g., pavements or bridges) or a particular function (e.g., planning or operations). Pavement management information, however, is cross-functional and does not fit well within the traditional organizational silos. Therefore, agencies with strong pavement management programs have often developed strategies for overcoming the challenges associated with silos through either formal or informal methods. For instance, the creation of the Pavement Preservation Engineer position in some state DOTs (discussed in Section 6.6) is an example of a formal process to facilitate coordination of capital improvement plans and maintenance activities. A more informal process might rely on the strong relationships of several key individuals housed in different departments or divisions.

The size of the organization and its culture can also have an impact on the presence of institutional issues that impact pavement management. Small agencies in which a few individuals perform all the pavement management functions have different issues than large agencies that have many individuals involved in the process. For instance, individuals in small agencies may have multiple responsibilities, which may impact the amount of time available for pavement management activities. Individuals in larger agencies may also have to deal with not having the time available to support pavement management, but may have additional challenges related to finding the right people to provide necessary information or securing the necessary approvals required to make changes to the analysis models or to accept the recommendations for changes to the software.

The quantity and availability of resources has a tremendous impact on pavement management and the quality of the recommendations that are generated. Pavement management requires an on-going commitment of resources to update the pavement condition information and to run the analysis. Providing these resources can be a challenge in any sized organization. Therefore, it is important for upper management to be aware of the benefits to using a pavement management system and to understand the importance of quality data.

### 8.4.3 Other Factors

There are undoubtedly other factors that contribute to the presence of institutional issues affecting pavement management. For instance, the software itself may cause some institutional issues if the program's complexity or adaptability do not meet the agency's needs. Consider a situation in which an agency sets a performance target for providing smooth, safe roads. If an important metric for avoiding wet-weather crashes includes pavement surface characteristics, but that data cannot be incorporated into the agency's pavement management system, there will be a discrepancy between the software and the agency's decision process that will need to be resolved by either acquiring new software or by upgrading existing software.

Another cause of institutional issues results from the lack of adequate training for pavement management staff. Since pavement management is not included in the typical civil engineering curriculum, most of the training is provided through on-the-job experience. If transitions in pavement management personnel are not carefully planned, changes can lead to disruptions in the use of the pavement management software if adequate training has not been provided. Therefore, it is important to ensure that multiple people are familiar with the software and that a pavement management handbook has been developed to explain the model development and the reasoning behind any changes. The existence of a pavement management steering committee can also be beneficial in this type of situation to provide the new pavement management engineer with a historical perspective.

One of the more difficult issues to address concerns the lack of stature for pavement management within some agencies, as evidenced by inadequate resources to support pavement management activities or by the agency's failure to utilize pavement management information in its decision processes. This is a challenge for an agency to overcome. It requires a continued commitment to providing the best possible information with the resources available, to network with other pavement management practitioners to build a knowledge base, and to find opportunities to provide pavement management information to others within the agency to address challenges they face. These strategies all take time to have a positive impact on an organization, but many of the early champions of pavement management were able to gain success by instituting similar activities. Coupled with the transitions occurring at the national level in the United States, and the resulting increase in the use of a performance-based decision process within transportation agencies, practitioners are likely to find that management will recognize the importance of pavement management information as the agency responds to these changes.

## 8.5 TRANSITION PLANNING

Although not all transitions in staffing can be planned, there are several steps that an agency can take to help ensure that pavement management continues to operate effectively even though personnel changes take place. The following suggestions will help prepare an organization for a transition:

- Involve more than one individual in the development and operation of the pavement management system. Even if one person is primarily focused on data and another on the models and analysis features, be sure each person is familiar with and comfortable with what other people are doing.
- Maintain documentation of the pavement management models and the justification for any changes that are made. This may be tracked in the form of a pavement management handbook, such as the Synopsis prepared by the South Dakota Department of Transportation that is posted on their website (http://sddot.com/transportation/highways/planning/pavemanage/docs/Synopsis2007.pdf).
- Create a pavement management steering committee that represents key stakeholders as well as pavement management personnel. The steering committee can often serve as the institutional knowledge that withstands the changes in personnel.
- Provide opportunities for reward and advancement within pavement management so key individuals do not have to leave in order to advance within the organization.
- Keep pavement management from becoming stagnant so personnel recognize opportunities for growth and increased responsibility.

## 8.6 CHAPTER SUMMARY

This chapter focused on the issues associated with the implementation of a pavement management system. Since there is a great deal of variety in the complexity and adaptability of different software programs, this chapter summarized some of the key differences between public domain and proprietary software. In addition, it outlined ten steps to guide the implementation of a pavement management system.

The chapter also introduced some of the common institutional issues that impact the success of pavement management within an organization. In addition, strategies for overcoming these hurdles were introduced. The importance of communicating pavement management information to a variety of stakeholders was discussed. Although communication cannot resolve all the institutional issues that often exist in an agency, the detrimental effects that the lack of communication can have are evidenced in several of the institutional issues presented in this chapter. Other strategies for resolving institutional issues include building cross-functional teams, regularly demonstrating the benefits of the use of pavement management information, and providing the training necessary to transition knowledge from one generation of practitioners to the next.

CHAPTER NINE

# Future Directions

## 9.1 INTRODUCTION

Pavement management continues to evolve as technology advances, as the economic environment changes, and as transportation agencies respond to political, legislative, and cultural initiatives. Since pavement management first emerged as a process for using pavement performance data to identify and prioritize needed pavement improvements, it has become an important tool for supporting agencies' efforts to improve transparency in pavement-related decisions, to provide a performance-based culture that supports long-term decisions, and to better understand and respond to the needs of a diverse group of stakeholders. Pavement management has matured as a field of study and it is now widely used at the federal, state, and local levels in the United States and worldwide.

In 2010, FHWA sponsored the development of a 10-year Pavement Management Roadmap to identify the steps needed to address current gaps in pavement management and to establish research and development initiatives and priorities (FHWA 2010e). The Roadmap defined a total of 47 combined short- and long-term needs, representing a total of nearly $15 million, in the following four areas (FHWA 2010e):

- The use of existing technology and tools.
- Institutional and organizational issues.
- The broad role of pavement management.
- New tools, methodologies, and technologies.

Through comprehensive and coordinated efforts to address the 47 research, development, technology, and workforce development initiatives listed in the Roadmap, practitioners foresee the following vision for pavement management by the year 2020 (FHWA 2010e):

*"Pavement management will make use of a new generation of technology so agencies are less dependent on manual labor for data collection. Pavement management tools will allow agencies to communicate effectively with stakeholders, using clear statements that are tied to agency goals and pavement worth. Within an asset management framework, pavement management will be used for investigating decisions and program options in both private and public sectors. A pavement management analysis*

*will consider new materials and construction/design practices, as well as other factors that influence project and treatment selection, including safety, congestion, and sustainability. As a result of these changes, pavement management will be robust, comprehensive, and credible, and will address agency needs at the project, network, and strategic levels."*

Also, the Pavement Management Roadmap (FHWA 2010e) identified the need for better access to pavement management information and the need for summaries of best practice. Other areas that will require further study to advance the state of the practice include the following four topics:

- Marketing of pavement management benefits.
- Use of pavement management data to support design activities.
- Incorporation of a broader range of factors in project and treatment selection, including sustainability and risk.
- Privatization of highway maintenance.

Each of these areas is described in more detail in this chapter.

## 9.2 MARKETING PAVEMENT MANAGEMENT BENEFITS

As transportation agency budgets continue to tighten, agencies must continue to demonstrate that they are investing available funds wisely. As a result, pavement management practitioners are seeking improved methods of demonstrating the value of continued investments in data and personnel to support pavement management activities. This will require strategies for quantifying the impact of different investment levels in pavement management on the quality of the decisions being provided. For instance, if agencies elect to reduce the data collection budget for pavement management by 50 percent, what impact will that have on the quality of the improvement recommendations generated by the pavement management software?

It is also important for practitioners to develop and implement better techniques for quantifying the benefits associated with using sound pavement preservation strategies for maintaining the road network. To date, most agencies rely on qualitative improvements that result from the use of a pavement management analysis, such as better decision making, improved access to data, and more efficient use of available resources (AASHTO 2001). Some researchers have published quantitative results showing the benefits to using pavement management by comparing the cost of a worst-first strategy to an optimized pavement preservation strategy generated by the pavement management system (Falls et al. 1994; Hudson and Haas 1994). The studies show tremendous benefit-to-cost ratios of at least 14 to 1 associated with savings due to the selection of less costly rehabilitation strategies, and when savings in user costs are taken into consideration the ratios become even larger (Falls et al. 1994). However, further work is required to better capture the broad range of benefits that pavement management provides to an agency in a defensible manner.

## 9.3 USE OF PAVEMENT MANAGEMENT TO SUPPORT DESIGN ACTIVITIES

Historically, pavement management has primarily been used for the planning and programming of pavement preservation activities. However, as data integration efforts have enabled transportation agencies to broaden the access to information to a wider representation of agency personnel, the interest in pavement management data is increasing. For instance, agencies are investigating the potential use of pavement management data to support the calibration of the new DARWin-ME software (AASHTO 2008). The use of a pavement management system to provide data for the calibration process is possible, but it may require some changes in the way the agency currently collects and tracks data. For instance, the results of material testing are not commonly linked to pavement condition survey data, which makes it difficult to link in-situ properties with the performance data required for calibration. The calibration process may also end up influencing the way that pavement condition data are collected if the agency desires to more closely comply with the LTPP data collection procedures that were used in calibrating the original MEPDG models.

There are other ways in which pavement management can support an agency's design activities that will become more common as data collection procedures continue to evolve. For instance, pavement structural condition has been difficult to measure economically on a network-wide basis, especially on high-volume facilities. With the potential development of automated methods of collecting pavement structural condition, it is likely that the pavement management analysis will be better prepared to consider this type of information in recommending pavement rehabilitation activities. Pavement design would also benefit from the availability of site-specific performance models that allow the agency to further investigate the circumstances under which certain pavement improvements perform best.

## 9.4 INCORPORATION OF SUSTAINABILITY, RISK, AND OTHER FACTORS INTO PAVEMENT MANAGEMENT DECISIONS

Ideally, the project and treatment recommendations from a pavement management analysis closely match the construction projects that are funded. Unfortunately, there are often differences between the projects that are constructed and those that are recommended by the pavement management software because of the differences in factors that are considered in the analysis. The pavement management system typically relies on current and projected pavement condition information along with certain considerations such as traffic volume or functional class to differentiate between treatment types, because of the availability of this type of information in the database. Those in the field who are making project and treatment decisions are often aware of many additional factors that need to be taken into account, such as safety, congestion, and environmental or sustainability issues. Therefore, strategies must be developed for incorporating these other factors into the pavement management analysis to better link the projects in the field with those being recommended by the pavement management system.

One of the areas of increasing importance to transportation agencies is the incorporation of sustainability into investment decisions. This has become increasingly important as agencies strive to reduce greenhouse gas emissions to help reduce the impact of climate change and as agencies strive to improve the triple bottom line (e.g., social, economic, and environmental factors) over the life cycle of an asset.

Schmidt and Meyer (2009) introduced a framework for incorporating these factors into transportation planning activities, which is illustrated in Figure 9-1. The framework emphasizes the importance of linking performance measures to agency goals and objectives, leading to the selection of mitigation strategies that will enable the agency to reach its goals. However, this will require that agencies develop methods of quantifying the impact of different pavement treatment options on the triple bottom line so that different strategies can be evaluated. According to a recent survey of state practices in the United States, agencies vary considerably in how they are addressing these issues (Barrella et al. 2010). For instance, some state DOTs are responding to national or state land use policies to make transportation planning more sustainable, but only five state DOTs were found to have a formal sustainability plan or program in place (Barrella et al. 2010).

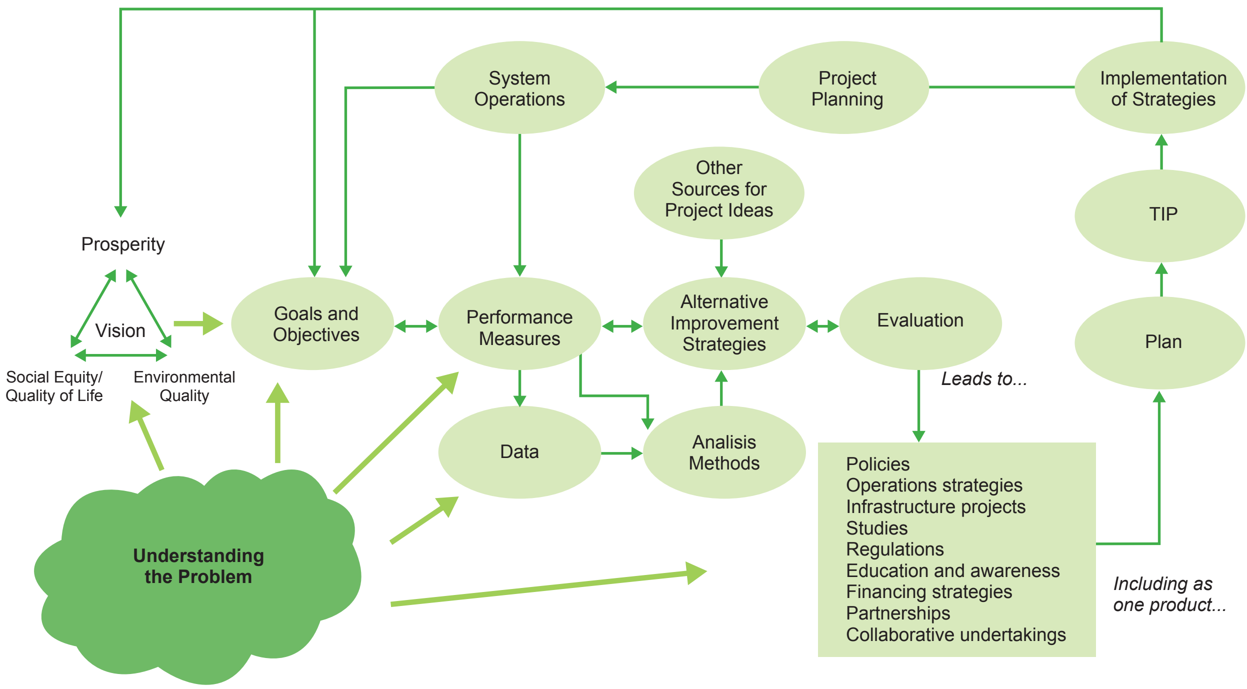



**Figure 9-1. Conceptual Framework for Considering Sustainability in Transportation Planning (Schmidt and Meyer 2009)**

Another trend that is impacting pavement management is the increased consideration of risk in transportation agencies. These assessments are used to identify and evaluate sources of risk and to develop strategies for mitigating risk. Internationally, risk assessment has been an increasingly important part of transportation asset management programs, to help agencies assess their vulnerability to both natural and man-made events. A risk assessment typically includes an assessment of the likelihood that a catastrophic event will take place, the identification of the possible consequences associated with the event, and an estimate of the asset damage or loss of function that may be caused by the event (AASHTO 2011). A risk assessment score can be assigned based on the likelihood, consequences, and impact of an extreme event and can be used to prioritize mitigation alternatives. Pavement management, therefore, can assist agencies in conducting a pavement risk assessment by providing much of the information related to potential damage and mitigation strategies.

## 9.5 PRIVATIZATION OF HIGHWAY MAINTENANCE

Long-term, privatized maintenance contracts have emerged as an alternative to traditional contracting approaches in the United States and internationally. These contracts, often referred to as performance-based contracts, shift responsibility for highway maintenance to a contractor for a multi-year period (often 5 to 10 years) in accordance with pre-specified performance criteria. They may be operated as a public–private partnership (PPP) under a design/build/operate/maintain (DBOM) contract, an operations and maintenance concession, or under a more traditional contracting agreement.

One of the keys to the success of this type of contract is in developing effective performance standards that help guide the contractor's decisions regarding maintenance activities. If the performance measures are selected appropriately, they help to ensure that the agency's expectations are met by the contractor over the life of the contract. Otherwise, the contractor is penalized for failing to achieve the terms of the contract.

Pavement management will be impacted in several ways by the increased use of public–private partnerships. Perhaps most importantly will be the shift in responsibility for identifying and selecting pavement preservation activities from the agency to the contractor. This will place more responsibility on the contractor to use sound pavement management principles and to collect pavement condition data regularly to drive investment decisions. The agency's data collection responsibilities for the portion of the network being managed through this type of contract are primarily driven by the need to document the contractor's performance and to assess bonuses or penalties, or both. Therefore, the pavement condition data collected by the agency must be defensible in case there are any disagreements with the contractor.

Another impact on pavement management is the loss of historical data, unless provisions are included in the contract for the contractor to report activities to the contracting agency. Since the contractor assumes all risk for pavement improvements under this type of contract, the contractor decides the types and timing of various treatments that ensure that the performance criteria are met. Therefore, unless special considerations are worked out during the contract negotiation phase, it is not likely that the agency will receive work history data for the network they are responsible for managing.

Pavement management can also be used during the initial phases of these types of contracts to establish the performance targets and intervention levels that the contractor will be held to. Performance measures should be comprehensive and clearly understood by both the agency and the contractor, and should cover safety, serviceability, and sustainability factors that are important to the agency.

## 9.6 CHAPTER SUMMARY

The implementation of a pavement management system is not a static event. Instead, pavement management must continue to evolve to meet the changing needs within transportation agencies. This means that pavement management practitioners must be able to adapt to changes in technology, changes in the decision processes used to make investment decisions about the preservation of the pavement network, and changes in the demands of the various stakeholders for accountability and transparency in the agency's decision processes. This chapter introduced some of the changes that pavement managers are facing and identified future areas of development that are needed within the pavement management community.

## ABSTRACT

The American Association of State Highway and Transportation Officials (AASHTO) has supported the development and use of pavement management since the early 1980s. In 1990, AASHTO published the *AASHTO Guidelines for Pavement Management Systems*, which introduced the concepts and outlined the components of a pavement management system, and documented the steps to implement a computerized system. In 2001, AASHTO published the *Pavement Management Guide*, which covered pavement management concepts in much more detail.

While many of the topics included in the 2001 *Pavement Management Guide* are still relevant today, there are several significant advancements that have taken place since its publication. For instance, there is an increased emphasis on pavement preservation programs and there are advancements that have taken place in terms of data quality and integration issues. There are also recent initiatives that are impacting the types of data required by pavement management. The increased importance of performance measurement and asset management principles will further influence the practice and future of pavement management.

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# EXECUTIVE SUMMARY

## IMPORTANCE OF PAVEMENT MANAGEMENT

In light of an economic environment in which funding constraints force managers to do as much as possible with the dollars provided, transportation agencies have sought methods of managing their roads, bridges, and other highway assets using systematic processes based on reliable data. Defined in 1993 by the American Association of State Highway and Transportation Officials (AASHTO) as "a set of tools or methods that assist decision-makers in finding optimum strategies for providing, evaluating, and maintaining pavements in a serviceable condition over a period of time," pavement management has been used by federal, state, and local transportation agencies to perform the following activities:

- Assess both current and future pavement conditions.
- Estimate funding needs to achieve targeted condition levels.
- Identify pavement preservation and rehabilitation recommendations that optimize the use of available funding.
- Illustrate the consequences of different investment levels and treatment strategies on both short- and long-term pavement conditions.
- Justify and secure increased funding for pavement maintenance and rehabilitation.
- Evaluate the long-term impacts of changes in material properties, construction practices, or design procedures, or some combination thereof, on pavement performance.

The idea of managing transportation assets effectively is not new. In fact, state DOTs have been managing roads, bridges, and other highway assets since public road departments were first established in this country. Today's agencies understand the typical life cycle of a pavement and recognize the need for periodic preservation, rehabilitation, and reconstruction activities. However, as these agencies seek ways to preserve their transportation investments, they are doing so in an environment that offers tremendous challenges from both internal and external forces. These challenges can often have long-lasting impacts on the manner in which an agency manages its transportation assets. For instance, agencies are facing severe funding reductions and pressure from elected officials and the traveling public to improve efficiency and to demonstrate that funds are being used wisely. There is increased pressure to streamline organizations and, as a result, institutional knowledge, which has been the backbone of transportation agencies for many years, is diminishing as experienced workers retire or leave government employment. There is also more competition for available funding and some agencies are responding by outsourcing or privatizing the maintenance of a portion of their network. Additionally, increased pressure for improved accountability in the use of public funds is causing agencies to establish performance-based metrics that allow agencies to defend funding requests and to document how funds have been used and what benefits have been gained.

As a result of these pressures, stewards of transportation agencies have placed more of an emphasis on preserving their existing assets and better linking investment decisions to agency priorities and performance data. This has led to a shift in the way agencies think about asset investments, with more consideration for the interrelationship between funding decisions. This shift has fueled the development and acceptance of data-driven management as a way of preserving the investment in transportation assets. Since pavements represent one of the largest single transportation investments, the efficient management of pavements is a high priority within these agencies. As a result, pavement management has become increasingly important to address these needs.

## INTRODUCTION TO THE NEW PAVEMENT MANAGEMENT GUIDE

AASHTO has supported the development and use of pavement management since the early 1980s. In 1990, AASHTO published the *AASHTO Guidelines for Pavement Management Systems* (AASHTO 1990), which introduced the concepts of pavement management, explained the differences between network- and project-level analyses, outlined the components of a pavement management system, and documented the steps to implement a computerized system. In 2001, AASHTO published the *Pavement Management Guide* (AASHTO 2001), which covered pavement management in much more detail.

This updated *Pavement Management Guide* contains the nine chapters listed below:

Chapter 1: Introduction to the Guide
Chapter 2: Managing Transportation Assets Effectively
Chapter 3: Inventory Data Collection and Data Integration
Chapter 4: Pavement Condition Assessment
Chapter 5: Pavement Performance Modeling
Chapter 6: Project and Treatment Selection
Chapter 7: Using and Presenting Pavement Management Results
Chapter 8: Implementation Activities
Chapter 9: Future Directions

Chapters 2 through 5 provide the foundation for understanding pavement management. Chapter 2 begins with the premise that pavements are an important asset that have a significant value and represent a major investment. It emphasizes the importance of establishing a link to asset management principles by introducing the five core questions that every agency should be able to answer about its pavements, bridges, and other roadway appurtenances to manage them cost-effectively. In addition, this chapter introduces the components of a pavement management system; the use of pavement management at the project, network, and strategic levels; and the differences between the types of information used at each of the three decision levels. Finally, Chapter 2 introduces the benefits of using pavement management to support agency decisions.

Once the fundamental principles of managing assets have been established, the guide then addresses several basic pavement management components, including the establishment of an inventory and the types of data integration issues that arise when sharing data (in Chapter 3), the assessment of pavement condition (in Chapter 4), and pavement performance modeling (in Chapter 5). Chapter 3 discusses the importance of the availability and accessibility of reliable inventory and condition information for pavement management. Because of the number of sources of pavement management data, data integration and data sharing are critical to the success of pavement management. This chapter introduces several methods of integrating pavement management data, including the use of a Geographic Information System for data storage, retrieval, analysis, and presentation. The chapter also identifies strategies for managing data effectively.

Chapter 4 introduces the importance of a consistent and reliable method of assessing pavement conditions as the basis for all pavement management recommendations. The chapter introduces a variety of methods to assess the structural and functional condition of a pavement, including surface characteristics (such as pavement distress, longitudinal profile and roughness, and surface texture and friction), subsurface characteristics, and structural evaluation. Various methods of conducting network-level pavement condition surveys are presented, and methods of developing pavement condition indices are introduced.

This chapter also presents some of the current changes that may influence the types of pavement condition data that are being collected and the frequency with which surveys are conducted. For instance, new Highway Performance Monitoring System (HPMS) reporting requirements include cracking, rutting, and faulting. The new mechanistic-empirical design procedures that have recently been developed require calibration of the performance models using pavement management data. Additionally, new technology is being developed that may influence an agency's ability to assess pavement structural condition at a network level. These, and other types of changes, are forcing agencies to periodically revisit their data collection activities to determine whether adjustments are needed to continue to meet changing agency demands.

Chapter 5 introduces some of the different methods used to develop pavement performance models that are used in pavement management to demonstrate the impact of different funding scenarios, to determine the best use of available funds, and to estimate changes in resource needs to address pavement deficiencies. Several methods of developing pavement performance methods are introduced, including deterministic, probabilistic, Bayesian, and subjective approaches. Methods of evaluating the reliability of the models are also provided.

One of the more common methods of developing pavement performance models discussed in Chapter 5 is the family modeling approach, in which condition data for pavement sections with similar characteristics are grouped together to determine a representative model to signify the typical deterioration pattern for the data set. The use of certain characteristics to group pavements into families reduces the number of variables used directly in the model (e.g., reduced to a single variable) and reduces the specificity required of the data. This simplifies the modeling process by reducing the data demands for developing the models. Since a family model represents a general performance trend for a group of pavements, the chapter also introduces a method of shifting the family performance model to predict the condition of an individual section.

Chapter 5 concludes with a discussion of the use of performance models beyond the traditional applications of pavement management. This section discusses the use of performance models to evaluate new designs and mixes, to determine the benefit of using preventive maintenance treatments, to support a forensic analysis, to estimate Remaining Service Life, and to calibrate mechanistic-empirical pavement design models.

At its most basic level, a pavement management system is used to identify and prioritize pavement preservation and rehabilitation projects. Chapter 6 introduces and illustrates methods used to develop both treatment and impact rules. The treatment rules used in pavement management describe the conditions under which a treatment is considered feasible and impact rules describe the pavement performance that might be expected following the application of a treatment. Special considerations for developing treatment rules for preventive maintenance treatments are also presented in Chapter 6.

The chapter also introduces three common methods of project and treatment selection under constrained conditions: ranking, multi-year prioritization, and optimization. A multi-year prioritization approach, which includes incremental benefit-cost and marginal cost-effectiveness analyses, is currently the most commonly used approach for project and treatment selection at the state highway level.

The chapter concludes with a discussion of the importance of coordinating pavement management with maintenance and operations, especially as pavement preservation programs increase in popularity and size. Strategies for strengthening the links between pavement management and maintenance are also provided.

Chapter 7 presents methods for using pavement management results to support agency decisions. First, it presents strategies for using pavement management results to determine pavement needs, to determine the consequences associated with different strategies, and to identify projects and treatments that make the best use of available funding. In addition, the chapter describes the use of pavement management information for allocating funding, for establishing performance targets, and for long-term planning activities. The chapter concludes with suggestions for effective use of pavement management information in presentations.

The steps involved in the implementation of a pavement management system are introduced in Chapter 8. It discusses the different types of software available and the typical steps that agencies will follow as they move forward with their pavement management implementation. The chapter also addresses some of the institutional issues that agencies face as they adopt pavement management practices and the importance of transition planning.

The guide concludes with Chapter 9, which presents a summary of some of the evolving issues that should be addressed to keep pavement management viable into the future. These issues include national initiatives in sustainability and livability that are influencing the types of data that should be considered in making pavement preservation and rehabilitation recommendations. Other considerations that are impacting pavement management, such as support for the calibration of mechanistic-empirical pavement design models and increased privatization of highway maintenance activities, are explored.

The guide's Appendices include a glossary of common terms and acronyms and a useful list of references sorted by topic area.

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TRB Liaison. . . . . . . . . . . . . . . . . . . . . . . Amir Hanna

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# Appendix A: Glossary

**Allocate**—Distribution of available resources among programs or geographic districts/regions.

**Alternatives**—Available choices or courses of action that can be considered at each stage of resource allocation or utilization.

**Analytical Tool**—Process or procedure (typically computer-based) for reviewing an asset's effectiveness.

**Asset**—The physical infrastructure (e.g., right-of-way, pavements, structures, roadside features). Assets can also include other agency resources capable of providing added value (e.g., human resources, real estate, equipment, and materials).

**Asset Management**—Business processes for resource allocation and utilization with the objective of better decision-making based upon quality information and well-defined objectives.

**Asset Management Plan**—Tactical plan for managing an agency's infrastructure (or other assets) to deliver an agreed upon level of service. Typically, the asset management plan encompasses more than one asset (e.g., a system approach).

**Audit**—Evaluation of a person, organization, system, process, product, or project. In the area of quality, audits are used to verify the existence of a process, assess the successful implementation of a process, assess the effectiveness of a process for achieving the defined objectives, and provide evidence of process improvement.

**Benefit-Cost**—A comparison analysis of the economic benefit of an investment to its cost. The benefit-cost analysis should include all costs and benefits to both the agency and the users of the facility over an appropriate life-cycle period. In asset management, benefit-cost can be applied for prioritizing projects, evaluation of the benefits and costs for all projects in a program, and determination of program tradeoffs.

**Capital**—Type of investment that generally involves construction or major repair and can include: new construction, reconstruction, structural and functional improvements, and rehabilitation.

**Condition**—Measure of the physical state of an asset as affected by deterioration and past maintenance and repair.

**Corridor Approach**—An approach to perform construction projects, scheduled maintenance, and utility work at the same time (or at least at coordinated times) on a specified segment of a transportation corridor to minimize road closures and traffic delays.

**Data**—Measurements (or observations) that represent a qualitative or quantitative attribute of a variable or set of variables.

**Data Integration—**Process of sharing data from one source among multiple applications, or of merging data from multiple sources for use by a single application.

**Decision—**Determination of a course of action or selection of an option from available choices.

**Decision Support—**The use of information (e.g., from management systems, other analytic tools, or estimates and studies by staff) to help understand the consequences of decisions.

**Deficiency—**Gap between an asset's current condition/performance and a defined target or threshold value; deficiency implies a need for work.

**Deficiency Criteria—**Threshold value for quantitatively identifying when an asset has reached the need for maintenance, rehabilitation, restoration, or reconstruction.

**Framework—**Basic conceptual structure used to solve or address complex issues.

**Funding Levels—**Sum of money that is either dedicated to or needed for a transportation asset.

**Geographic Information System (GIS)—**A tool to organize geographically-based data, create maps, and perform spatial analyses.

**Global Positioning System (GPS)—**satellite based navigation system.

**Goals—**Desired outcomes, broadly defined, as expressed in policy.

**Heuristic Decision Rules—**Process of acquiring knowledge (typically through observations) for generating a decision using established rules.

**Impact—**Effect or result, as of a project, program, policy, level of investment, or budget.

**Improvement—**A project or investment that enhances transportation system functionality; may include capacity additions or operations enhancements to existing facilities, or construction of new facilities.

**Information—**Processed or refined data in a form that communicates meaningful indications of current status or calculations and predictions useful for decision support.

**Integration—**Combining of data or results from multiple systems.

**Intergovernmental Agreements—**Agreements between agencies or levels of government to purchase or exchange services, often with the aim of greater efficiency and cost-effectiveness.

**Inventory—**A compilation of the agency's infrastructure assets, relevant characteristics (e.g., count or quantity, location, size, functional classification, traffic usage, district responsibility), and depending on agency practice, may include condition or performance data.

**Investment Analysis—**System or process that provides general guidance on predicting the performance of one or more assets within a specified budget level.

**Level of Service (LOS)—**Measures related to the public's perception of asset condition or of agency services; used to express current and target values for maintenance and operations activities.

**Life Cycle—**A length of time that spans the stages of asset construction, operation, maintenance, rehabilitation, and reconstruction or disposal/abandonment; when associated with analyses, refers to a length of time sufficient to span these several stages and to capture the costs, benefits, and long-term performance impacts of different investment options.

**Linear Referencing System (LRS)—**Protocol for locating features on a highway system. The LRS enables mapping and locating asset condition, performance measures, traffic characteristics, crashes, and performance of work activities.

**Long-Range Transportation Plan (LRTP)—**Federally mandated, 20-year statewide transportation plan.

**Maintenance**—Activities that enable a transportation system to continue to perform at its intended level; comprises a range of services in preservation, cleaning, replacing worn or failed components, periodic or unscheduled repairs and upkeep, motorist services (incident response, hazardous materials response), snow and ice control, and servicing of traffic devices and aids; does not add to structural or operational capacity of an existing facility.

**Maintenance Standards**—Procedures and policies for the selection, design, and construction of maintenance activities.

**Management System**—System that is designed to support one or more assets, such as bridge management, maintenance management, pavement management, and others. These systems generally include data related to asset inventory and condition levels. Can also consist of a software application that supports a particular set of an agency's business processes, whether in managing assets or resources (e.g., pavements, bridges, human resources, equipment fleets, materials stockpiles, lands and buildings), performing prescribed functions (e.g., planning, project development, construction management, maintenance management), recording and managing transactions (e.g., financial management and accounting, payroll), or processing and communicating information (e.g., executive information, customer comments and complaints).

**Monitoring**—Collecting and processing condition and performance data and related data (e.g., traffic usage) to understand the current status of the transportation system, identify problem areas, gauge improvements resulting from investments, and track progress toward performance targets; provides a feedback mechanism for resource allocation and utilization decisions.

**Need**—Work required to help attain a policy objective or performance target, or to address a problem or deficiency.

**Needs Identification and Project/Treatment Evaluation**—System or process that uses data contained within other management systems to perform analyses for identifying the needs of the asset; evaluating various policies for project scoping, treatment timing, or design; evaluating projects or strategies; conducting a whole-life cost analysis; and risk analysis.

**Network**—System of assets to provide transportation services to customers.

**Network-Level**—The most common level at which pavement management decisions are made. Network-level decisions typically involve choices about how to use available funding across the entire road network. Other decision levels include project-level and strategic-level.

**Objective**—Translation of a policy goal into a more specific measure of attainment (e.g., a policy goal of improved pavement performance expressed as improved serviceability or ride quality, or reduced roughness; a policy goal of improved mobility might be expressed through an objective of reduced travel time or total trip time, percentage increase in user benefits, or improvement in congestion measures or indexes).

**Operational Improvements**—Investments and activities to improve the efficiency and safety of traffic movement on the existing transportation system (e.g., through improved signal timing, installation of variable message signs and other ITS devices, improved traffic monitoring and reporting of problem locations, traffic metering).

**Optimal**—The preferred or best option based on specified criteria.

**Optimization**—Process for determining the best available value (e.g., cost, performance life) within a given set of constraints.

**Options**—See alternatives.

**Outcome**—Result or consequence (especially in terms of performance), as of an investment decision, a particular allocation of resources, completion of a project, conduct of maintenance at a particular level of service, or selection of a particular alternative.

**Output**—A product or service produced by a program or process.

**Pavement Management**—A set of tools or methods that can assist decision-makers in finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition.

**Pavement Management System**—A computerized tool used to assist decision-makers in finding cost-effective strategies for providing, evaluating, and maintaining pavements in a serviceable condition.

**Performance Measure**—An indicator, preferably quantitative, of service provided by the transportation system to users; the service may be gauged in several ways (e.g., quality of ride, efficiency and safety of traffic movements, services at rest areas, quality of system condition).

**Performance Target**—Threshold value of a performance measure.

**Performance-Based**—Characteristic of an asset that reflects its functionality or its serviceability as perceived by transportation users; often related to condition.

**Preservation**—Actions to prevent or correct deterioration of an asset to extend its useful life; does not entail structural or operational improvement of an existing asset beyond its originally designed strength or capacity.

**Preventive Maintenance**—Proactive approach that applies maintenance treatments while the asset is still in good condition; extends asset life by preventing the onset or growth (propagation) of distress.

**Program**—A set of projects of similar type of work (e.g., pavement rehabilitation) or serving a similar objective (e.g., to improve mobility or safety).

**Project**—Construction work to address a need or deficiency in system preservation, improvement, or operations.

**Project-Level**—One of the three decision levels used in pavement management (with network- and strategic-levels). At the project level, very detailed information on a small subset of the network is used to design the appropriate treatment.

**Project Prioritization**—Process for comparing and ranking projects according to cost, benefit, and other performance standards.

**Rehabilitation**—Project to perform structural repair or capacity, operations, or safety improvements of an existing asset.

**Resource**—An input to the construction, operation, maintenance, repair, renewal, or disposal of transportation infrastructure assets; provides added value to these processes; may include labor knowledge and skills, financial capacity, real estate, corporate information, or equipment and materials.

**Results Monitoring**—Systems that help track treatment (e.g., maintenance or new construction) performance and cost with time.

**Risk Assessment**—Process to determine risk of system failure, predict the consequences of risk, and assist in prioritizing investments for mitigating risk.

**"What If" Analysis**—Analytic study of the consequences of different actions or assumptions; in asset management, often refers to predictions of asset condition and performance for different budget or revenue assumptions, levels of investment, or sets of policies.

**Self-Assessment**—Process by which an agency self-evaluates its compliance with established standards, guidelines, and procedures.

**Stakeholders**—A person, group, or organization that affects or can be affected by an agency's actions.

**Strategic**—A view of assets that are policy-based, performance-driven, long-term, and comprehensive.

**Strategic-Level**—One of three decision levels used in pavement management (with network- and project-levels). Strategic decisions typically include policy and investment decisions made by upper-level management.

**Tactical**—Strategy for achieving a specific objective or goal.

**Trade-Off Analysis**—Comparisons of alternative solutions, particularly involving consequences of reallocating funds between programs.

**User Benefits**—Economic gains to the transportation users resulting from a project or investment strategy; may include monetary value of travel time savings, accident reductions, reduced costs of vehicle operation, and savings or advantages gained from more reliable transportation services.

**Utilization**—Process of applying labor, funds, information, and other resources to implement projects and services for the transportation system.

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# Appendix C: Index

| **Index Terms** | **Links** | | | |
|---|---|---|---|---|

## J



## L



## M

| **Index Terms** | **Links** | | | |
|---|---|---|---|---|
| **N** | | | | |
| ***National Cooperative Highway Research Program (NCHRP)*** | 2-2 | 3-2 | 3-3 | 3-4 |
| | 4-3 | 4-21 | 4-22 | 4-23 |
| | 4-26 | 4-27 | 7-11 | |
| ***non-destructive testing (NDT)*** | 4-1 | 4-3 | 4-17 | 4-18 |
| **P** | | | | |
| ***parameter*** | 4-16 | 4-31 | 5-8 | 5-9 |
| | 6-19 | 6-23 | 7-14 | |
| ***pavement condition indices*** | 4-34 | 4-42 | 5-2 | 5-3 |
| | 5-11 | 5-14 | | |
| ***pavement design models*** | 2-6 | | | |
| ***pavement preservation programs*** | 1-2 | 1-3 | 4-2 | 4-40 |
| | 6-1 | 6-4 | 6-15 | 6-22 |
| | 6-25 | 6-26 | 6-27 | 6-30 |
| ***pavement network*** | 1-1 | 1-4 | 2-1 | 2-7 |
| | 2-11 | 2-16 | 3-1 | 4-1 |
| | 4-3 | 4-9 | 4-14 | 5-13 |
| | 6-1 | 6-4 | 6-17 | 6-19 |
| | 6-24 | 7-1 | 7-3 | 7-4 |
| | 7-5 | 8-6 | | |
| ***pavement management software*** | 1-2 | 2-2 | 2-12 | 2-13 |
| | 2-16 | 4-16 | 5-3 | 5-5 |
| | 6-5 | 6-6 | 6-9 | 6-10 |
| | 6-11 | 6-12 | 6-25 | 6-29 |
| | 7-10 | 8-1 | 8-2 | 8-3 |
| | 8-5 | 8-6 | 8-9 | 9-2 |
| | 9-3 | | | |
| ***pavement surface rating (PSR)*** | 4-12 | 6-29 | | |
| ***performance indicators*** | 4-28 | | | |
| ***performance measures*** | 2-4 | 4-3 | 4-31 | 4-41 |
| | 7-11 | 7-12 | 9-4 | 9-5 |
| ***performance modeling*** | 4-8 | 4-39 | 4-40 | 4-42 |
| | 5-1 | 5-2 | 5-3 | 5-12 |
| | 5-13 | 5-14 | 5-15 | 5-16 |
| | 5-17 | 6-5 | 6-6 | 6-7 |
| | 6-8 | 6-22 | 6-25 | 6-26 |

| Index Terms | Links | | | |
|---|---|---|---|---|
| *performance modeling* (Cont.) | | | | |
| | 6-29 | 8-5 | 8-6 | 8-7 |
| | 9-3 | | | |
| *performance targets* | 1-3 | 2-4 | 2-5 | 2-7 |
| | 2-8 | 2-11 | 2-13 | 2-14 |
| | 4-41 | 7-1 | 7-11 | 7-14 |
| | 9-5 | | | |
| *Portland cement concrete (PCC)* | 1-3 | 2-4 | 2-5 | 2-7 |
| | 2-8 | 2-11 | 2-13 | 2-14 |
| | 3-2 | 3-13 | 4-10 | 4-13 |
| | 4-41 | 6-6 | 6-7 | 6-8 |
| | 6-27 | 7-1 | 7-14 | 9-5 |
| *Privatization* | 9-2 | 9-4 | | |
| *prediction models* | 3-2 | 5-1 | 5-7 | 5-10 |
| *present serviceability index (PSI)* | 4-12 | | | |
| *preventive maintenance* | 1-2 | 1-3 | 2-7 | 2-10 |
| | 4-40 | 4-41 | 5-13 | 5-14 |
| | 5-17 | 6-1 | 6-2 | 6-3 |
| | 6-4 | 6-6 | 6-7 | 6-12 |
| | 6-13 | 6-15 | 6-25 | 6-29 |
| | 6-30 | 7-2 | 7-3 | 7-4 |
| *project and treatment selection* | 1-2 | 1-3 | 2-11 | 2-16 |
| | 6-1 | 6-9 | 6-16 | 6-17 |
| | 6-18 | 6-20 | 6-30 | 8-4 |
| | 9-2 | | | |
| *programming* | 2-11 | 3-12 | 3-13 | 6-17 |
| | 6-19 | 6-23 | 6-24 | 7-10 |
| | 7-11 | 7-12 | 8-3 | 9-3 |
| *proprietary systems* | 2-13 | 8-2 | 8-3 | |
| *protocols and standards* | 4-10 | 4-31 | | |
| *public domain systems* | 2-13 | 8-2 | 8-3 | |
| *public–private partnerships (PPP)* | 1-4 | 9-5 | | |
| *punchouts* | 4-6 | 4-42 | 5-17 | 6-10 |

## Q

| Index Terms | Links | | | |
|---|---|---|---|---|
| *quality assurance* | 3-10 | 3-11 | 4-23 | 4-26 |
| | 4-27 | | | |

| **Index Terms** | **Links** | | | |
|---|---|---|---|---|

## R

| Index Terms | Links | | | |
|---|---|---|---|---|

## T



## V



## W

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