Local Agency Pavement Management Application Guide

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Introduction

Purpose of the Guide

This guide should serve as a tool to assist local agencies in utilizing a pavement management system (PMS) to its fullest extent. It was developed to serve as a companion guide to the previously published *A Guide for Local Agency Pavement Managers,* which provides an excellent framework for implementing a PMS. This guide focuses on how to maximize the benefits of a PMS once it has been implemented.

Organization of the Guide

The guide is organized into 8 chapters, followed by a glossary of terms, a bibliography of "recommended additional sources of information," and appendices. Each chapter is followed by a list of references. The following chapters are included:

Chapter 1 — Overview of Pavement Management. Chapter 1 gives an overview of pavement management. It begins with a very brief review of the basic information provided in *A Guide for Local Agency Pavement Managers*. The pavement manager's role within a local agency is discussed, the potential users of pavement management information are identified, and the costs and benefits of a PMS are addressed.

Chapter 2 — Maintaining a Pavement Management System. Chapter 2 provides guidance on how to maintain a PMS once it has been implemented. It covers such topics as required resources, updating the PMS database, quality control issues, security of data, and continued training and education.

Chapter 3 — Customizing Pavement Management Software. Chapter 3 describes the different parameters that can be modified within a pavement management software program, such as repair alternatives, unit cost information, priority guidelines, and performance prediction models. Chapter 3 provides the theoretical background necessary to understand Chapter 4.

Chapter 4 — Analyzing Pavement Management Data. Chapter 4 describes the analysis of data using a PMS and how modifying the different parameters can alter the results.

Chapter 5 — Incorporating Preventive Maintenance into the Pavement Management Process. Chapter 5 discusses the use of preventive maintenance and its role in the pavement management process. It identifies commonly used preventive maintenance techniques and the use of a PMS to develop a preventive maintenance program.

Chapter 6 — Communicating the Recommendations of a Pavement Management System. Chapter 6 covers the different approaches an agency can use to effectively communicate with various users of pavement management information. It identifies the primary users of pavement management information, describes the type of information often requested by the users, and recommends presentation methods that work well for each of the different groups.

Chapter 7 — Overcoming Application Challenges. Chapter 7 addresses some of the issues that may stall continuing pavement management efforts within an agency. It discusses the institutional, technical, and funding challenges that often affect an agency and methods that can be used to successfully address these challenges.

Chapter 8 — Applying New Pavement Management Technology. Chapter 8 briefly reviews some new technologies which are beginning to impact the way agencies go about pavement management. It describes geographic information systems, the integration of a PMS with other management systems, new data collection equipment, new training techniques, and the use of expert systems within a PMS.

Throughout the guide, case studies are presented that describe how local agencies within Washington State are using pavement management. When reading these case studies, keep in mind that they are examples of how a given agency, with it unique personnel, budget, and operating constraints, has dealt with pavement management issues. Every agency is different, and will have to deal with problems and issues in its own way. However, it is hoped that these case studies will provide insight on ways to approach different situations.

Limitations of Guide

The guide does not duplicate the specific PMS aspects and details that can be found in other available materials. For example, information on rating pavements in the field can be found in the *Pavement Surface Condition Rating Manual* and is not repeated in this guide. In addition, since the purpose of this guide is to present general information on pavement management, specific pavement management software programs are not covered. Specific pavement management software programs may have some or all of the features described, and may have additional features not mentioned. To obtain more information on a specific pavement management software package, refer to the documentation provided with the software or contact the software vendor.

Terminology Used in This Guide

At times, the terminology that is used to describe pavement management-related activities may vary from agency to agency. The guide uses the following terms:

- Condition Index (CI) — the value that is assigned to describe the condition of the pavement based upon a visual survey. Different agencies and software programs may use other terms in place of CI, such as visual condition index (VCI), pavement condition index (PCI), pavement condition rating (PCR), and pavement surface condition (PSC).
- Roughness refers to the rideability of the pavement.
- Friction refers to the skid resistance of a pavement surface.
- Project refers to a section of roadway that has similar age, geometry, and construction type.
- Segment is a subdivision of a project. There may be one or more segments within a project, such as city blocks.

Please refer to the Glossary of Terms for further definitions.

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Chapter 1 Overview of Pavement Management

This chapter provides an overview of pavement management, from the perspective of the pavement manager. It begins with a very brief review of the basic information provided in the beginning chapters of *A Guide for Local Agency Pavement Managers* (1). It describes the pavement manager's role within a local agency, the potential beneficiaries of a pavement management system (PMS), and the costs and benefits of a PMS. Finally, the use of a PMS as a decision-making tool is discussed.

What Is Pavement Management?

Definition

A PMS is a tool that can be used to make informed decisions about the maintenance and rehabilitation of a pavement network. The American Public Works Association (APWA) defines a PMS as, "…a systematic method for routinely collecting, storing, and retrieving the kind of decision-making information needed to make use of limited maintenance (and construction) dollars." (2) The American Association of Highway Transportation Officials (AASHTO) states that the "…function of a PMS is to improve the efficiency of decision making, expand its scope, provide feedback on the consequences of decisions, facilitate the coordination of activities within the agency, and ensure the consistency of decisions made at different management levels within the same organization." (3)

It is important to remember that the PMS itself does not make the decisions. The decisions are made by the people using the information provided by the PMS. A PMS converts raw data into usable information. It is then up to the user to combine that information with experience and the consideration of outside factors before making final recommendations pertaining to the pavement network.

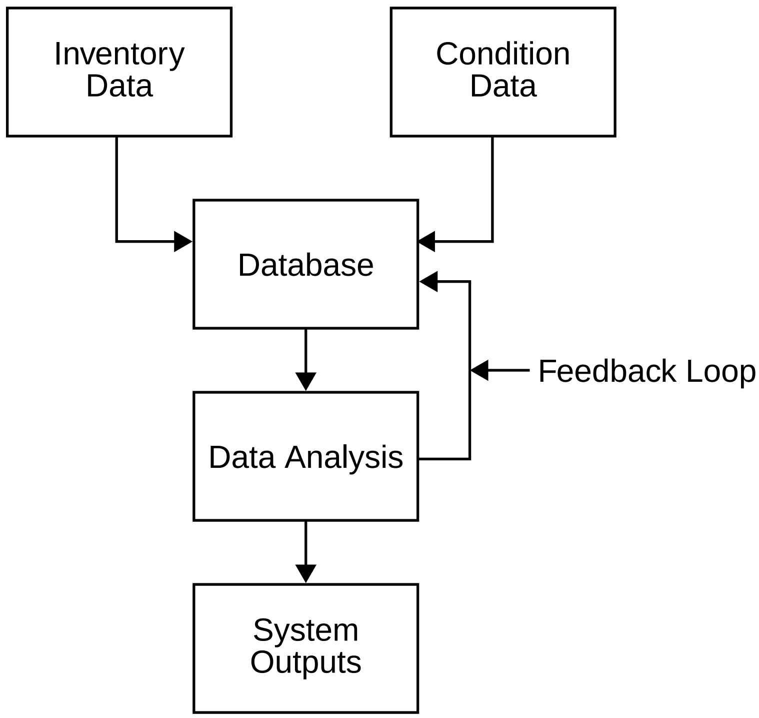
Levels of Pavement Management

Pavement management can occur at the network level and the project level. Network level management involves the evaluation of all pavements under an agency's jurisdiction. The primary objective of network level management is to develop an agency-wide prioritized pavement repair program that will yield the least total cost or greatest benefit under overall budget constraints. Network level management works on more approximate data than does project level management.

Project level management focuses on a particular location and usually comes after network level analysis in local agencies. Once a segment has been identified as a candidate for repair at the network level, an engineering analysis is then performed at the project level. This level of analysis requires a more detailed evaluation, since the information gathered at the network level does not normally include the type of data needed to make detailed design decisions for an individual project. Additional testing, such as coring and nondestructive testing, is often conducted during a project level analysis to provide additional knowledge about pavement condition and cause of deterioration.

Typical Components

A PMS can be broken down into six basic components, as shown in the following figure: inventory data, condition data, database, data analysis, system outputs, and feedback loop.



Inventory Data

Inventory data include information that pertains to the physical characteristics of the pavement being managed. It can include information such as road geometrics, location reference identifiers, functional classification, jurisdiction (or ownership), as-built materials and thickness, surface types, and maintenance histories.

Another type of inventory data is traffic information. Traffic directly impacts the rate of pavement deterioration. Therefore, when economically possible it is important to collect traffic data for use in the pavement management process. Both the volume of traffic and the type of traffic are needed. Keep in mind that trucks and other heavy weight vehicles do by far the most damage on a street, so it is more critical to gather data on these vehicles than to obtain detailed passenger car counts. Where traffic data are not available, functional classifications provide an indication of traffic levels.

Trucks and other heavyweight vehicles do by far the most damage on a street.

The exact type of inventory information required is dependent upon the agency requirements and the PMS software requirements. At a minimum, inventory data that define the pavement network in terms of physical dimensions, surface type, and age must be included in the pavement management database. Beyond that, two general guidelines should be used for determining the extent of information to include in the network inventory. First, the data should be fairly easy to obtain so that large amounts of time are not invested in the search for records. Second, the collected information should serve a purpose. If the information will not be useful in making some type of decision regarding the maintenance or rehabilitation of the network, it will most likely not be worth the effort to collect it. Of course, if the PMS software will not run without a specific data element, the agency will need to collect it.

Condition Data

Pavement condition data are used as the basis for every decision made with the PMS. If the condition data are not reliable, none of the recommendations of the system will be reliable. In Washington State, three types of condition assessment are performed by local agencies: visual rating, nondestructive testing (NDT), and destructive testing. The type of condition data needed to effectively manage a pavement network will depend upon the agency and the level of data analysis required.

Visual assessments of pavement condition can be conducted via walking surveys, windshield surveys, bicycle surveys, or using automated data collection equipment. It is extremely important to select a procedure for visually rating pavement condition that is objective and repeatable. The procedure must produce evaluations that are consistent from one year to the next and from one rater to the next. For local agencies in Washington State, the visual rating method is described in the *Pavement Surface Condition Rating Manual* (4).

A Case Study: Spokane County (5)

When Spokane County began collecting visual condition data in 1992, it had to decide how to collect the data. The county considered walking surveys, windshield surveys using a Blazer, and windshield surveys using a van. In addition, for the county had the option of using different vehicle speeds and different rater positions (front or back) within the vehicle. Before the county felt it could make an informed decision, it wanted to evaluate the reliability of the data collected using the different techniques on both asphalt concrete pavement (ACP) and bituminous surface treatment (BST) pavement surfaces.

To evaluate the different rating techniques, the county set up a test program. It established test sites on both ACP and BST roads. County staff then evaluated each test site using a walking survey, which served as the control data for the test. The test sites were then evaluated using the following approaches:

- *Van at 5 mph*
- *Van at 10 mph*
- *Blazer with rater in front at 5 mph*
- *Blazer with rater in back at 5 mph*
- *Blazer with rater in front at 10 mph*
- *Blazer with rater in back at 10 mph*

Spokane County used a spreadsheet to evaluate the rating of individual distress types (alligator cracking, longitudinal cracking, transverse cracking, and patching) as swell as the total deducts resulting from each survey method. Samples of the graphs developed using these data are shown in Appendix A Case, Study #8.

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Spokane County was surprised at the variability it saw among the different approaches. It decided that for its urban system, a walking survey would yield the quality of data it needed to make pavement repair decisions. For rural roads, Spokane County determined it could not afford to perform a walking survey and instead would use a windshield survey conducted with a Blazer at 5 mph with the rater seated in the passenger seat.

The purpose of this case study is not to recommend one inspection technique over another. Since each local agency will use different personnel, vehicles, and often rating procedures, Spokane County's results cannot be directly applied to another agency. However, this case study does illustrate how a local agency can set up its own test program to evaluate different survey methods.

Nondestructive testing includes pavement evaluation techniques that do not disturb the pavement. Roughness (or ride) evaluation, friction (or skid resistance) evaluation, and drainage evaluation are all examples of nondestructive testing methods. On the other hand, coring, boring, and test pits are all examples of destructive testing methods used to evaluate pavement condition. These methods damage a small portion of pavement in the testing process. They are described further in *A Guide for Local Agency Pavement Managers* (1).

In order to ensure consistent and reliable collection of structural testing information using a Road Rater, Spokane County developed a checklist for equipment operators. It covers the daily calibration of the equipment, field testing, and data reduction (see Appendix A, Case Study #7).

Road Rater

Database

Once the inventory and condition data have been collected, the information is stored in a database. The database allows the effective use of the collected information and provides input to the data analysis portion of the pavement management software. Data are only useful if accessed and used to make pavement management decisions; therefore, it is very important to provide easy data access and retrieval within the pavement management software.

Very large agencies, such as state highway agencies, often store pavement data on a mainframe computer and download the data to a personal computer for analysis. Smaller organizations, such as cities and counties, typically store data on a personal computer. Agencies with very small road and street networks may even use a simple paper filing system as a database.

Cities and counties typically store data on a personal computer.

Data Analysis

The database alone is of little use to pavement managers without a method to identify and prioritize needs, predict future condition, assess costs and benefits, and select effective management strategies based on existing data. A critical component of a PMS is the data analysis portion of the system. It is here that potential rehabilitation needs are evaluated and prioritized for planning and scheduling budget needs so that the agency makes the best use of the limited funds available to it for rehabilitation work.

Most pavement management software provides the following analytical capabilities: determination of current condition levels, prediction of future pavement condition, identification of feasible repair alternatives, selection of the optimal repair alternative, prioritization of projects, and development of multi-year repair programs and maintenance plans. In addition, pavement management software may contain analytical routines to assist the user in pavement design, construction, and maintenance. As with the data collection component, the level of sophistication required for data analysis should be tailored to meet the needs of the agency implementing the PMS.

System Outputs

Pavement management software can produce several types of output, including reports, graphics, and maps. Reports can be generated by a pavement management program in several ways. Some software provides “canned” reports. These are reports that provide preselected information that the user cannot modify in any way. A novice user may find this type of reporting capability sufficient. Other software provides reports that can be tailored to meet an agency's needs. Ad hoc reporting capabilities may also be provided, which permit the user to design and customize unique reports.

Pavement management software may also be linked to computer-aided drafting (CAD) systems or geographic information systems (GIS) for a more visual representation of the data contained in the database or the report outputs. This capability has greatly enhanced the usefulness of a PMS to managers who need to convey as much information as possible in a very short time period.

Feedback Loop

It is extremely important to continuously monitor, evaluate, and recalibrate a PMS using a feedback system. Feedback loops must be established within the pavement management process so that performance and repair cost data are constantly updated within the system; this process will improve the reliability of the PMS. In addition, the feedback process can be used to quantify the cost-effectiveness of various pavement repair techniques and to check the accuracy of design procedures. In most cases, feedback is a manual process.

Typical Implementation Steps

The basic steps that an agency undertakes during a PMS implementation are shown below.

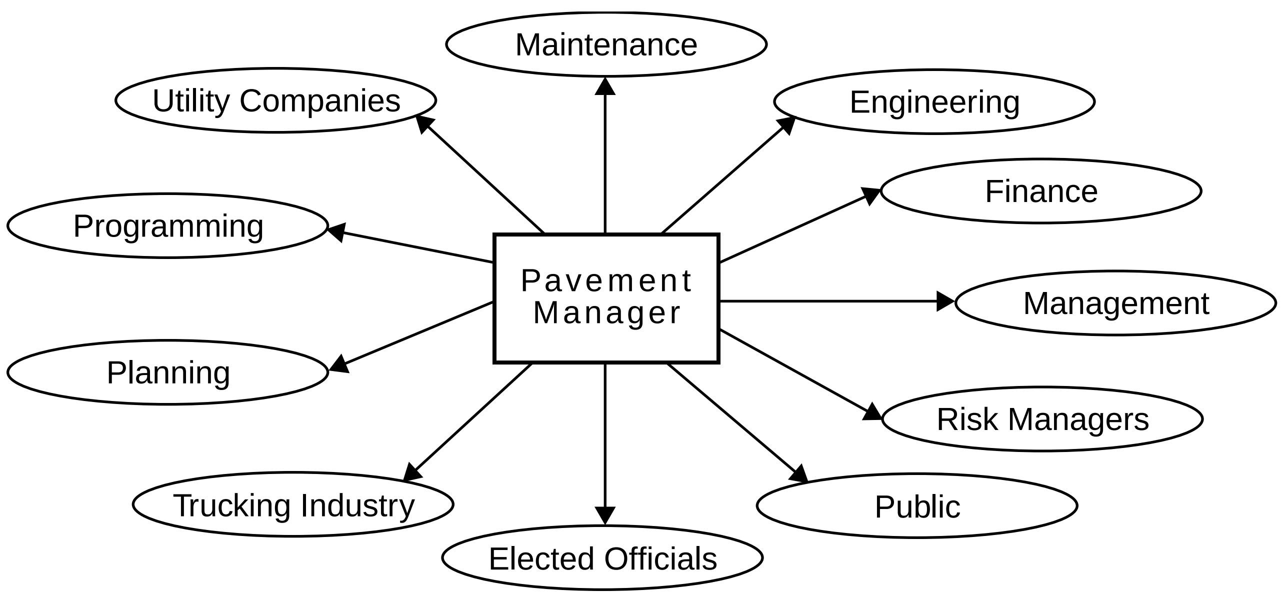
1. Decide to implement a PMS.
2. Determine what is needed in the PMS.
3. Present a work plan to upper management and elected officials.
4. Select pavement management software.
5. Define the pavement network.
6. Collect inventory data.
7. Collect monitoring data.
8. Establish a PMS database.
9. Analyze data.
10. Present data.
11. Train (ongoing throughout implementation and operation).
12. Maintain the PMS.

The first eight steps are described in detail in *A Guide for Local Agency Pavement Managers* (1), and the remaining steps are addressed later in this guide.

Pavement Manager's Role Within a Local Agency

The pavement manager serves a very important role within a local agency. This is the person that has the responsibility for collecting, managing, analyzing, and communicating information pertaining to the pavement network. Since the pavement network represents a very large capital investment and directly impacts the safety of the traveling public, the pavement manager has an extremely serious responsibility.

The PMS provides information used to identify and prioritize maintenance and rehabilitation projects, monitor the performance of those repairs and strategies, determine the impact of funding decisions on the future condition of the network, and estimate funding needs. Therefore, a pavement manager has many customers, both inside and outside the agency. He or she must provide pavement information to a wide variety of people, including maintenance divisions, engineering divisions, management, programming divisions, elected officials, and the public. In fact, it may be easiest to define the role of the pavement manager as the hub of pavement information within an agency, as illustrated in the following figure.



Ironically, although the role of the pavement manager is extremely important, the fiscal reality in most local agencies is that this is just one responsibility that person often has to fulfill. Typically only the largest cities and counties have pavement managers dedicated solely to that task. This situation makes the role of pavement manager a challenging, and sometimes frustrating, one.

Users of PMS Information and Recommendations

As mentioned previously, many different groups use the information contained within a PMS. The pavement manager should actively seek out the information each group needs to make their particular decisions. The pavement manager should consider the questions, “What is it the different users need to be able to better manage their resources? In what format do they need that information?” As the pavement manager consistently meets the users’ needs, he or she will become an indispensable source of information throughout the agency and will facilitate the effective and efficient use of agency roadway resources. The pavement manager will also have the tools available to keep the public informed and to positively affect public relations.

The type of data that each decision maker needs and the level of detail required varies. The decision makers can be grouped under these broad headings: elected officials, public, management, planning, finance, engineering, maintenance, trucking industry, utility companies, risk managers, and others. Chapter 6 of this guide, Communicating the Recommendations of a Pavement Management System, covers this topic in detail.

Elected Officials

Elected officials use the output of a PMS in a variety of ways. The most common use is for the justification of budget requests pertaining to the pavement network. The elected officials can use the information from the PMS to weigh requests for pavement dollars against competing requests for other uses of the funds. Typically, the elected officials want to know the effect of the requested budget on the future condition of the pavement network. Or, they may want to know what funding level is required to maintain the pavement network at its current condition level or at some other selected level. Elected officials can also use PMS output as a justification to their constituents for why a specific road/street was or was not repaired.

Frequently, the elected officials want the answers to “what if” type questions. “What is the effect of reducing funding?” “What is the effect of delaying work?” “What is the effect of lowering standards?” The challenge with providing information to elected officials is to keep it clear, concise, and visually powerful without relying too heavily on technical terms. Normally the elected official does not allot much time for an agency to make its case for pavement dollars.

The public can use PMS information in a broad variety of ways.

Public

The public is a very broad term that includes citizens groups, residential groups, bicyclists, pedestrians, and other specialty groups. These groups can use the information contained in a PMS in a broad variety of ways; following are just a few examples.

- Obtain information on why a given street or subdivision has not received the pavement repair that a given public group feels is needed.
- Determine whether other factors, such as the provision of bike lanes or sidewalks, are taken into account during the project prioritization process.
- Obtain justification on how tax dollars are being allocated and spent.
- Determine whether the roads are being maintained in a sufficient manner to protect residential property values.

A town meeting is a good place to convey PMS information.

Management, Planning, and Finance Divisions

Management, planning, and finance groups within a local agency use the PMS to identify potential projects, to prioritize pavement repair needs, and to prepare multi-year repair programs and budgets. These users need a combination of technical information and the answers to "what if" questions. They often are the groups that present the final recommendations and information to the elected officials.

Following are examples of the types of information management and planning groups often require from a PMS:

- Current status of the pavement network.
- Prioritized list of projects based upon well-understood prioritization criteria.
- Answers to "what if" questions, such as "What if maintenance or rehabilitation is deferred?" or "What will the future condition of the network be for expected funding levels?"
- Analysis of how much it costs to first implement, and then maintain, a PMS.

Engineering Division

The engineering staff access information from the PMS to help them evaluate the current condition of pavements, to analyze the cause and extent of pavement deterioration, and to identify the most cost-effective maintenance or rehabilitation action to take to improve pavement condition.

Engineering might also use PMS information at the project level. For example, Engineering could use the information in the pavement management database, such as pavement cross-section, traffic, and performance, to evaluate the performance of different pavement rehabilitation techniques and designs.

Maintenance Division

Maintenance staff use PMS information to identify areas requiring maintenance and to estimate the cost, labor effort, and materials required to perform the maintenance. The PMS data can also be used to pinpoint locations that have severe distresses but are not in the current project list, so that the Maintenance Division can develop a plan for maintaining these areas until a rehabilitation project can be scheduled. In addition, the maintenance staff can use a PMS to evaluate the effectiveness of different maintenance techniques and materials.

Pavement Manager

The pavement manager uses PMS information in a myriad of ways. PMS output can be used to verify database accuracy, determine the sensitivity of PMS analysis routines to different variables, and provide input for the feedback loop established within the PMS.

The pavement manager use PMS information in many ways.

Trucking Industry

Trucking companies represent another group that are directly affected by roads and pavement management. The livelihood of truckers depends on the economic and efficient use of vehicles, which is directly dependent on the condition of the roadway system. In addition, a PMS can be used to assess the damage caused by trucks on haul roads. This information can then be used to collect for extraordinary damages, via haul road permits, caused by trucks using roads that were not designed or constructed to accommodate heavy hauling. Some local agencies use structural testing information (collected as part of their pavement management efforts) to establish truck load limits during spring thaw periods. A trucking company can use an agency proposed list of projects to discuss their near-term haul road needs with the agency to minimize damage to newly rehabilitated pavements and reduce their pavement repair costs.

Trucking companies represent another group that are affected by roads and pavement management.

Utility Companies

Utility companies represent another group that often uses pavement management information. In many local agencies, after a multi-year program for pavement repair has been developed it is distributed to the utility companies. This allows the utility companies to schedule planned utility work prior to pavement overlays when possible. If a utility company can perform its work prior to an overlay, its cost for trench restoration is reduced. This coordination effort also yields an added benefit to the local agency of reducing the number of times a utility company cuts into a newly repaired street. By working together, utility companies and road/street departments can reduce interference with traffic flow and provide a better pavement surface.

Risk managers are also interested in Pavement Management information.

Risk Managers

Risk managers, risk pools, and agency insurance companies are also interested in the information a PMS can provide. These groups want to know the history of the road during certain litigation situations. For example, if a citizen claims he or she has been injured by the presence of a pothole in a road, the pavement management database may provide the type of information necessary to show that responsible repairs of the pavement were being conducted by the agency prior to the accident or to ascertain the condition of the pavement at the time of the accident.

A Case Study: Thurston County (6)

A driver ran off a road in Thurston county and claimed that the reason he did so was due to a very large pothole near the shoulder of the road. Thurston county reviewed videotapes it had collected as part of its pavement management program. These videotapes were taken just prior to the accident and clearly showed that the pavement and shoulder in the location of the accident was in excellent condition. The claim was denied and no lawsuit was filed.

Others

There are other users of PMS information not mentioned yet. Transit systems, port authorities, and urban planning organizations are just a few examples of groups that often use PMS output for planning and programming purposes.

A Case Study: Spokane County (5)

The Spokane County pavement management group has found that it has many customers, each requiring different information, as detailed in the following table. A copy of the "State of Pavement" Report can be found in Appendix A, Case Study #6.

Pavement Management Customer	***Product Provided by Pavement Management Group***
Programming	*Project lists for maintenance and rehabilitation candidates, along with project estimates.*
County Engineer and Public Works Director	*State of Pavement Report; Needs Report*
Design	*Surface condition data; design input (overlay thicknesses); project estimates.*
Maintenance	*Project lists for maintenance and programming input.*
Trucking Industry	*Load restriction testing results and recommendations for seasonal load restrictions.*
Land Development Support Service Department	*Input on road design requirements for new developments.*

Costs and Benefits of a PMS

Each individual agency must conduct its own comparison of the costs and benefits associated with a PMS implementation. It is tempting to just say, "Of course the benefits of a PMS outweigh the costs." However, at a minimum an agency should identify qualitatively the costs and benefits of implementing and maintaining its PMS. This information will be invaluable if the agency is ever faced with a cutback of funds for the maintenance of its PMS, and needs ready justification for the pavement management program's continued full financial support.

Benefits

The literature on pavement management and interviews with agencies using pavement management yielded the following general list of benefits obtained from using a PMS:

- Facilitates decision-making; increases chance of making optimal decision.
- Provides timely and accurate information for use in needs assessment.
- Provides a means to monitor pavement network condition and provides a quantifiable assessment of network condition.
- Provides a means for evaluating various rehabilitation strategies and option trade-offs.
- Improves the prioritization of pavement repair work, which in turn reduces excessive rehabilitation costs caused by delayed action.
- Provides a way to analyze the consequences of various funding levels.
- Provides a sound basis for allocating resources.
- Provides objective information to balance political (subjective) input.
- Improves the effectiveness of dollars spent on the pavement network.
- Provides a savings in user costs.
- Enhances an agency's credibility with elected officials, top management, and the public.
- Provides valuable feedback on pavement design, maintenance, rehabilitation, materials, and construction; in the long term, this improves engineering and results in better pavements.
- Improves communications.
- Allows an agency to answer "what-if" type questions regarding pavement repair programs and funding levels.

Notice that these benefits, while very real and recognized throughout the country as being valid, are difficult to quantify.

Costs

The cost of a PMS directly relates to the implementation and upkeep of the PMS itself, including the software and data collection costs, and the actual expenditures made on the pavement network. These costs may be broken out as follows:

- Data collection (initial and future updates).
- Software acquisition (initial and future upgrades).
- Hardware acquisition (initial and future upgrades).
- Consultant services.
- In-house staff time (data processing, data analysis, system maintenance, and training).
- Actual expenditures on the pavement for maintenance and rehabilitation.

Overhead and other indirect costs, such as work done by agency staff, need to be included for an accurate evaluation of cost. Very few agencies have kept historical records of pavement management costs, particularly those stemming from the use of internal staff, so the agency will need to make its best estimate.

A Case Study: Clark County (7)

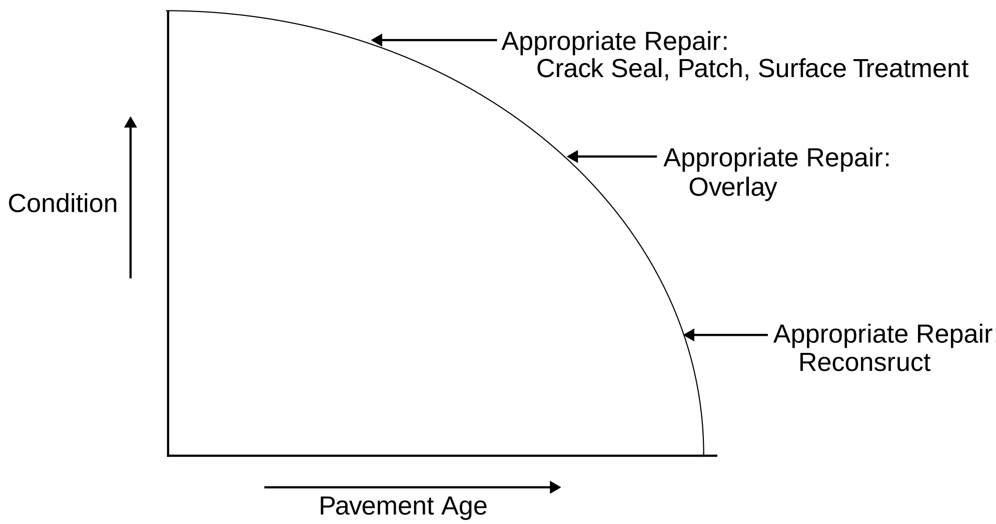
Clark County has been tracking the cost of conducting pavement management activities since 1993 (the year it began implementing a computerized PMS), as shown in the following table. It is interesting to compare these costs, which average approximately $100,000 annually, to the money Clark County expends each year on road repairs and rehabilitation. Clark County expended $4.9 million 1993, $4.5 million in 1994, and $6.16 million in 1995 on its pavement maintenance and rehabilitation program. In future years, once its PMS is fully implemented, Clark County anticipates that it will spend approximately 2 percent of its entire road repair and rehabilitation budget on pavement management activities.

Year	***Expense Item***	***Cost***
1993	*Total Salaries and Wages*	*$41,265*
	Employee Benefits	*$11,075*
	Supplies	*$109*
	Temporary Staff	*$86*
	Consultants and Pavement Management Software	*$2,039*
	Postage, Telephone, and Freight	*$9*
	Machinery and Equipment	*$8,307*
	TOTAL	***$62,890***
1994	*Total Salaries and Wages*	*$66,287*
	Employee Benefits	*$18,785*
	Supplies	*$242*
	Temporary Staff	*N/A*
	Consultants and Pavement Management Software	*$21,264*
	Postage, Telephone, and Freight	*$110*
	Machinery and Equipment	*$2,970*
	TOTAL	***$109,658***
1995	*Total Salaries and Wages*	*$74,213*
	Employee Benefits	*$20,776*
	Supplies	*N/A*
	Temporary Staff	*N/A*
	Consultants and Pavement Management Software	*$12,409*
	Postage, Telephone, and Freight	*$68*
	Machinery and Equipment	*$5,819*
	TOTAL	***$114,389***

The purpose of the case study just presented is to point out the types of expenses that are incurred during the implementation and upkeep of a PMS. Each agency must do its own cost analysis, because the cost of a PMS varies significantly depending upon many variables, such as the number of miles in the system, the type of software implemented, the type of data collected to store in the system, and so on.

Cost-Benefit Analysis

While it may be difficult to quantify all the costs and benefits of a PMS, an agency can perform a quick analysis to illustrate the cost-effectiveness of using a PMS. The following type of graph proves very useful in this calculation. It shows the different repair alternatives that an agency determines are feasible for different pavement condition levels.



In the case study just presented, a local agency spends roughly $100,000 per year to evaluate pavement condition and operate its PMS. That same agency spends approximately $70,400 per 24 feet wide mile to place a 3-inch overlay versus $1,000,000 to reconstruct that same mile of pavement. Obviously, if the PMS can be used to identify the optimal time to repair just a few miles of road the benefits of such a system will outweigh the costs.

A Case Study: Alberta, Canada (8)

One quantitative assessment of the benefits and costs associated with a PMS was conducted by Falls (8). Using data from a pavement management implementation in Alberta, Canada. This PMS was initiated in 1980, so it provided an extensive database from which to work. In addition, it contained well-documented information on pavement condition, the costs of the PMS development and operation, and the money spent each year on pavement maintenance and rehabilitation. User costs were calculated for an increase in average network condition over a 10-year period during which the budget remained constant. The benefits-cost ratio was calculated to be in the order of 100:1.

Summary

A PMS is a very powerful tool for storing, organizing, manipulating, and analyzing data. It takes raw data and puts it into a form that the pavement manager and other users can quickly use to help make pavement-related repair and funding decisions. A PMS provides consistent, accurate, and objective information to the decision maker.

While the PMS is an excellent resource for the decision maker, it does not remove sound technical judgment. There are many considerations that go into making pavement-related decisions that cannot be included in a PMS but are necessary for final decisions. Therefore, a PMS should be thought of as a tool to supplement the existing decision making process. The reader should refer to *A Guide for Local Agency Pavement Managers* (1) for an excellent discussion of what a PMS can and cannot do.

Chapter 1 References

1. *A Guide for Local Agency Pavement Managers*, Washington State Department of Transportation, TransAid Service Center, written by The Pavement Management System Guidebook Review Team and published by The Northwest Technology Transfer Center, December 1994.
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5. Spokane County Information provided by Chad Coles and Howard Hamby.
6. Thurston County information provided by Dave Whitcher.
7. Clark County Information provided by Bud Cave, Dave Shepard, and Elizabeth Gotelli, Clark County Department of Public Works.
8. Falls, L. C., S. Khalid, and R. Haas, "A Cost-Benefit Analysis of Network Level Pavement Management," Proc., Transportation Association of Canada Annual Conference, Quebec, Sept. 1992.

2:P:DP/PMAG

There is a temptation after the implementation of a PMS is completed to sit back comfortably, secure in the knowledge that the hard work is over. Realistically, however, pavement management is not a one time event. It is a continuous process that includes updating the database and obtaining training. This chapter covers what an agency should be doing to keep its PMS current and useful, and how to address security issues and quality control processes.

Ongoing Nature of Pavement Management

Pavement management is a dynamic process. It is essential that data are complete, accurate, and current. Reports generated using outdated data can be dangerously misleading, since the data are no longer representative of actual pavement conditions within the network. For the PMS to provide useful output, the database must be routinely reviewed and updated. It is important to recognize the ongoing nature of pavement management and to plan for it during implementation. Otherwise, sufficient support may not be available when needed to repeat the data collection and analysis activities on a periodic basis in the future.

Pavement management is a dynamic process.

In addition to keeping the pavement management database current, it is just as critical to make sure that pavement management remains an integral part of how the agency makes pavement-related decisions. As Smith and Hall stated, "A PMS should be considered implemented only when the recommendations of the software are routinely used to assist in selecting pavements to repair, allocating funds among competing pavement requirements, determining overall network needs, and justifying funding needs to governing authorities and the public." (1) If pavement management is to be effective, it must become a part of the routine management process and affect the pavement-related decisions being made within an agency.

Responsibility For a PMS Within an Agency

As discussed in Chapter 1, the pavement manager plays an extremely important role within a local agency. Time and other resources available to pavement managers vary from agency to agency. The largest cities and counties may have a dedicated pavement manager, often with a staff to help with the pavement management activities. The reality for most local agencies, however, is that the pavement manager often does not have permanent staff to assist with pavement management work. Furthermore, the pavement manager usually has many more responsibilities within the agency than just pavement management.

To supplement the work effort of the pavement manager, many local agencies use summer interns and/or part-time staff. While this structure may not be ideal for providing good continuity of work effort and quality control, it may be necessary and does happen frequently. Agencies that are structured in this way need to guard against two situations that can jeopardize the entire pavement management process:

1. *Reliance on a Single Person Responsible for Pavement Management Within an Agency*. Many small and medium size local agencies assign one person within the organization, the pavement manager, with the responsibility of running the pavement management program. The pavement manager is the person who knows the pavement management software, who understands the data collection and entry process, and who is familiar with analyzing the data and preparing reports using the program. If the pavement manager leaves that position, especially if little advance warning has been given, all that knowledge and experience can be lost and the learning process has to start over again with the new pavement manager. This can have a devastating impact on an agency's pavement management program, and has caused some agencies to completely abandon their pavement management efforts or to start the implementation process over again.

   There are some steps an agency can take to avoid this potentially devastating situation. If at all possible, it is recommended that a minimum pavement management staff of two be used. This provides protection when staff changes occur and increased safety during data collection. Cross-training is another good solution to this potential problem. However, this will take extra effort. As previously pointed out, local agency staff members already have numerous responsibilities. The concept of cross-training may be formally adopted within an agency, but unless a dedicated effort is made to make sure it happens — it won't.

> *Case Studies: Clark County and Skagit County (2)*
>
> *Two local agencies, Clark County and Skagit County, have recently begun taking their own precautions to minimize the effect of staff turnover. They are preparing documents that outline the activities that the pavement manager undertakes within their agencies. While these documents will take a significant effort to complete, they will be invaluable to the agencies. In addition to protecting an agency if a sudden change in pavement manager occurs, the documents will provide an excellent training tool for new pavement management staff.*

2. *Loss of Data Integrity*. To deal with limited labor availability and tight finances, many local agencies use summer interns and part-time staff in the pavement management process. The pavement management group may also borrow inexperienced staff from other divisions within the agency during the busy data collection and data entry periods of pavement management. While this approach has proven successful in many cases and is used widely, the agency must be very careful to make sure that the integrity of the data is maintained. Lack of accuracy and consistency in the data collection efforts from year to year will jeopardize the reliability of the PMS.

   A good training program and an enforced quality control program should both be part of the pavement management process, whether or not non-pavement management dedicated staff assist in the work. However, these programs are particularly vital when using staff members that are not working with the pavement management program on a continuing basis.

A Case Study: City of Renton (3)

The city of Renton implemented a PMS to manage its streets and collects visual distress data for input into the system. The city uses summer interns to collect the visual distress data, and over time has developed a training and quality control program that has proven highly effective in producing consistent, good quality distress data from year to year.

The city of Renton finished the inventory portion of the database in 1987. In 1988 and 1989, the city conducted windshield visual distress surveys to evaluate the condition of its roadway network. Unfortunately, the city was not satisfied with the quality of the information collected. This led the city to investigate the use of automated videotape equipment to collect visual distress data in 1991. The results of this effort were mixed, and the city decided that it needed to conduct walking surveys to obtain the quality of data it needed to run its PMS.

Walking surveys conducted in 1993 and 1995 used summer interns. The city of Renton wanted to make sure that the quality of data collected each year was consistent and accurate. One step it took to improve the data collection efforts was to use only college engineering students as interns. It was felt that these students would have a greater interest in the type of information being collected, and therefore would care more about the quality of the information they were collecting. The city of Renton also recognized that the collection of visual distress data can become a mundane and boring activity, so it made every effort to rotate the work that the interns were doing. One final step the city took to ensure that quality data were being collected was to institute a training and quality control program.

The training program is conducted by the same engineering consulting firm every year. This maintains consistency in the instructions and guidelines presented to each year's interns. The consulting firm presents a training course that consists of one day of classroom instruction and two days of field instruction. During the field instruction the interns rate street segments independently and the instructor works with them until he is satisfied that they are rating the streets correctly and consistently with one another. The interns then begin to rate the street system on their own. Approximately two weeks later, the instructor returns to evaluate the streets that the interns have rated in the interim and works with them to correct any problems with their inspections.

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Since it takes approximately 10 weeks for the interns to rate 160 miles of road, the city of Renton felt it was important that the interns calibrate their inspections throughout this time period. A test section is established at the beginning of the inspection cycle, and every two weeks the interns reinspect this portion of road and the city street maintenance service lead evaluates their inspection results. About midway through the inspection cycle, the test section is moved to another site.

Required Resources

There must be a commitment to continue to support the PMS in future years before an agency undertakes a PMS implementation. Resources include internal staffing to manage the PMS, funding for periodic data collection and data entry (performed internally or through a consultant), and funding to support the pavement repair programs developed through the use of the PMS. In addition, other resources for items such as equipment and training will be required on a periodic basis.

Staffing

Staffing levels must be sufficient to maintain the PMS after its implementation. The database must be kept current, and this involves both data collection and data entry time. Periodically, the pavement management software will be used to perform analyses and generate reports, and this takes time also. If staffing levels are insufficient to support the program using in-house personnel, the agency should consider supplementing its effort with the outside assistance of a consultant.

Allocation of Time

Agency hours for PMS compete with other staff activities, such as design, maintenance, and construction. Data collection must be conducted during dry conditions, which is also peak maintenance and construction season. These potential conflicts need to be addressed early on in the pavement management process.

Funding

There are two types of funding requirements related to a PMS. The first type of funding is obvious. Money is needed to actually fund PMS operations. This includes staff salaries, any outside consultant fees, and software upgrade and support fees. Since pavement management is an ongoing process, this type of funding needs to be built right into the agency's annual budget.

The second type of funding pertains to funding the pavement maintenance and rehabilitation recommendations developed with the PMS. A basic function of a PMS is to assist the agency in determining the most cost-effective time to fix a pavement, and the best method to use to perform that fix. An agency that finds itself in a situation where it has many pavements in very poor condition and is under severe funding constraints may not be able to take advantage of all the PMS' recommendations. Many PMS programs have the ability to support backlog analysis (discussed further in the following chapters of this guide), which can assist with this problem. However, a PMS can only be used to analyze what will happen under these conditions. The use of a PMS cannot improve overall network condition if the funding levels are significantly inadequate.

Other Resources

A variety of other resources are required to support a PMS. For example, except for small agencies using a manual PMS, computer equipment is required for a PMS. Intermittently, the computer equipment will need to be upgraded to continue to support improvements in the pavement management software. Also, resources for training will be required on a periodic basis. Finally, the commitment of the agency at all levels, particularly upper management, to maintain the PMS is a required resource. This may not appear to be a resource in the traditional sense, but it is absolutely necessary if the PMS is to be successful over the long run.

Obtaining Required Resources

Obtaining resources for PMS will be an ongoing effort every year. However, the groundwork should be laid prior to implementing a PMS. A work plan should be developed, preferably by a pavement management steering committee as described in *A Guide for Local Agency Pavement Managers* (4), which states the goals and objectives of the PMS. This work plan should also identify key milestones in the implementation process and resource requirements. When it is completed, this workplan should be presented to the city council or board of county commissioners. It will serve as a means to formalize the elected officials' commitment to pavement management.

An outline for such a work plan follows.

Pavement Management System Workplan

I. PMS Goals and Objectives

II. Identification of PMS Users Within the Agency and Their Requirements

  A. Elected Officials
    i. Current Status of Network
    ii. Future Needs of Network
    iii. Project Prioritization Recommendations
    iv. Budget Options and Their Impact on Network

  B. Management
    i. Current Status of Network
    ii. Future Needs of Network
    iii. Project Prioritization Recommendations
    iv. Budget Options and Their Impact on Network

  C. Engineering
    i. Design Input
    ii. Performance Data
    iii. Performance Prediction Models

  D. Maintenance
    i. Repair Quantities
    ii. Repair Locations
    iii. Repair Cost and Labor Requirements
    iv. Performance of Different Maintenance Techniques

  E. Programming/Planning
    i. Budget Information

  F. Public
    i. Project List
    ii. Project Justification

  G. Other
    i. Utility Companies
    ii. Trucking Industry

III. Implementation Steps
   A. Pre-Implementation
      i. Decision to Implement a PMS
      ii. Formation of Agency PMS Steering Committee
      iii. Gaining Commitments for Funding the PMS
      iv. Selection of Pavement Management Software
   B. Trial Implementation and PMS Modification
   C. Full-Scale Implementation
      i. Inventory Data Collection
      ii. Mapping
      iii. Condition Data Collection
      iv. Database Establishment
      v. Pavement Management Software Calibration
      vi. Data Analysis
      vii. Presentation of PMS Recommendations
      viii. Training
   D. PMS Update
IV. Resource Requirements
   A. Funding
   B. Staffing
   C. Other
V. Implementation Schedule and Important Milestones
VI. Summary

PMS Database Update

Any type of analysis performed with the pavement management software, whether it is preparing a 6-year repair program or determining the impact of a 10 percent budget cut, uses the data contained in the database. If the data are not kept current, the data analysis results will not be reliable. Two basic types of information need to be kept up-to-date, as described in Chapter 1 of this guide: inventory data and condition data.

If the pavement management software is stored on a single computer or is on a Local Area Network (LAN), the problem of multiple databases should not occur. However, in some agencies the software may be loaded on multiple computers that are not networked together. In this case, the agency must develop a procedure for updating the pavement management software on all computer. It is also critical to ensure that the data stored on each computer is current and the same.

Inventory Data

Unless a new pavement is constructed, an existing road is rehabilitated, or maintenance is performed, basic inventory information, with the exception of traffic data, does not normally change over time. Since pavement management software is often used sporadically during the year, an agency should put in place a method to make sure that as construction and rehabilitation activities are completed on the pavement network, this information gets input into the database. This means that the pavement manager must work closely with the maintenance and engineering staff within the agency to obtain this information.

When a project is completed, the pavement manager should run through the following checklist:

1. Update basic inventory data.

   If it is a new road, the basic inventory information for it needs to be input into the PMS database from scratch.

When a road has been resurfaced, this information needs to be added to the PMS database.

   If it is a rehabilitation project, the date of last construction and surface type need to be updated in the database. If pavement geometrics were changed as a result of the rehabilitation, these need to be modified in the database. Rehabilitation may define new segment boundaries, so this needs to be reviewed and updated within the database if necessary. Also, if the pavement management software does not automatically reset the condition level when the last construction date is changed, make sure to update the condition of the segment. Finally, the road's functional classification may have changed and should be checked.

Note: In some cases, an agency has a separate database (or even multiple databases) where its inventory information is stored. If this occurs, there needs to be a mechanism established to transfer information from wherever the inventory data resides into the PMS database. Otherwise, there is the potential problem of performing analysis on an outdated database.

2. Update construction history data.

   It is very important to store information in the pavement management database about the actual work that was done. The type of repair performed (for example, asphalt overlay), the thickness of the repair, and the cost of the project are all items that will prove to be extremely useful if stored in the database. This information can be used to separate pavements into like performers for performance modeling and to provide feedback as to typical unit costs.

> *A Case Study: Skagit County (5)*
>
> *At times, it can be difficult to obtain information from different departments within an agency when construction projects are completed. Skagit County found this to be a problem, and developed two forms which the Design/Construction and the Development Review Divisions have to fill out and submit to the Pavement Management Division whenever a pavement construction project is completed. Copies of the forms can be found in Appendix A, Case Study #5.*

   If any pavement testing was performed during the project, such as coring, the results of these tests should be stored in the database if possible.

3. Update maps.

   If an agency has maps associated with its PMS, these need to be updated to reflect any new roads or segment changes.

4. Update maintenance history data.

   When maintenance projects, such as crack sealing, are performed or are identified during visual inspections, this information can be entered into the PMS database. The type of work, quantity of work, cost of work, and date performed are all useful information. Many local agencies use separate maintenance management systems to store this type of information; however, it is recommended that this information be ported into the pavement management database if possible.

5. Update traffic data.

The pavement management database may contain traffic data. Traffic directly impacts the rate of pavement deterioration, and is critical in high growth areas and high truck areas. Within a PMS, traffic data can be used to predict future pavement condition and to identify feasible repair options.

Unfortunately, many agencies have no traffic information or only have access to vehicle counts that have not been separated out by traffic categories. In this case, a road's functional classification may be the best information available; however, roads within the same functional classification, such as collector arterials, can have substantially different amounts of truck traffic.

If an agency stores traffic data within its PMS database, this information will need to be updated. How often new traffic counts are conducted will depend upon financial constraints and the anticipated rate of change in traffic levels. After new traffic counts are taken, or if the functional classification of a road changes, the database must be updated to reflect this new information. In addition, if a performance model was assigned to that road, it should be checked and changed if appropriate.

Condition Data

Condition data may include results from a variety of evaluation methods, including visual inspection, nondestructive testing, friction (or skid resistance) testing, roughness (or ride) testing, and destructive testing. What condition information an agency decides to collect and how frequently an agency decides to reevaluate the condition of its roadway network will depend upon several factors, including funding availability, staffing levels, and a determination of how rapidly the condition of the network is anticipated to change over time.

For counties, WAC 136-320 (6) requires that all arterials shall be surveyed for visual pavement distress at least every two years. Based upon interviews with counties throughout Washington, it is common for these agencies to inspect arterials every other year and other roads (such as local access and residential) every three years. It is not uncommon for an agency to inspect annually when it is just starting the pavement management process, so that it can rapidly establish a historical database of condition. Once three inspection cycles have been completed, the frequency of inspections is often decreased. Most cities interviewed stated that a two year inspection cycle was desirable.

Quality Control

Quality control throughout the data collection and data entry process is extremely important. The output from the pavement management software will only be as good as the data within the database. Quality control must be an integral part of the pavement management process.

Quality Control During Data Collection

The appropriate quality control method to use during data collection depends upon the type of information being collected. The *Pavement Surface Condition Rating Manual* (7) provides guidance on quality control during a visual inspection. For specific information on nondestructive testing equipment operation and calibration, refer to the equipment manual.

A Case Study: Spokane County (8)

Spokane County's visual data collection quality control efforts are ongoing throughout the inspection season. Two teams are used to rate the pavements, and each team consists of one experienced full-time employee and one summer help. When the summer help arrives, they begin their training by reading the Pavement Surface Condition Rating Manual (7) and watching the Pavement Surface Condition Rating Videotape (9). They also read literature on pavement management and material properties to increase their understanding of the overall process.

After the summer help has completed this preliminary training, the two teams meet and discuss their interpretation of the rating manual. After both teams are comfortable with the procedure, field training begins. Each member of the team rates selected segments independently. They then walk the same segments and discuss the extent and severity of the defects as they proceed. The rating that the four team members perform together serve as the control ratings for those segments. The objective of this process is to get each team member rating distresses consistently with the other team members.

The data collected by each team independently, and the data collected by all four raters working in conjunction with one another, are then brought into the office and put into a spreadsheet. This permits comparison of one rater to another and to the control rating. This calibration process continues until each rater is within 5 deduct points of each other and the control. At this point, the teams go into the field to start the actual inspections.

After that, each week the supervisor randomly selects a test segment from each crew and rates it. The supervisor's rating is then compared to the crew's rating. If they do not meet calibration specifications (plus or minus 5 deduct points), the crew is suspended from rating and returns to the calibration process until they once again meet the calibration criteria.

Quality Control During Data Entry

During data entry, it is easy for mistakes to be made. If possible, it would be great to check every piece of data entered into the PMS database. However, that is often not practical or affordable. A straightforward and affordable way to monitor the quality of the data being entered is to check 10 percent of the entered data. This is done by printing out, in hard copy form, a sample of the entered data and then comparing it to the original data entry forms. It is recommended that a person other than the one entering the data performs the quality check. If a substantial number of problems are noted, additional checks of the data should be made.

It is important to conduct a well-planned quality control program to ensure accurate information is being collected.

Security of Data

The quality of the PMS database can be compromised in two ways: computer hardware failure and human actions (accidental or malicious). It takes time and money to implement and maintain a PMS. It is important to protect that investment by controlling who has access to the pavement management software and by frequently backing up the database.

Controlling Access to the Pavement Management Software

Pavement management software is used by different people within an agency in different ways. Some personnel need access to the software to actually enter, modify, and delete information contained in the database. Others need access to the data analysis and reporting portions of the software, but have no need or reason to be modifying the database itself in any way. There should be a clear understanding within the agency of who has control and responsibility for the database.

The ability to change the database in any way should be carefully restricted to those personnel who have the training and the authorization to enter, modify, or delete data. Remember — pavement management relies on the quality of the data and the database must be protected. Most pavement management programs allow the use of passwords to prevent anyone from modifying the database unless they have entered the right password first. Other users can be allowed access at what is called a “read-only” level. This means the user can look at the data, analyze the data, and generate reports and other output from the data; however, the user cannot modify the database. A different password is assigned to these users.

In some local agencies, the data contained within the pavement management database may be confidential. Each agency should review and follow its policy with respect to this matter.

Backups

Even with the level of access controlled by passwords or other security devices, data can still be destroyed by other means. For example, the hard drive on the computer could crash, the building that houses the computer could burn down, or a computer virus could infect the database. This is where "backup" procedures are required.

Making a backup is simply making a copy of the data so that if the database being used is damaged or lost, the copy can be retrieved and used to replace the damaged database. There are many ways to make backup copies of databases. Most database managers and disk operating systems have backup tools. There are also software packages for making backups that many people find much easier to use. External or internal tape backup systems can also be put on your computer to facilitate the process. If the PMS software and data are on a Local Area Network (LAN), make sure that the LAN is backed up routinely and that the PMS software and data are included in the routine period backup. In periods of heavy use, it may be prudent to backup the data independent of the routine network backup.

How often to backup a database is a function of the importance of the data and the extent of changes being made to the data since the last backup. At certain times of the year, such as when pavement condition data are being collected and entered into the database, a new backup copy might be necessary as often as once a day. At other times of the year, even if changes are not being made to the database, it is wise to make backups at least monthly (weekly would be better).

It is usually recommended to keep the last two or three months worth of backups, in case a virus or some other data problem occurs in the database without the pavement manager's immediate knowledge. Remember to store the backups in a different building than the pavement management software is installed in, to prevent the backups being destroyed along with the computer in case of fire or flood.

Training and Education

Training and education are critical to the pavement management process. There are two types of training that occur during the pavement management process. The first is the initial training an agency obtains during the actual implementation process. The second is the periodic, follow-up training that the staff receives as the agency continues to maintain and use the PMS during the years that follow the initial implementation.

Ongoing training is a key component to ensure successful implementation of a PMS.

Initial Training and Education

Training should not just occur for the people who physically use the pavement management software. It should also encompass those who use the outputs and recommendations of the program. In this situation, the training takes on a more educational perspective. A discussion of the different types of training appropriate for the different users of the PMS follows.

Pavement Manager and Staff

The pavement manager and pavement management staff need training in all aspects of the pavement management process. Initially, this type of training should cover topics such as network definition, data collection, data entry, data analysis, data interpretation, and the generation of output with the pavement management software (reports, graphs, maps, and so on). Over time, training can be expanded to include such items as the selection of appropriate maintenance and repair techniques, different methods of prioritizing pavement repair programs, and so on.

Training should combine classroom-type lectures with plenty of hands-on instruction. Classroom lectures are most appropriate for training personnel in the basics of pavement management principles and data presentation. These lectures should include as many relevant case-study examples of the topics being taught as possible. Hands-on training, using workshops, is most effective for teaching staff to use the software itself and to generate output.

Data analysis and data interpretation are taught through a combination of lectures and hands-on examples. Training in the collection of data is best performed using a combination of lectures and field work. Sample outlines for pavement management training courses are presented later in this chapter.

For cities and counties, this training can be acquired through WSDOT TransAid Service Center; for counties, training is available from the County Road Administration Board (CRAB). Other sources of training include the WSDOT Northwest Technology Transfer (T^2) Center, University of Washington TRANSPEED, Northwest Pavement Management Association, industry associations, and city and county associations. Some agencies may also wish to obtain training from pavement management consultants.

Programming, Engineering/Design, and Maintenance

Other users of PMS information within the agency, such as the programming department, engineering/design department, and the maintenance department, also need training. These groups need to understand basic pavement management concepts and be able to interpret the output of the PMS. If they will need to actually generate reports or perform other activities with the software itself, then they also require training in those activities.

This type of training should cover topics such as the basic concepts of pavement management, the type of data stored in the PMS database, the use of pavement management data, and the interpretation of pavement management software outputs (reports, graphs, and maps). The programming department needs instruction on how pavement maintenance and rehabilitation budgets are developed using the program. The engineering department needs training on how the data are collected, the level of accuracy of the stored data, data available for design performance evaluation, and the type of analysis that could be performed using the pavement management software. The maintenance department needs training on how visual distress data are collected and how maintenance quantities, costs, and labor estimates are calculated by the program.

These training sessions are normally classroom-type lectures. Since the attendees have many other time commitments, the training is normally broken down into a series of short (30- to 45-minute) presentations. These training sessions are an excellent opportunity for the pavement manager to find out more from each of the PMS users about what type of information is most valuable to them and in what format it should be provided. It is also a good forum to promote the benefits of pavement management.

Upper Management, Elected Officials, and the Public

Upper management, elected officials, and the public need education in pavement management since they either directly use, or are impacted by, the output of the PMS. This educational process is not as rigorous or technically detailed as the training sessions just discussed. The educational process is usually conducted through small presentations, information brochures, and press releases. The topics covered may include an overview of pavement management, the uses of pavement management, and the benefits of pavement management.

> A Case Study: City of Bellevue (10)
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> *In 1992 the city of Bellevue prepared a management brief describing its pavement management efforts. This brief was distributed to staff and the city council. During a recent open-house, it was revised and distributed to the general public. This document provides an overview of pavement management efforts in the city of Bellevue, describes how pavement life is predicted and used within the PMS process, and outlines how the city prioritizes pavement repair projects. This brief is reproduced in its entirety in Appendix A, Case Study #1.*

Follow-Up Training

It is accepted that training and education are needed during the initial implementation of a PMS to learn how to collect the data, operate the software, and analyze the data. However, sometimes not enough attention is given to subsequent training and continued education after the implementation is completed. Continued training is needed for these reasons:

- The training that occurs during the initial implementation of a PMS usually concentrates heavily on how to collect data, establish a database, and modify a database over time. Some attention is given to how to analyze the data and prepare reports, but until a user has had time to really work with the system it is difficult for him or her to assimilate all the information introduced during this training session. The staff needs follow-up training to reinforce concepts learned during initial training and to refine their skills after having some practical experience.
- Pavement management software is often only accessed intermittently throughout the year. This means that people working with the program may have many months when they do not work with the software, and could forget some of the things they need to operate the program as efficiently as possible. Follow-up training serves to refresh skills after a period away from the system.
- Software and pavement management techniques evolve and change over time. Training is needed to take advantage of these improvements when they occur.
- Personnel changes mean that new people are often being introduced to the pavement management process and require training.

An added benefit of these sessions is that feedback from students can be used to improve the PMS.

Training Frequency

To help "calibrate" pavement raters a training course in the collection of visual distress data should be conducted before each new cycle of data collection, usually every one to two years. Most agencies interviewed during the preparation of this guide have found that training in the visual distress data collection procedure is important, even if a rater has experience in the procedure. Training in the use of nondestructive testing equipment should also occur annually and any time new staff are added.

A refresher course in the pavement management process and the use of the pavement management software should be offered at least once every two years, and every time a new staff member is brought into the pavement management group.

How to Set Up an In-House Training Program

It is possible for an agency to provide many of its training needs internally by establishing its own pavement management training program. This program should focus on thoroughly training the pavement management staff in their primary functions and providing cross-training in their secondary functions.

PMS Staff Training

The basic steps involved in setting up a training program are:

1. Assign a specific person within the pavement management group with the responsibility for training. This person needs to be experienced in all aspects of the pavement management process. In addition, it is recommended that the trainer be active in the Northwest Pavement Managers Association (NWPMA), especially at the chapter level, and be in the software user's group. Attendance at regional and national pavement management conferences to exchange information and learn new ways of doing things is also highly beneficial.
2. Establish a frequency for training in-house staff. It is recommended that training in the visual data collection process be conducted prior to each round of inspections (usually annually or every two years). This course will include topics covering pre-survey activities (preparing field sheets, identifying areas to be inspected, and so on), distress identification, filling out survey sheets, and safety issues. A training course in the operation of any nondestructive testing equipment used by the agency should also be held annually. This course will include such topics as an overview of the equipment, calibration of the equipment, testing with the equipment, analyzing data, and safety issues. A full-comprehensive training session will be needed when new staff become involved with the pavement management process.

3. Develop training materials and document the training process. This will facilitate the transfer of the training responsibilities to a new staff member if the existing trainer leaves that position. Training material sources include the WSDOT Northwest T^2 Center, the University of Washington TRANSPEED, the WSDOT TransAid Service Center, the Federal Highway Administration (FHWA), the Washington State County Road Administration Board (CRAB), the American Association of State Highway Transportation Officials (AASHTO), the vendor of an agency's pavement management software, and the manufacturer of nondestructive testing equipment. Training materials available from these sources include:
   - *Pavement Surface Condition Rating Manual* (7)
   - *Pavement Surface Condition Rating Videotape* (9)
   - *A Guide for Local Agency Pavement Managers* (4)
   - *AASHTO Pavement Management Guide* (11)
   - *FHWA Pavement Management Course Notebook* (12)
   - Software Manuals
   - Equipment Manuals

   Examples of training course outlines follow at the completion of this section.
4. Conduct the training courses.
5. Make sure the trainer (and preferably all pavement management staff) periodically attends outside training sessions and conferences to refresh his/her knowledge, exchange information, and learn new ways of doing things.

At the completion of the training process, it is highly recommended that at least two people in the agency have a thorough understanding of how to use and maintain the pavement management program.

Visual Distress Data Collection Training Course Outline

I. Overview of Pavement Management

II. Role of Distress Data in a Pavement Management System

III. Types of Pavements and Their Behavior

IV. Visual Survey Methodologies

  A. Walking

  B. Vehicle

  C. Bicycle

  D. Automated

V. Getting Ready to Conduct a Visual Distress Survey
   A. Training
   B. Preparation of Field Sheets
   C. Preparation of Schedule
   D. Preparation of Safety Plan
VI. Pavement Distress Identification
   A. ACP Pavements
   B. BST Pavements
   C. PCC Pavements
VII. Conducting a Visual Distress Survey
VIII. Entering Distress Data into a PMS Database
IX. Quality Control Procedures
X. Field Training

Structural Testing Training Course Outline

I. Overview of Equipment
II. Use of Equipment
III. Calibration of Equipment
IV. Field Testing
V. Data Analysis
VI. Quality Control Procedures
VII. Safety Procedures
VIII. Field Training

Pavement Management Training Course Outline

I. Overview of Pavement Management
II. Agency's Approach to Pavement Management
III. Implementation Process
IV. Network Definition
V. Data Collection
   A. Inventory Data
   B. Condition Data

VI. Data Storage

VII. Data Analysis and Interpretation

VIII. Report Generation and Presenting Results

IX. Software Use

X. Trouble Shooting

XI. Quality Control Procedures

Cross-Training

Cross-training can be a combination of formal and informal training. The formal portion of cross-training could include the following two activities:

1. Present short courses providing an overview of pavement management and the PMS.
2. Install the pavement management software and database on a computer in another division and train those staff in its use.

The informal portion of cross-training could include the following steps:

1. At meetings, discuss how PMS recommendations were made.
2. Exchange PMS information with people from other divisions or departments within the agency.
3. Involve other divisions or departments in improvements to the PMS (for example, designing reports).
4. Become involved with NWPMA and other pavement managers in the region and around the State.

System Documentation

It is very important to have documentation about the pavement management process. Often, information on the pavement management process is only stored in the pavement manager's mind. If the pavement manager suddenly becomes unavailable, that information is all lost. Therefore, it is very important to have written documentation on the PMS. Not only will this document serve to preserve knowledge in the case of an unexpected staffing change, it will also serve as a valuable resource for people using the system or new people learning the system.

The following types of documentation are recommended:

1. Information on the pavement management process itself within the agency is needed. A flow chart, accompanied by a written description, should track the process from initial network definition through the final presentation of pavement repair recommendations. This document should include the individuals or positions involved with each of the steps, along with their phone numbers and addresses. The quality control process

used during pavement management activities should be presented in this document. Database backup procedures and the location of backup software and database should also be included.

2. The pavement management software itself should be described in detail in a document. It should thoroughly describe every data field used within the program and provide guidance in the use of the software. This document should also describe the methods and models used within the pavement management software for analyzing data. It should include the vendor's phone number and software support representative. This should be a very comprehensive and detailed document, and is often provided by the software vendor.
3. A software applications guide is also highly recommended. This document provides examples of ways to manipulate and analyze the data. It also often describes the sensitivity of the system to different types of data, so that the reader can understand the impact that various parameters and inputs have on the final recommendations made by the PMS.
4. A software trouble log should be established where the user notes down any problems encountered when using the pavement management software along with any corrective action taken. This document will allow a reoccurrence of the problem to be addressed quickly. It will also serve as a way to identify problem trends so that they can be corrected.
5. Another type of document that is not an absolute requirement, but can prove extremely useful, is an executive summary that presents an overview of the system capabilities. This is not a technical document, but one that can be used to describe the usefulness and general capabilities of the PMS.

Summary

Pavement management is a continuous process. It is extremely important to make sure that pavement management remains an integral part of how an agency makes pavement-related decisions. A PMS can be considered truly implemented and used to its fullest potential when it becomes part of the routine management process and affects the pavement-related decisions being made within an agency.

Chapter 2 References

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3. City of Renton information provided by Bill Wressell and Jack Crumley.
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10. City of Bellevue information provided by Bob Goenen.
11. AASHTO, *Guidelines for Pavement Management Systems*, American Association of State Highway and Transportation Officials, Washington, D.C., 1990.
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3:P:DP/PMAG

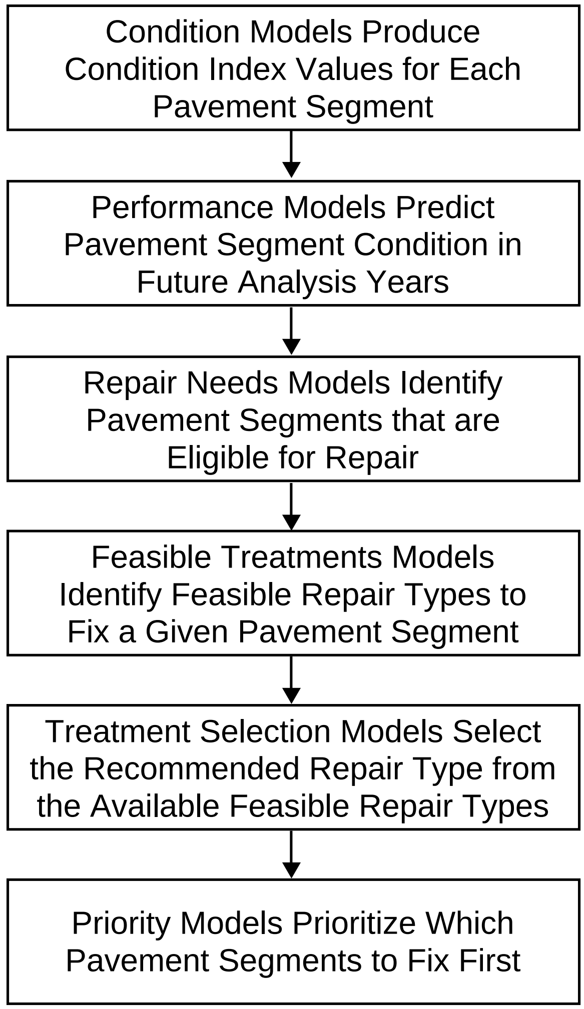
After all the effort expended getting pavement management software up and running, there is a tendency to continue using the program just as it was initially installed. However, almost all pavement management software programs permit the user some level of ability to adjust the models used within the program and agencies should take advantage of this capability. In addition, few agencies use actual data collected over time and stored in the pavement management database to improve the models used in the software. This feedback process would enable the agency to continually improve its PMS as it learns more about its system and roads. This chapter provides guidance on how to calibrate a PMS and establish a feedback process.

Types of Pavement Management System Models

The management process is dependent on an extensive database, which includes inventory and condition data. The database alone is of little use, however, without mathematical expressions, or models, to predict future pavement condition, to assess costs and benefits, and to select effective management strategies. These models directly impact how reliable the recommendations made by a PMS will be, and making sure that they are fine-tuned is an important responsibility of the pavement manager.

Models are mathematical expressions used to represent or describe relationships between different elements (1). For example, a pavement performance model is a mathematical equation that could represent pavement condition as it relates to pavement age or load repetitions. Before examining the calibration of the models, it is appropriate to review the different models used within pavement management software and their interaction. The flow chart on the following page shows how these models interact.

- Condition Models: The most basic calculation that is performed in pavement management is the determination of a condition index (CI) from visual inspection data. In Washington State, the CI is a number from 0 (failed) to 100 (new). The actual calculation of the index is dependent upon the rating method used, since agencies have the option of either measuring the actual quantity of distress present or identifying standardized ranges of extent. The *Pavement Surface Condition Rating Manual* (2) provides detailed information on the calculation of a CI from visual distress data.



- Performance Models: Performance prediction models are used to estimate the condition of the pavement in future years. These models may be segment-specific or developed for a group of pavement segments expected to perform in a similar manner. The majority of local agencies interviewed during the preparation of this guide use visual condition data to track and predict pavement performance. However, a few agencies also assess current condition and predict future performance based upon structural data.
- Repair Needs Models: After the CI, or other measure of condition, of each segment has been calculated, repair needs models are used to identify which pavement segments should be considered for repair in a given analysis year.
- Feasible Treatments Models: Once a segment has been identified as a candidate for repair, the pavement management program applies analysis routines to determine which repair alternatives would be appropriate to fix the pavement.

- Treatment Selection Models: If more than one repair alternative has been identified as feasible for fixing a pavement segment, treatment selection models are used to select the recommended repair.
- Priority Models: After the segments that are eligible for repair in a given year have been identified and the recommended method for repairing each of the eligible sections has been identified, priority models are used to determine the priority in which pavement segments will get funded when there are insufficient funds available for all the triggered projects.

When Should PMS Models Be Changed?

As mentioned before, it is tempting to use the default values that came with the pavement management software or to leave the initial analytical routines developed during the initial implementation alone. Often, an agency is very conscientious about updating the database itself. However, too frequently the analytical routines used within the software are not modified after the initial implementation.

An agency should make a planned effort to review the majority of the models used in the pavement management software after the program has been in use for a year. This is important because during the initial implementation of a PMS there is often limited information available to develop some of the models. For example, an agency just starting the pavement management process may have little or no historical condition information available. Therefore, the development of performance models at this stage relies heavily upon the agency's personal experience and knowledge of its street network's pavement deterioration behavior. These models can be greatly improved to more accurately reflect the actual performance after a database containing historical condition information has been established and can be used to calibrate the models.

Performance models, repair needs models, feasible treatment models, treatment selection models, and priority models should all be reviewed and revised annually. If done carefully, all of these modifications will improve the analysis results of the PMS.

The visual condition models should only be modified after careful consideration. For example, if an agency changes the deduct values that are used in calculating a CI, the historical CI values stored in the database will no longer be consistent with new CI values. This situation could be rectified by recalculating the historical CI values using the new deduct values, but it does illustrate that an agency needs to think about all the possible ramifications of modifying a portion of the pavement management software before jumping in and changing anything.

Model Development and Calibration

Following is a discussion of the types of models within pavement management software that should be periodically reviewed and refined.

Performance Models (3)

Performance prediction models are an essential part of the pavement management process. Performance prediction models can be used to:

- predict future pavement condition
- analyze pavement life-cycle costs
- estimate the type and timing of pavement maintenance and rehabilitation needs
- develop a feedback loop with the pavement design process

Performance Model Development

There are many different ways of developing pavement performance models. An agency should understand the type of performance model being used within its pavement management software, both in terms of its limitations and appropriate uses. The agency should also understand the data that are needed to support the model.

Based on how the performance models are developed, they can be broken down into two broad categories: deterministic and probabilistic. Deterministic models predict the average value of a dependent variable (such as the remaining life of a pavement or its level of distress). Most deterministic models used in pavement management are based on regression analysis. Deterministic performance models are typically used by Washington State local agencies.

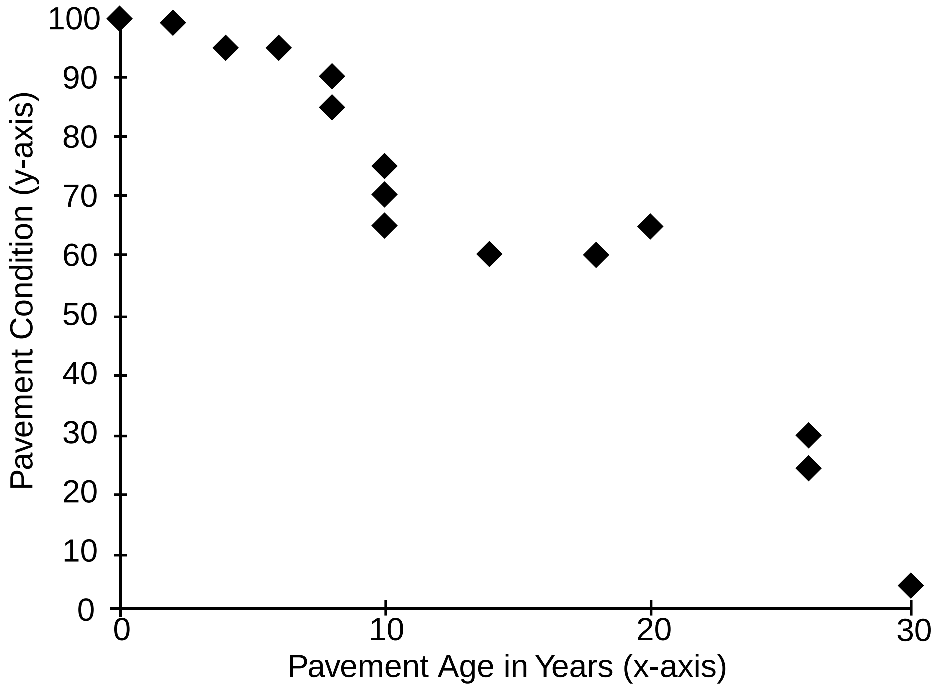
Probabilistic models predict a range (or distribution) of values for a dependent variable. Most probabilistic models used in pavement management are based on Markovian theory. Probabilistic performance models are not typically used by Washington State local agencies.

Performance models can also be classified as mechanistic, empirical, or mechanistic-empirical, depending on their formulation and whether mechanistic variables are used in the model. Empirical models are based upon results of experiments or experience. Mechanistic models are based on fundamental principles of pavement behavior under load. Empirical-mechanistic models incorporate elements of both approaches. (4)

Deterministic Models

The deterministic model types may be either empirical or mechanistic empirical correlations which are typically calibrated using regression techniques. Regression is a statistical tool that is used to relate two or more variables in a mathematical equation. In a pavement performance model, condition is modeled as a function of variables, such as pavement age, traffic, environment, pavement construction and characteristics, and maintenance and rehabilitation actions. The functional form is often based on an S-shaped deterioration curve.

In pavement performance modeling, it is common to start with a set of data points that have condition (y-axis) plotted versus pavement age (x-axis), as shown below. Regression analysis is one technique that can then be used to develop a mathematical relationship for these data points.



The variable being predicted is often designated as y and the variable used to predict y is designated as x. Since y changes as a result of a change in x, y is called the dependent variable and x is the independent variable. The best relationship to use to predict some y from x is one that minimizes the differences between the regression line (or curve) and the actual data.

The form of a regression equation is:

$$y = b_0 + b_1(x) + b_2(x^2) + b_3(x^3) + \ldots + b_n(x^n)$$

where, y = predicted value

x = independent variable

b = regression constants

The simplest form of regression is linear regression, which is given by the equation:

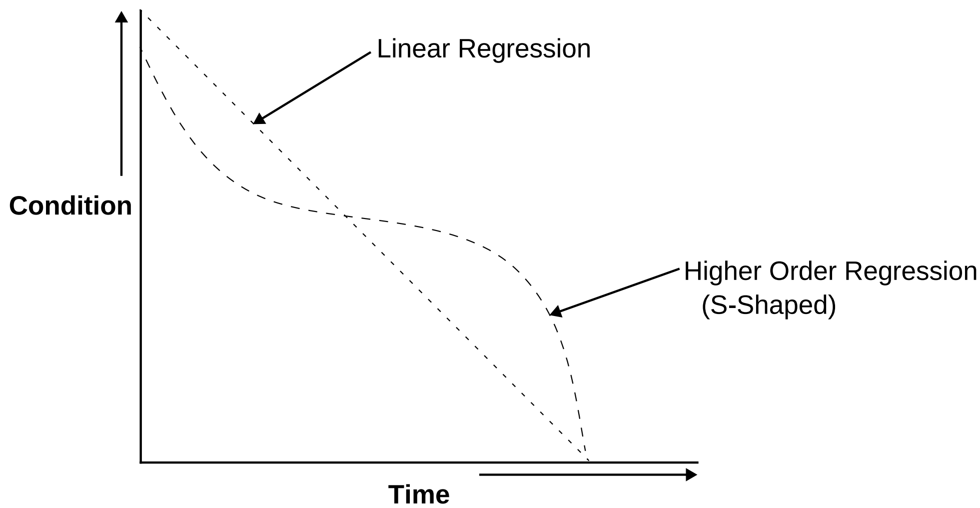
$$y = b_0 + b_1(x)$$

where, y = predicted value

x = independent variable

b = regression constants

This regression represents a straight line. Higher order (polynomial) regressions yield curvilinear relationships between the independent and dependent variables. In PMS applications, these models are constrained to be ever decreasing if the independent variable is age and the dependent variable is condition (in other words, condition is not permitted to increase with age). An example of two types of regression models is shown in the following figure.



Single variable regression models are easy to develop and understand. However, their accuracy can be limited due to the simplifying assumption that a single variable (pavement age) is used to predict another single variable (pavement condition).

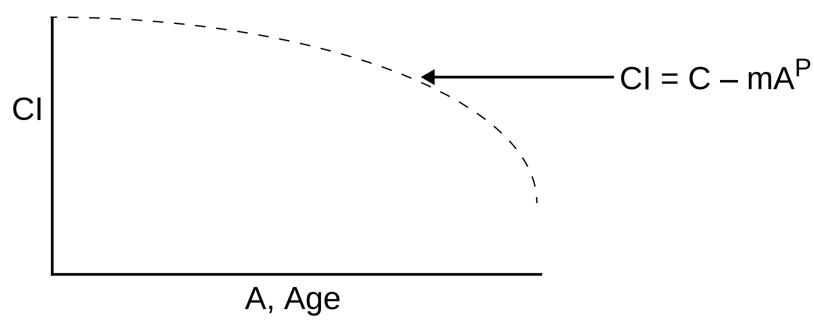
A Case Study: WSDOT Pavement Management (5)

The current general model used by WSDOT in its pavement management system (WSPMS) to predict CI versus age is:

$CI = C - mA^P$

where CI = *Pavement Structural Condition Rating*
C = *model constant for maximum rating (usually 100)*
m = *regression slope coefficient*
A = *age (time since construction or the last resurfacing, in years)*
P = *selected constant that controls the degree of curvature of the performance curve*

The general shape of the curve is shown below.



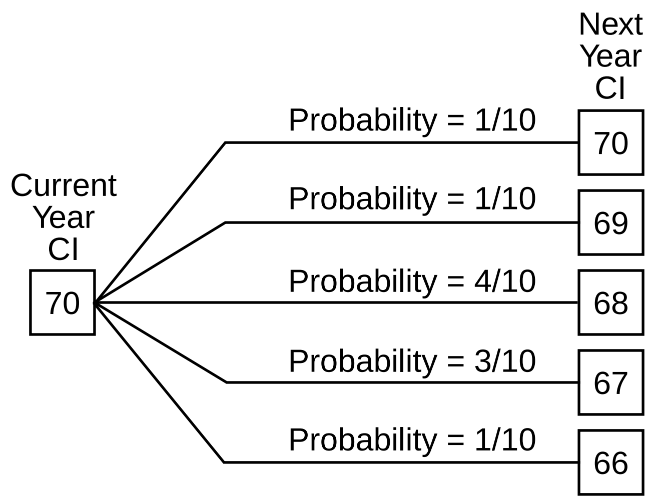
This model has been used by WSDOT for the past 15 years. Changing the value of m affects the slope of the resulting curve. Changing the value of P affects the degree of curvature of the resulting curve. In fitting the best curve to the pavement ratings, the program substitutes a number of different exponents (B) to obtain the best fit. The best fit is determined by the highest R^2 *value (coefficient of determination) using the sum of least squares method.*

It is possible to incorporate more than one independent variable into the analysis. This is called multiple regression. Some of the independent variables in the prediction equation could include traffic, structural capacity, and climate. These models tend to become very complicated and usually require complex and comprehensive data.

For further information on regression analysis, and other statistical curve-fitting techniques, please refer to WSDOT's report (7), *Statistical Methods for WSDOT Pavement and Material Applications.*

Probabilistic Models

Although not commonly used by Washington agencies, some systems use probabilistic type models that have most often been based on Markovian theory. Markovian theory is founded on the assumption that the probability something will change from one condition state to another is only dependent on its current state. In a pavement management application, this assumption means that a pavement segment's current condition is only dependent on its preceding prior condition and that the next year condition of a pavement segment is dependent only on its current year condition. For each given condition state, estimates are developed to predict what percentage of the pavement sections in that state will a) stay in the same condition or b) move to another condition state. The following figure (6) illustrates the use of Markov transition probabilities.

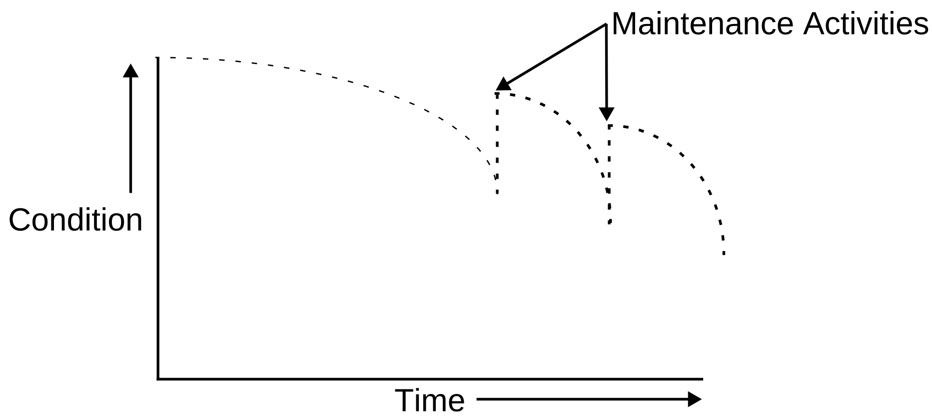


Markov-based models recognize and accommodate uncertainty. They can incorporate the experience of an agency and can be used in situations where there is no historical database available. After time, as field data become available, these models can be further calibrated.

However, Markov models depend only on the present state (in the case of PMS, present condition) in predicting the future state (predicted condition) and various studies have shown that other variables such as loading and age of pavement are also significant in predicting a pavement's future state. Markov-based models also assume that transition probabilities are constant over time. Since traffic loads generally increase over time and maintenance methods also vary over time, this may be unrealistic. This can be taken into consideration by assuming that the process is only stationary during piecewise increments of time. When this is done, it is called a Semi-Markov model.

Individual Segment Models and Family Models

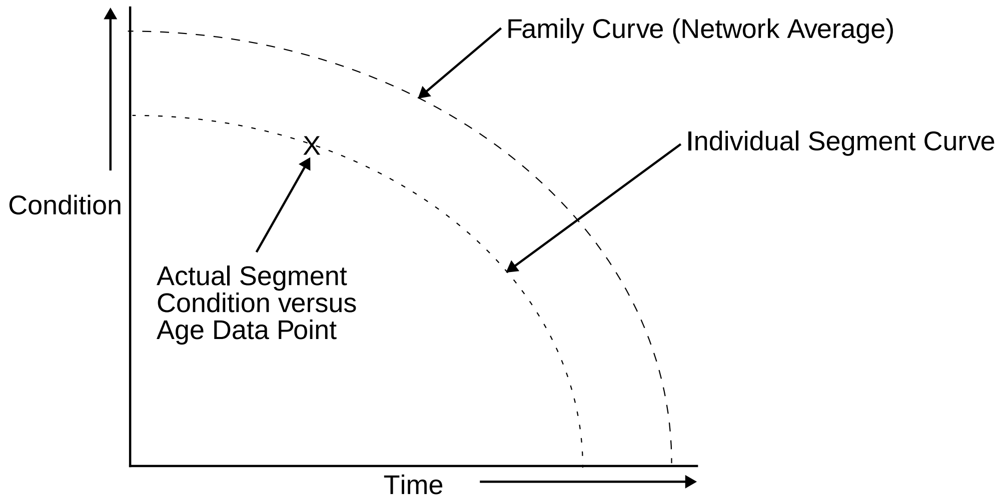
The Washington pavement management system is based on the individual segment model approach. An individual segment model uses historical data from that particular piece of pavement to develop a performance model. Constraints are normally applied to the resulting equation to prohibit the model from showing periodic increases in pavement condition with age. These increases could occur due to maintenance activities, as illustrated in the following figure.



Segment-specific performance models need three data points to develop a curvilinear model. However, during the period when there are not enough years of historical condition data available, a default curve for the appropriate type of pavement and geographic location can be used by fitting the default curve through the last condition versus age point.

Another approach is the family performance curve model. Family performance models involve grouping pavement segments that are anticipated to perform in a similar manner together into “families.” An example of a pavement family would be bituminous roads in a given geographic region that have not been overlayed and serve heavy levels of truck traffic. The age versus CI data points for a given family are then plotted and a regression model is developed to fit those points. This results in a standard family curve.

The PMS then uses the individual segment’s condition versus age point relative to the standard curve to predict future condition. The family curve is adjusted, as shown in the following figure, to account for the individual segment performance which will be worse or better than the standard family curve would indicate. Family models can use one inspection data point since the models use data from segments that are anticipated to deteriorate in a similar manner.



Performance Model Evaluation and Modification

Regardless of the type of performance model used within an agency's PMS, the models themselves should be periodically reviewed and refined. Performance models directly impact the year a pavement segment is selected for repair. The impact of poor performance models on the reliability of the pavement management software analysis depends partially upon the current condition level of the pavement segment in question. For example, if the segment is already in very poor condition it will probably be triggered for repair within the next year or two regardless of whether the performance model is accurate. However, if a segment is in very good condition right now a poor performance model could over or under predict the need for repairs by several years. Therefore, it is important to periodically review the accuracy of the performance models and determine over what prediction range they can be used reliably.

Performance models can be continually improved as the historic database of performance data grows over time. It may be necessary during the early years of using a PMS, before a substantial historic database has been established, to supplement the existing data with expert opinion to obtain reliable performance models. As time goes by, however, and more performance data become available, the reliance on expert opinion should become less and less. The specific procedure used to modify the performance models is highly dependent upon the pavement management software being operated.

A Case Study: City of Bellevue (9)

The city of Bellevue has been using a PMS for over a decade and has performed multiple inspections of its pavements. The software the city uses supports segment-specific performance models. When the city first began using its system, only one inspection had been performed. At that time, the city used default performance models contained in its software (defined by functional class and pavement type) that were fit through the single inspection/age data point that was available.

Over time, as additional visual inspections were performed, the city was able to use the option of attempting a curve fit (regression analysis) to each segment's data. The city runs the curve fit routine, and if the R^2 of the resultant curve is acceptable (as specified by the city) that is the model used by the program. If the R^2 is unacceptable, the program uses the default curve fit through the first and last condition/age point. This process is all done automatically by the pavement management software.

After the city of Bellevue runs its network analysis, which generates a list of projects for each analysis year, the pavement manager manually checks the performance models for each of the selected projects. If a performance model appears to be tracking data points reasonably well and looks okay, the city leaves it alone. If the city feels it is not representative of actual field conditions, it modifies the curve using expert points.

Repair Needs Models

Analytical routines are used in the pavement management process to identify when a segment should be repaired. These models can be set up to trigger repair based upon any measure of condition an agency wants, such as roughness, CI, structural adequacy, surface friction, and so on. While state agencies often use multiple criteria within their PMS (for example, roughness, CI, and structural adequacy could all be used together to identify when a pavement segment will require repair), local agencies often use only one or two criteria to determine when work is needed.

Repair Needs Model Development

The first step in developing a repair needs model is to select the triggering criteria that will be used to identify the segments needing repair. Depending upon the pavement management software being used, an agency could be limited to using only visual condition data as a trigger for pavement work. Other PMS programs offer a full-range of triggering criteria, including roughness, skid, structural capacity, and so on. The majority of Washington State local agencies interviewed during the preparation of this guide depend upon visual condition criteria to identify project needs, with a few using visual condition in conjunction with structural capacity information. An example of how one local agency uses both visual and structural data to identify repair needs is discussed in the following case study.

A Case Study: Clark County (10)

When Clark County decided in 1993 to implement a PMS, it felt that was very important to ensure that the PMS software could utilize both the visual and structural information within it analytical routines.

The first step in integrating the visual data with structural data was to determine how both should be used to assess pavement maintenance and rehabilitation needs. Visual distress data provide an excellent indication of the current functional condition of the pavement. The type of visual distress present also give an indication of the primary deterioration mechanism at work in the pavement (load, environment, material, or other). However, visual distress data provide no measure of the structural adequacy of the pavement structure. Therefore, the data cannot be used to design a structural repair for that pavement or to identify pavement segments that are structurally inadequate but have not begun to display visual signs of deterioration.

Structural data obtained using devices such as the Road Rater or falling weight deflectometers provide information on the structural improvements to the pavement, such as overlays. However, structural data alone would not provide any indication that there were functional problems with a pavement, such as flushing, raveling and weathering, and low severity cracking.

For subdivision pavements, Clark County determined that the collection and use of visual data alone are sufficient to program those road's repair activities. For the other types of roads within the county (such as collectors and arterials), it was determined that both structural and visual data were needed to adequately assess the condition of the pavements.

Therefore, Clark County designed its PMS to be a "combination" program that can utilize visual data alone or both visual and structural data. The structural data are processed and analyzed to determine whether a structural overlay is required to accommodate the projected traffic levels. The analysis is performed initially using the DARWin software produced by AASHTO. If the results appear questionable, they are checked against the results of other analysis programs. The final results of the structural analysis are ported directly into the PMS database.

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For the subdivision pavements, the PMS uses only the visual data to identify when pavement repair is needed. For other pavement classifications, the PMS uses both the visual data and structural data. In this situation, the structural data is the trigger for pavement repair. If the structural analysis results indicate that a structural inadequacy exists in the pavement structure, the estimated overlay thickness calculated by DARWin is the recommended repair identified by the PMS. On the other hand, if the structural analysis indicates that the pavement is adequate, then the visual data are used to identify when, and what type, of pavement repair is required.

Clark County has found this approach to pavement management best meets its needs with respect to pavement condition assessment and pavement repair programming. Since this type of approach is more costly due to the dual data collection efforts (visual and structural), Clark County pavement managers made a strong effort prior to beginning the PMS implementation process to explain to the county executives how the benefits of this approach exceeded the costs. The county anticipates that after the PMS is fully implemented and the database is completely established, the ongoing annual pavement management costs will total approximately 2 percent of the total pavement improvement budget.

The second step in developing a repair needs model is to set thresholds that will trigger specific repairs. For example, if a CI is going to be used as the factor to determine when a pavement is eligible for repair, then the CI level that will trigger the repair must be defined. At this point, the type of repair to be used is not being defined; just the fact that repair is required.

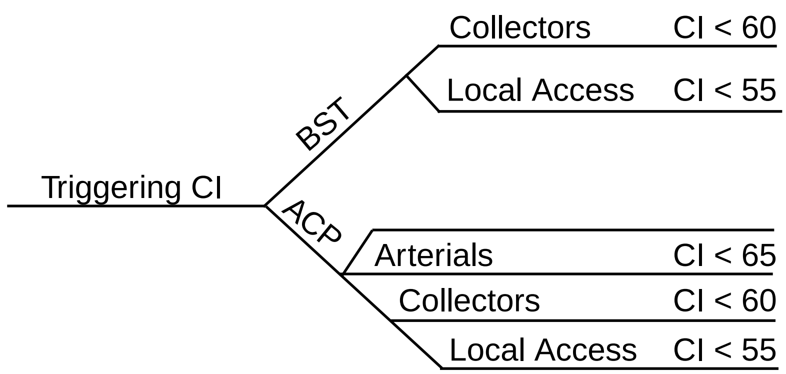
In most cases, these thresholds will vary based upon different parameters set by the agency. Traffic level, or functional classification, is the most commonly used parameter. For example, a CI index of 50 may be the threshold set to trigger work on a road serving little traffic whereas a CI index of 65 may be the threshold set to trigger work on a road serving a large amount of traffic. Agencies may also use surface type to set different thresholds. For example, an agency may use a CI of 40 as the threshold to trigger work on a BST road versus a CI of 50 as the threshold to trigger work on an ACP road.

Basically, the development of the repair needs model during initial PMS implementation involves the agency staff devising a set of decision rules pertaining to how it currently (without the aid of a computerized PMS) identifies when pavement segments need to be repaired. A decision tree or matrix is often used to express these rules, which are then incorporated into the PMS. The decision tree or matrix is nothing more than a way of defining the rules that dictate when a segment is identified as needing repair. For example, in the following decision matrix it can be seen that for BST arterial roads the CI threshold value is 55.

Decision Matrix

Surface Type	***Functional Classification***	***CI Threshold Value***
BST	Collectors	55
	Local Access	60
ACP	Arterials	55
	Collectors	60
	Local Access	65

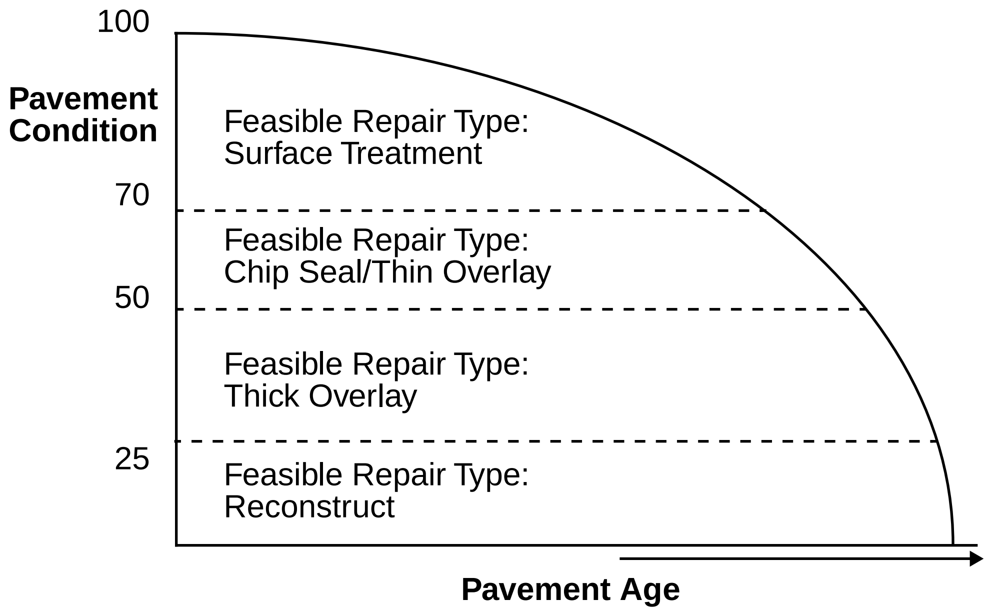
A decision tree expresses the same information as a decision matrix, just in a different format. The same information that is shown in the above decision matrix is shown below in a decision tree.



Repair Needs Model Evaluation and Modification

As with performance models, repair needs models need to be periodically reviewed and modified. One basic way to check how well the models are performing is to compare the list of segments that were repaired during the past year with the list of segments that the PMS program recommended for repair. If these lists do not match well, the repair needs models need to be reviewed.

An agency should understand how changing the repair needs models will affect the PMS output. Basically, changing any of the trigger limits will either advance or delay the year that a given segment is identified for repair. For example, if an agency increases the CI threshold for repair from 45 to 60, segments will be triggered for repair earlier. Changing trigger thresholds can also affect the feasible repair types. For example, if the CI threshold is set very low then the only feasible repair type at that point may be an expensive alternative such as major rehabilitation or reconstruction. This is illustrated in the following figure.



In the above figure, if the threshold limit is set at 50 or above, the feasible repair types include minor rehabilitation activities such as thin overlays and surface treatments. If the threshold is set lower than 50, the feasible repair types become thick overlays and reconstruction. Of course, this may be an over simplification since repairs may be triggered based upon criteria other than CI.

Feasible Treatments Models

Once a pavement segment has been triggered for repair in a given year, the PMS uses models to determine which repair alternatives would be appropriate to use to fix the segment. These models are usually set up to select appropriate repair alternatives based upon factors such as pavement condition in the repair year, surface type, traffic level, and so on. Some agencies may have many repair alternatives at their disposal whereas others may have only a few repair alternatives that they use.

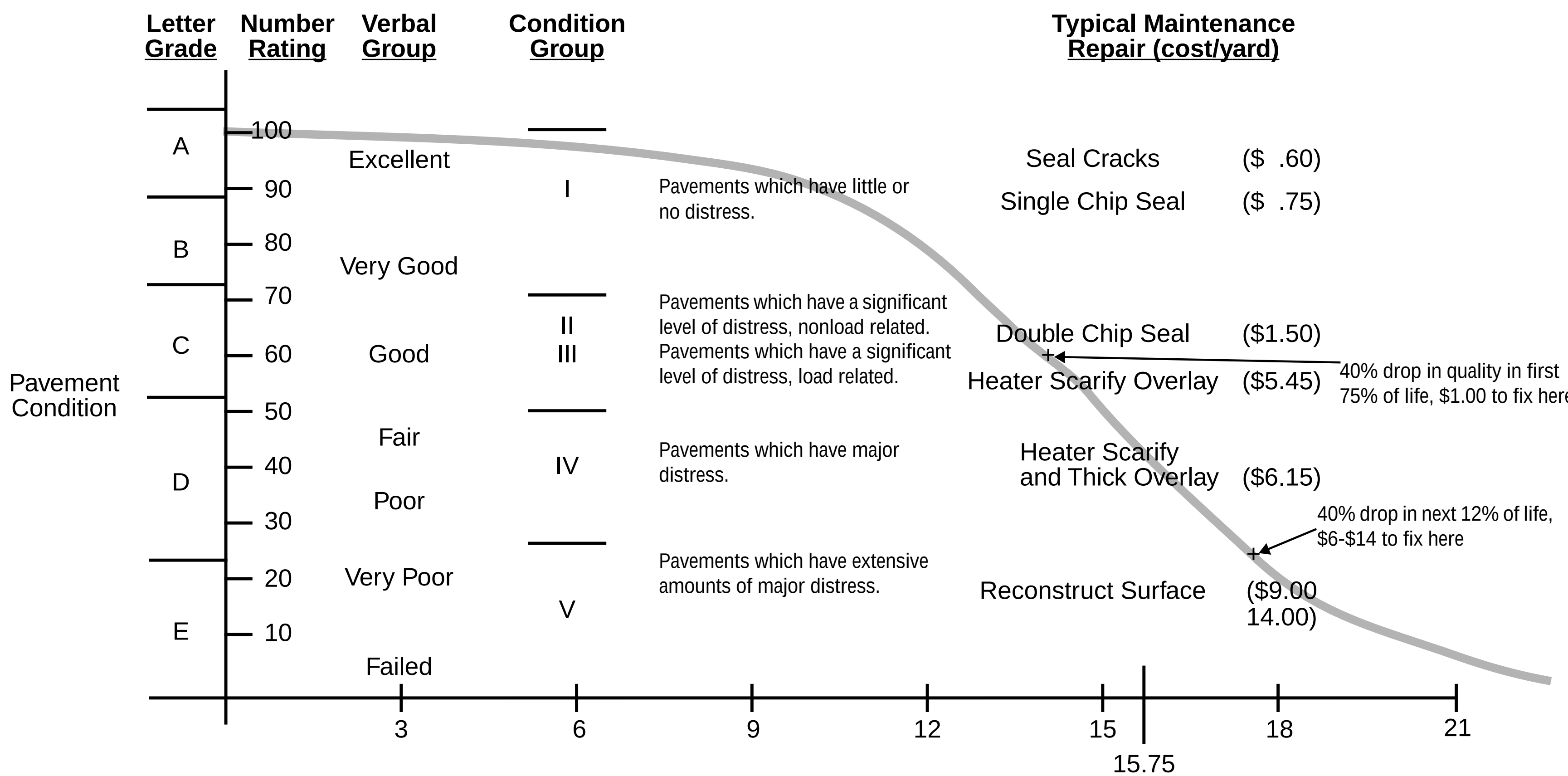
Feasible Treatments Model Development

During the initial development of the feasible treatments model, the agency should carefully and clearly define all the available repair techniques. *A Guide for Local Agency Pavement Managers* provides a list of repair types that have been used in Washington State (11). Another source of information on feasible repair types can be found in WSDOT Final Report WA-RD 214.1 (12). This report contains the results of a questionnaire that was distributed in 1990 to Washington State cities and counties. The questionnaire asked each agency to identify the repair type it uses to correct different distress types, how long the repair type is expected to last, and its unit cost. The report also provides a discussion of the different repair methods that are available, and makes recommendations as to which ones might be successfully used by local agencies in Washington State. Portions of this report are reproduced in Appendix B.

Once these repair alternatives have been identified, the agency must define under what conditions each is considered feasible. These conditions could include factors such as surface type, traffic, user acceptance, cost, life expectancy, functional class, types of distress present, the agency's long range strategy for pavement repair, and so on. For example, one condition could be that a chip seal is only allowed on rural roads that are not exhibiting extensive structural damage. Note that it is not unusual during the course of assigning feasible repairs to the various conditions to end up with multiple repair options for each condition; however, depending upon the pavement management software being used, the agency may have to select only one for each condition set.

The agency's rehabilitation strategy needs to be defined in the pavement management software. The most common ways for accomplishing this are a distress strategy matrix, a rehabilitation matrix, and a decision tree process. In the distress strategy matrix approach, the type of distress present is the main criteria used for determining what repair type to use. In the rehabilitation matrix and decision tree methods, the overall condition index is the driving factor for selecting feasible repair types. All three of these methods are described in detail in Chapter 7 of *A Guide for Local Agency Pavement Managers (11)*.

The following figures (13) show how one agency prepares its decision tree for the selection of feasible repair alternatives. The first figure illustrates the thought process behind the final decision tree. It shows the different repair types that are considered feasible for different CI and distress types (load-related versus non-load related). The second figure shows the final decision tree that is developed, with breakdowns by functional classification, surface type, and condition. Feasible repair types are identified, along with their unit costs.



Note: Costs are in 1993 Dollars

MTC PMS DECISION TREE
(Maintenance Treatments and Costs)*

CLASSIFICATION	SURFACE TYPE	CONDITION TYPE		MAINTENANCE REPAIR STRATEGY		Cost	
ARTERIAL	AC	I	1.	Preventive Maintenance**	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	7.23	sq yd
		II	2.	Single Chip Seal		1.11	sq yd
		III	3.	Thin Overlay (1.5")		3.49	sq yd
		IV	4.	Thick Overlay (2.5")		6.37	sq yd
		V	5.	Reconstruct Surface		14.00	sq yd
	AC/AC	I	6.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	7.23	sq yd
		II	7.	Double Chip Seal		1.52	sq yd
		III	8.	Heater Scarify Overlay		5.95	sq yd
		IV	9.	Heater Scarify Overlay		6.14	sq yd
		V	10.	Reconstruct Surface		14.00	sq yd
	AC/PCC	I	11.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	7.23	sq yd
		II	12.	Double Chip Seal		1.52	sq yd
		III	13.	Heater Scarify Overlay		5.95	sq yd
		IV	14.	Heater Scarify Overlay		6.14	sq yd
		V	15.	Reconstruct Surface		14.00	sq yd
	ST	I	16.	Do Nothing		.00	sq yd
		II	17.	Do Nothing		.00	sq yd
		III	18.	Do Nothing		.00	sq yd
		IV	19.	Single Chip Seal		1.42	sq yd
		V	20.	Thick AC Overlay		7.67	sq yd
COLLECTOR	AC	I	21.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	5.04	sq yd
		II	22.	Single Chip Seal		1.11	sq yd
		III	23.	Thin AC Overlay (1.5)		3.99	sq yd
		IV	24.	Thick AC Overlay (2.5)		6.17	sq yd
		V	25.	Reconstruct Surface		11.38	sq yd
	AC/AC	I	26.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	5.04	sq yd
		II	27.	Double Chip Seal		1.52	sq yd
		III	28.	Heater Scarify Overlay		5.95	sq yd
		IV	29.	Heater Scarify Overlay		6.14	sq yd
		V	30.	Reconstruct Surface		11.38	sq yd
	AC/PCC	I	31.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	5.04	sq yd
		II	32.	Double Chip Seal		1.52	sq yd
		III	33.	Heater Scarify Overlay		5.95	sq yd
		IV	34.	Heater Scarify Overlay		6.14	sq yd
		V	35.	Reconstruct Surface		11.38	sq yd
	ST	I	36.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Do Nothing	.00	sq yd
		II	37.	Single Chip Seal		1.11	sq yd
		III	38.	Double Scarify Overlay		1.52	sq yd
		IV	39.	AC Overlay with Fabric		5.36	sq yd
		V	40.	Thick AC Overlay		7.47	sq yd
RESIDENTIAL/LOCAL	AC	I	41.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	5.04	sq yd
		II	42.	Single Chip Seal		1.11	sq yd
		III	43.	Thin Overlay (1.5")		3.49	sq yd
		IV	44.	Thick Overlay (2.5")		5.97	sq yd
		V	45.	Reconstruct Surface		8.75	sq yd
	AC/AC	I	46.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Mill & Thick Overlay	5.04	sq yd
		II	47.	Double Chip Seal		1.52	sq yd
		III	48.	Heater Scarify Overlay		5.95	sq yd
		IV	49.	Heater Scarify Overlay		6.14	sq yd
		V	50.	Reconstruct Surface		8.75	sq yd
	AC/PCC	I	51.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Do Nothing	.00	sq yd
		II	52.	Double Chip Seal		1.52	sq yd
		III	53.	Heater Scarify and Overlay		5.95	sq yd
		IV	54.	Heater Scarify and Overlay		6.14	sq yd
		V	55.	Reconstruct Surface		8.75	sq yd
	ST	I	56.	Preventive Maintenance	Seal Crack	$ .60	sq.yd
					Single Chip	.74	sq yd
					Do Nothing	.00	sq yd
		II	57.	Single Chip Seal		1.11	sq yd
		III	58.	Heater Scarify Overlay		1.52	sq yd
		IV	59.	AC Overlay with Fabric		5.36	sq yd
		V	60.	Thick AC Overlay		7.27	sq yd
OTHER							

* These are the current "default" values in the system. They should be reviewed and modified by each user to fit local conditions.

** Preventive maintenance repairs are sequenced as defined by the user. Currently, thin crack seals are every three years, chip seals every seven years and mill and overlay after two chip seals.

Note: Costs are in 1993 Dollars

A Case Study: City of Bellevue (9)

The city of Bellevue bases its decision matrix on street classification and condition index. The following table shows a portion of the decision matrix for the arterial streets.

Condition Rating	Principal Arterial	Minor Arterial	Collector Arterial
90 - 100	1.0	1.0	1.0
80 - 90	1.0	1.0	1.0
70 - 80	1.0	1.0	1.0
60 - 70	1.1 - 1.4	1.1 - 1.4	1.1 - 1.4
50 - 60	1.1 - 1.4	1.1 - 1.4	1.1 - 1.4
40 - 50	3.0 - 3.1	3.0 - 3.1	3.0 - 3.1
30 - 40	3.0 - 3.3	3.0 - 3.3	3.0 - 3.3
20 - 30	4.0 - 4.3	4.0 - 4.3	4.0 - 4.3
10 - 20	4.3	4.3	4.3
0 - 10	5.0 - 6.1	5.0 - 6.1	5.0 - 6.1

where:

1.0	Do Nothing	3.0	Thin Overlay (1.5″ - 2″)	5.0	Thick Overlay
1.1	Crack Sealing	3.1	Thin Overlay with Mill or Crack Prep.	5.1	Thick Overlay with or Crack Prep.
1.2	Patching — Low	3.2	Thin Overlay with Fabric	5.2	Thick Overlay with Fabric
1.3	Patching — Medium	3.3	Thin Overlay with Fabric + Mill	6.0	Reconstruct
1.4	Patching — Structural	3.4	Thin Overlay with Heater Scarify	6.1	In-Place Recycle and Overlay
2.0	Single Chip Seal	4.0	Structural Overlay (2″ - 4″)		
2.1	Double Chip Seal	4.1	Structural Overlay with Mill or Crack Prep.		
2.2	Slurry Seal	4.2	Structural Overlay with Fabric + Mill		
2.3	Fog Seal	4.3	Structural Overlay with Fabric + Mill		

A Case Study: Spokane County (14)

Spokane County uses both visual and structural data when selecting feasible repair types for its arterial network. By measuring both the structural condition and the surface condition of the road, the county feels it gets a better idea of the true condition of the pavement. The county then uses this information to select the appropriate repair alternative. For example, a segment that has a relatively low visual CI but is in good structural condition (measured by remaining life), does not need structural help but does require some type of surface treatment. Conversely, a segment with a high visual CI and a low remaining life indicates a road that needs structural repair (overlay). Spokane County's feasible repair type decision matrix is shown below.

Structural Remaining Life	Condition Index			
	0 - 39	**40 - 59**	**60 - 79**	**80 - 100**
0 - 5 years	Reconstruct	Reconstruct	Structural Repair	Structural Repair
6 - 8	Reconstruct	Structural Repair	Patch and Seal	Patch
9 - 16	Structural Repair	Patch and Seal	Seal Coat	No Action

Feasible Treatments Model Evaluation and Modification

The repair types initially defined by an agency during the implementation of a PMS usually represent current practice at that time. However, new repair types do become available over time and other repair types may prove ineffective. Therefore, it is important that an agency periodically review its feasible treatments model and modify it as needed to make sure that it is still reliable.

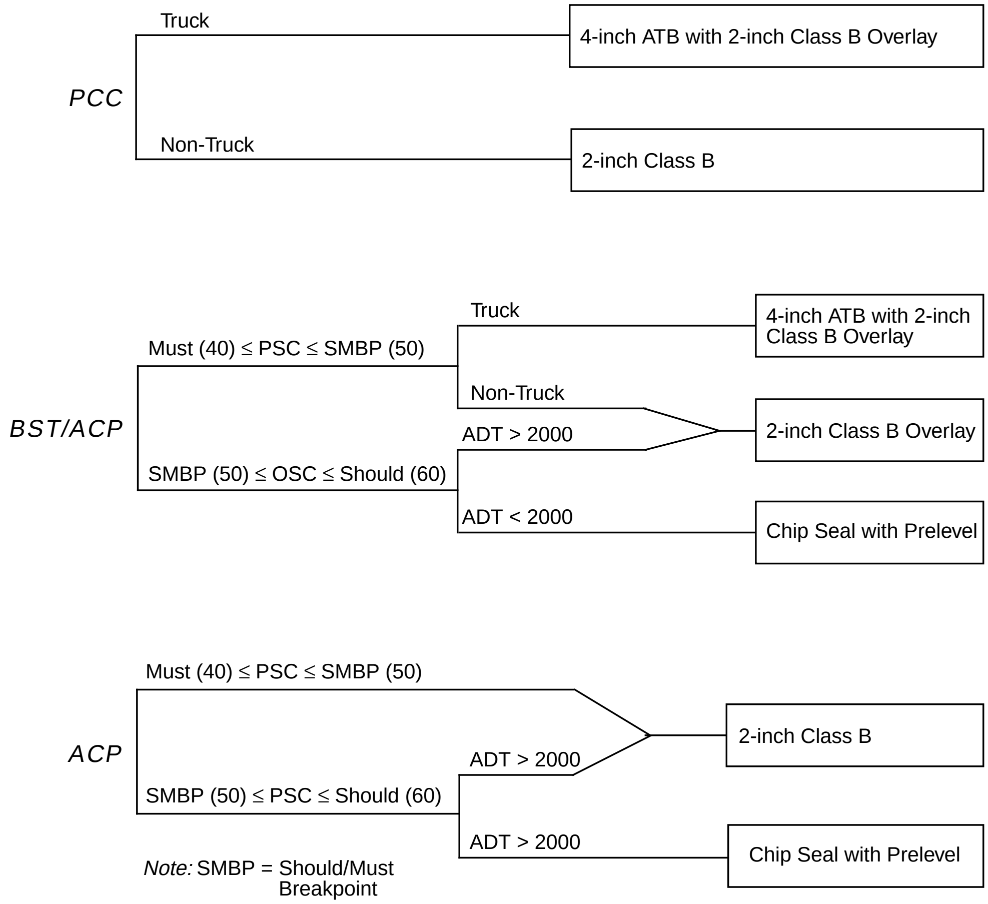
One basic check to make of the feasible treatments model is to compare the pavement repair types recommended by the PMS program to the repairs actually performed during the past year. If the program is consistently recommending repair types that are not implemented in the field, the feasible treatments model needs to be adjusted.

A Case Study: Skagit County (15)

Skagit County has been involved with pavement management for over seven years. When it first began using PMS software, it used the default treatment decision tree that came with the software. However, over time the county found that the default treatment types and selection criteria did not always match Skagit County's practices. Therefore, during the past few years Skagit County has been working with CRAB to develop its own decision tree.

CRAB assisted Skagit County in the development of the decision tree. It interviewed county personnel to identify the repair types and unit costs that were appropriate for Skagit County. CRAB also worked with Skagit County to identify under what conditions each repair type should be applied.

The following three decision trees were the result of the first modifications. There are separate decision trees for PCC, BST/ACP, and APC pavement:



Skagit County Decision Tree

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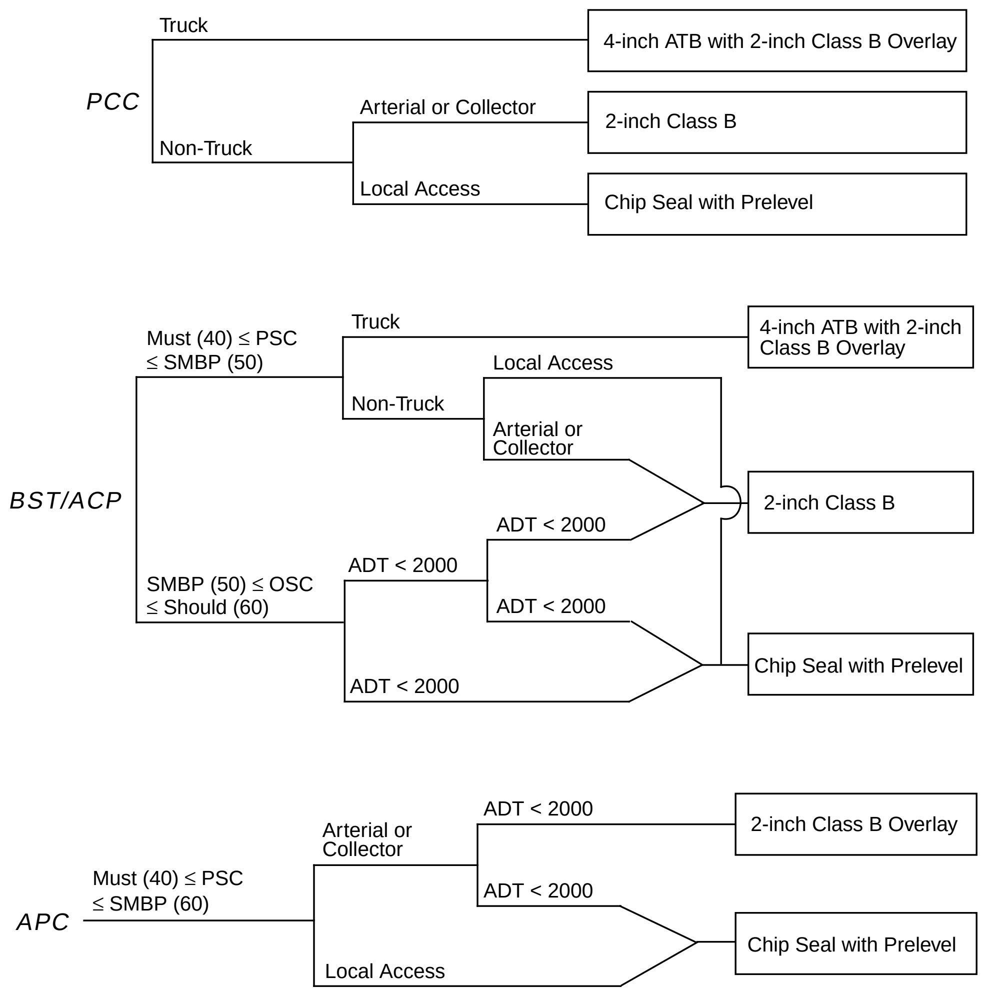
The next step was to add local access road treatments to the decision trees, as shown below:



Skagit County Decision Tree

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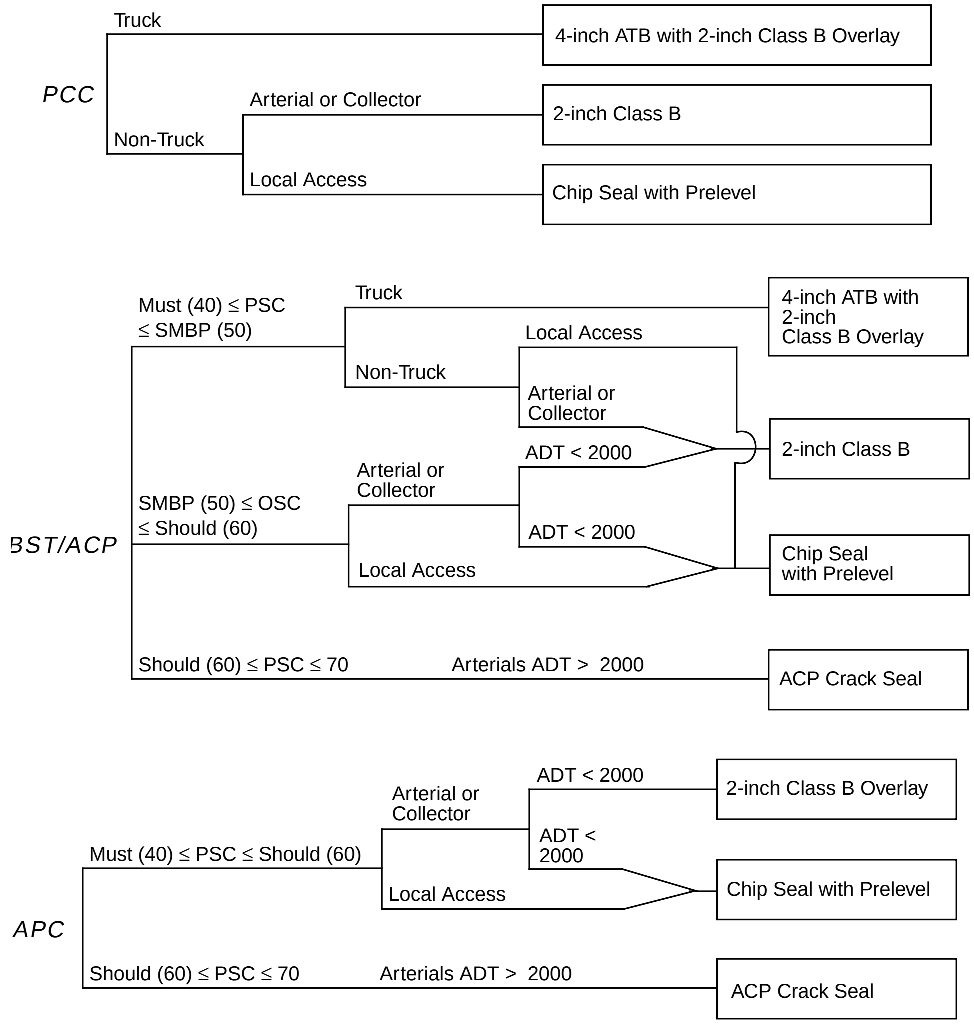
The final step was to add crack sealing, a maintenance activity, into the decision trees, as shown below:



Skagit County Decision Tree
(Preventive Maintenance)

Treatment Selection Models

When more than one repair alternative has been identified as feasible for repairing a given pavement segment, the PMS software uses models to select the recommended repair alternative. At their most basic, these models can be defined to mimic past practice by selecting the treatment alternative that has been historically used by the agency. However, a more sophisticated approach is to base the selection on some type of benefit-cost comparison.

Treatment Selection Model Development

At the simplest level, only one repair alternative is considered for a given set of conditions. For example, an asphalt pavement with a CI of 50, moderate traffic levels, and significant quantities of rutting and fatigue cracking would only trigger an asphalt overlay as a possible repair alternative. Therefore, an asphalt overlay is the rehabilitation alternative recommended by the PMS. Many of the local agencies interviewed during the preparation of this guide use this approach. The decision matrix presented in the previous case study of Spokane County is an example of this approach.

A slightly more advanced approach is also used by some local agencies in Washington. For each set of conditions, two repair alternatives are defined. One is considered the primary repair and the other is considered an alternative repair. The primary repair identifies the repair type the agency would like to use to repair the road. The alternative repair identifies a maintenance strategy to use if funding is unavailable for the primary repair.

More sophisticated PMS programs can be customized by the agency to allow the consideration of several different feasible repair alternatives for a given set of conditions. For example, perhaps the PMS identifies a chip seal, an overlay, and reconstruction as feasible alternatives. In this situation, the PMS uses analytical routines to select the recommended repair type. These routines can be based on initial cost, life-cycle cost, benefit-cost ratio, or cost-effectiveness. Each of these techniques is covered fully in the following section of this chapter on prioritization.

It should be recognized that the more advanced types of treatment selection models require computers, cost data, and performance models.

Treatment Selection Model Evaluation and Modification

Regardless of the type of model used within an agency's pavement management software to select recommended repair alternatives, the model itself needs to be periodically reviewed and adjusted. The following steps outline the basic process for adjusting a treatment selection model.

1. Unit cost information for each of the repair alternatives needs to be updated annually (or more often if fluctuating costs warrant it). Review the actual costs of projects completed during the past two years. Looking at bid sheets for that time period will provide good information on which to base unit costs.
2. The estimated life of each of the repair alternatives as defined in the PMS should be compared to actual repair performance by reviewing historical CI data (if available).

3. The repair methods used on projects during the past year should be compared to those recommended by the PMS. Take the list of projects and recommended repairs produced by the PMS for the year in question and compare that directly to the projects and repair types that were actually completed during that year.
4. If the actual repairs performed do not match well with those recommended by the PMS program, the selection model needs to be adjusted. How that adjustment is performed will depend upon the software.

Priority Models

Once a list of pavement segments requiring repair has been identified and the proper feasible repair assigned to it, the work needs to be prioritized based on criteria established by the agency. This is necessary because there is rarely enough funding available to complete all recommended projects. The pavement management software contains priority models to prioritize the different pavement projects within each analysis year. These models may range from simple ranking routines to complex optimization models.

Ranking versus Optimization (16)

Ranking

In this guide, ranking refers to prioritization that is performed in a sequential fashion. Prioritization can be either single-year prioritization or multi-year prioritization, depending on whether projects are considered independently in each of the analysis years (single-year prioritization) or whether projects are considered in each analysis year and the optimal timing for rehabilitation is identified (multi-year prioritization).

Single-year prioritization is the most common technique used for project selection. Each segment is considered independently to determine whether it meets the criteria established by the agency for repair. If a pavement section does need repair, agency policies are used to determine the appropriate repair treatment and associated cost. After all the segments have been evaluated for a single year, the cost to repair segments identified as needing repair is compared to the available budget. If not enough money is available to address all needs, the projects are prioritized by some factor such as least initial cost, worst condition first, and so on. The projects are funded until the available budget is expended. All projects not funded are considered again in the next analysis year and prioritized with any new projects that are identified.

Single-year prioritization is common because it is a simple process that does not require a computer. Multi-year prioritization, on the other hand, is more complex because projects are considered in each year of the analysis and the year that provides the most benefit to the agency is recommended as the repair year. Within each repair year included in the analysis, the recommended projects are prioritized by some factor such as greatest benefit, highest benefit to cost ratio, and so on. The highest priority projects are funded until the available budget is expended. Any projects not funded in the recommended repair year are re-prioritized among the projects for the year in which the second highest benefit to the agency was identified. This process is different than single-year prioritization because of the interconnectivity of each of the analysis years. For this reason, multi-year prioritization permits an agency to better evaluate the trade-offs of delaying a project.

Optimization

In this guide, optimization refers to an analysis technique that evaluates repair strategies for the network as a whole before any specific projects or treatments are identified. Agencies that use optimization typically analyze various network strategies to determine the strategy that optimizes the agency goals. For example, an agency may select a strategy that maximizes the number of pavement sections receiving some type of rehabilitation. As a result of the analysis, the strategy recommendations will include information regarding the number of miles of pavement in each condition level that should be improved to another condition level. The agency is then responsible for identifying the specific projects that meet these guidelines.

Optimization is a very sophisticated type of analysis that requires advanced computer equipment and personnel familiar with the mathematical concepts it involves. Because of this, optimization techniques are not usually used at the local agency level.

Priority Model Development

The basic types of prioritization approaches include subjective project selection, priority ranking, and optimization. It is important for an agency to carefully choose which method of project prioritization it will use within its PMS, because the prioritization method used will have a significant impact on the benefits received from the pavement dollars expended. For example, it has been estimated that a simple ranking procedure can provide an agency with 20 percent to 40 percent more benefit than subjective project selection and that a further 10 percent to 20 percent benefit can be achieved by using optimization methods over ranking procedures (16). Examples of each type of priority method can be found in Chapter 4.

Subjective Project Selection

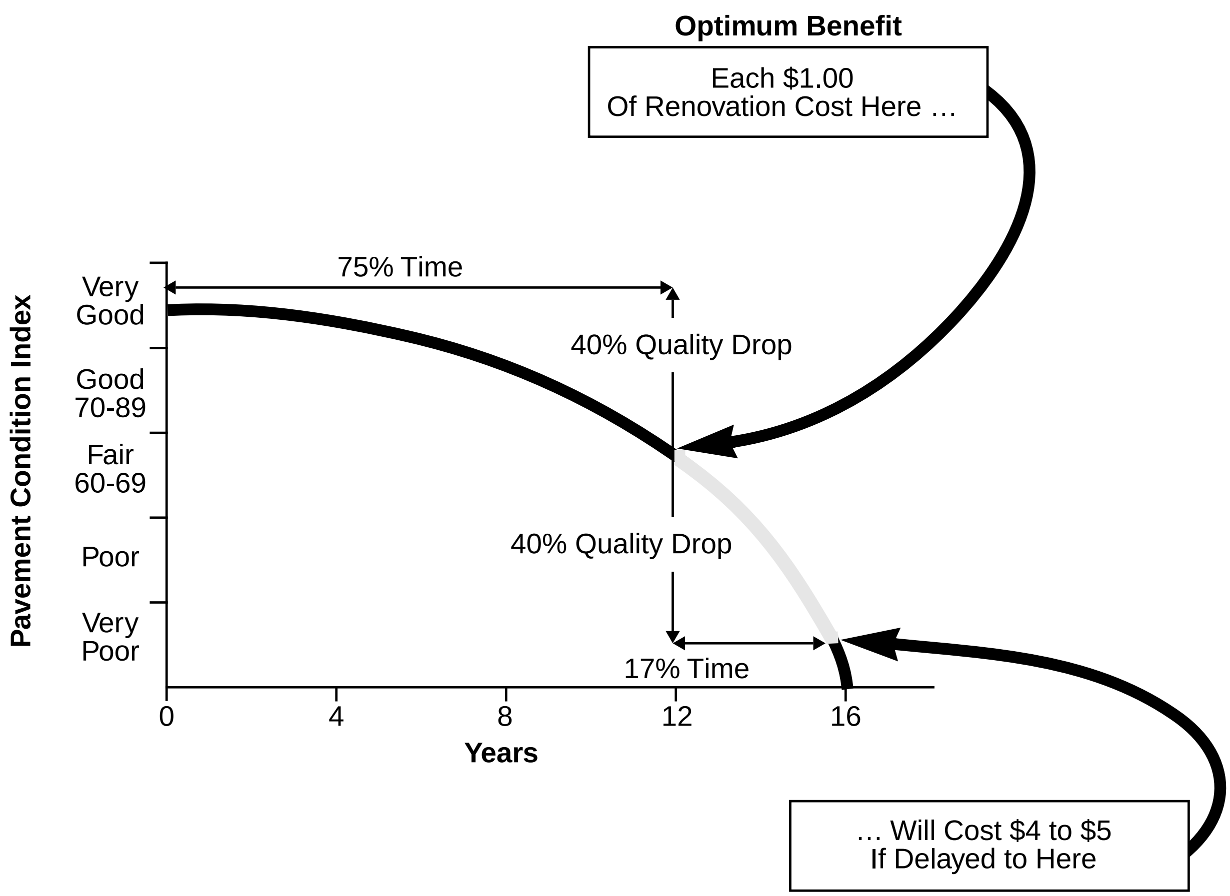
Subjective project selection involves an agency reviewing its list of potential projects and prioritizing the projects using its judgment and experience. This method has the advantage of being quick and simple. However, it is subject to bias and inconsistency and the results are usually far from optimal.

Ranking Methods (17,18)

Ranking Using a Single Condition Indicator: A single condition indicator (such as a CI, roughness index, structural index, and so on) can be used to rank projects.

One popular ranking approach using a single condition indicator is to fix the pavements in the worst condition, as defined by that condition indicator, first. This approach has the advantage of being simple and easy to use and appears to the public and elected officials to make sense. In addition, it does not require the development of performance models. The “worst first” ranking approach is the one most commonly used by Washington State local agencies.

On the surface, ranking those segments in the worst condition first seems logical. However, this type of ranking approach does not consider how much benefit is received for the funds expended. In fact, costs and benefits are not considered at all. Since it is much more costly to fix a pavement segment once it has deteriorated to very poor condition, as illustrated in the following figure prepared by Thurston County (19), this approach can be very expensive and is not recommended.



Another type of ranking using a single condition indicator, "reverse prioritization," has been used by some agencies to avoid the "worst first" problems. In "reverse prioritization," the highest priority is given to pavements that are at the point in their life cycle where repair is most cost-effective. An example of this prioritization approach is shown in the following table.

Condition Index	Major and Secondary Roads	Collector and Scenic Roads	Parking Areas
>60			
56 - 60	1	3	
41 - 55	2	5	
26 - 40	4	7	10
11 - 25	6	9	12
0 - 10	8	11	13

A Case Study: County Road Administration Board (CRAB) (20)

In CRAB's pavement management training courses, CRAB demonstrates the differences between using "worst-first" versus "reverse prioritization" approaches to project selection by actually running the different approaches using a sample database and a six-year analysis period.

This analysis always yields the results shown in the following table.

	Reverse Prioritization	Worst-First
Dollars Spent	*Same*	*Same*
Mile Rehabilitated	*Many More*	*Much Fewer*
Rehabilitation Type	*Seal Coats*	*Overlays*
Unit Cost	*Much Lower*	*Much Higher*
Overall CI	*Much Higher*	*Much Lower*

In one example that CRAB uses, the road network starts within overall condition of 65. At the end of the six-year analysis period, using equal budgets, the "reverse prioritization" approach results in an overall network condition of 54, whereas "worst-first" yields an overall network condition of 28.

> *A Case Study: City of Renton (21)*
>
> *While fixing the pavements in the worst condition first may not be the recommended ranking approach, many local agencies have such limited pavement repair budgets that it is all they can do just to keep the streets operational. One local agency, the city of Renton, wanted to break out of the cycle of repairing only the pavements in the very worst condition each year. However, with its existing annual allocation of funds for pavements, this was not possible. Renton went to the city Council, armed with facts and figures, and presented a case for a onetime infusion of money. The purpose of the money was to repair all the pavements in the poor to failed range. Once that was done, the city felt it would be able to switch its pavement management strategy to repairing pavements at the most cost-effective time in their life cycle. The council agreed to the request.*

<u>Ranking Using a Composite Index:</u> A composite index includes more than one ranking factor. For example, a composite index could be comprised of a condition index weighted 50 percent, a structural capacity index weighted 40 percent, and a traffic index weighted 10 percent. Each individual index of a segment is multiplied by its weighting percentage and they are added together to get a composite index. The composite indices are then used to rank the projects.

The most common ranking factors are pavement condition and functional classification. Factors such as structural capacity, roughness (ride), and truck traffic levels have also been used. When an agency uses this approach, it first determines what the major criteria are that it currently uses in determining which projects it undertakes when there is not enough money available to fund all needed projects. After it develops this list of prioritization criteria, it then determines how important each criterion is relative to the other criteria. Finally, the agency assigns a weight to each criterion based upon the results of its analysis.

While this approach is an improvement over ranking by worst first, because factors other than condition (such as traffic) can now be taken into account, the composite index itself is often difficult to interpret and still does not consider costs or benefits. This approach has the advantage of being simple and easy to use, and the development of performance models is not required.

<u>Ranking Using Initial Cost:</u> In this approach, those segments with the lowest initial repair cost are ranked highest. If this method is used, unit costs should be used to normalize for section size. This approach has the disadvantage of not considering repair performance, future costs, or benefits. It favors short-term inexpensive repairs over more permanent, initially more expensive repairs. It has the advantage of being relatively simple, and once again does not require the use of performance models.

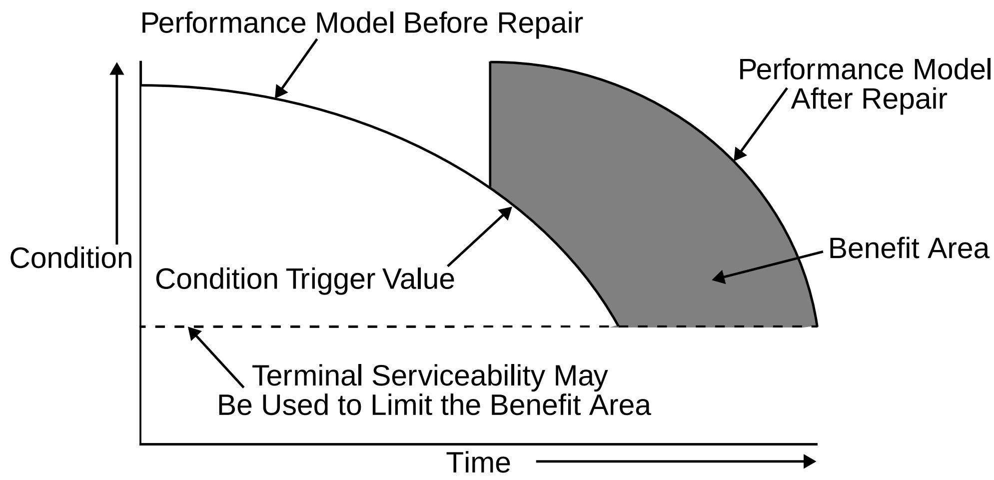
Ranking Using Least Present (Equivalent Uniform Annual) Cost: Ranking using least present cost is a form of life cycle cost (LCC) analysis. In this method, the total net present cost of repairing the segment is calculated. An analysis period is selected, and all future costs and salvage value are estimated. The segments needing repair are then ranked from lowest to highest present or equivalent uniform annual costs. A thorough discussion of how to perform LCC analysis, complete with examples, can be found in the WSDOT Pavement Guide (4).

The disadvantage of this approach, as with ranking using least initial cost, is that it only considers cost. LCC analysis assumes that all alternatives provide equal benefit over the analysis period. However, different repair alternatives almost certainly provide different levels of benefit to the user.

Ranking Using Benefit/Cost Ratio: In ranking by benefit/cost ratio, all costs and benefits from repairing each pavement segment are determined over the selected analysis period. The benefits normally considered are savings in accidents, travel time, and motor vehicle operating costs. The costs are calculated over the same analysis period, and include construction costs, maintenance costs, and future rehabilitation costs. Salvage costs also need to be taken into account during this analysis.

The analysis period should extend through at least one cycle of the strategy. Those projects which provide the greatest benefit for the funds expended are considered the best choices. Benefit/cost analysis is an improvement over the ranking methods described earlier, because benefit is taken into account for the first time. However, calculating benefit in terms of dollars is often difficult. Performance models are required for this approach.

Cost Effectiveness Analysis: Cost-effectiveness analysis is basically the same as benefit-cost analysis except that benefits are not expressed in monetary terms. In pavement management, one of the most common measures of benefit is the area under a performance curve. This assumes that the longer the pavement stays in good condition the more benefit will be accrued by the user. This is a reasonable assumption since pavements in poorer condition result in higher user costs. This concept is illustrated in the following figure.



The cost effectiveness is estimated using the following equation:

$$\text{Cost Effectiveness Ratio} = \frac{\text{Benefit Area} \times \text{Weighting Factor}}{\text{Total Cost/Area of Segment}}$$

Another approach to calculating cost-effectiveness annualizes the costs and divides the benefit area by the number of years in the life of the treatment to annualize the effectiveness as well. The equation then becomes:

$$\frac{(\text{Benefit Area/Years Affected}) \times \text{WF}}{\text{EUAC/Area of Segment}}$$

The weighting factor (WF) is used to adjust the procedure when it is used to prioritize pavement segments that do not serve the same levels of traffic. In this situation, the cost-effectiveness rating must be weighted by traffic volume to account for the number of users using a pavement segment. This adjustment ensures that the lower-cost repairs on low-volume roads are not necessarily ranked above the higher-cost repairs on heavily traveled roads.

The projects are ranked in order of the highest cost effectiveness ratio. This method has the advantage of not having to express benefit in terms of dollars, which is often very difficult to do.

<u>Incremental Cost-Effectiveness Analysis:</u> This analysis approach considers benefits, often in terms of additional life (area under the curve), and life-cycle costs over a given analysis period. The objective of this analysis is to select the optimal strategy for each pavement section so that benefits are maximized without exceeding the available funding levels of any given year. Although not a true optimization approach, the recommendations are nearly optimal and can be run very quickly on a computer.

The incremental cost-effectiveness analysis compares the incremental improvements provided by various rehabilitation strategies for each pavement section until the most benefit has been derived for the available funding levels. This is done by evaluating the change in benefit and cost between all feasible rehabilitation strategies for each pavement section. Projects are sorted in increasing order of incremental benefit cost (IBC) with the lowest IBC considered first. If any strategies result in a negative IBC, they are eliminated from consideration. However, if the IBC for one strategy is greater than was calculated for the first strategy considered, then the original strategy is eliminated if the budget can tolerate the additional cost of the new strategy. This iterative process continues until the available funding levels are depleted.

Optimization Method

The procedures presented so far have been based on deciding how to repair each individual segment and then ranking them in order of importance to come up with a network plan. Optimization involves two separate activities. First, overall network goals are established (such as optimizing condition versus money expended). Second, projects and treatments are selected to achieve the desired goal. The second step is often difficult for agencies because network goals may be to improve 20 percent of the segments in one condition to the next best condition. It is the agency's responsibility to then select which sections to improve.

There are a number of optimization tools available which can be used to determine the optimal allocation of funds. These include linear programming, integer programming, Markov decision analysis, and dynamic programming. For information on optimization, please refer to *NCHRP Synthesis 222: Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments* (16) which provides an excellent overview of the topic. It should be noted that none of the local agencies reviewed during the preparation of this guide use optimization in their pavement management process.

The advantage of optimization is that it provides optimal solutions for the network as a whole. The main disadvantage is that it is complicated and because network goals are established first, it is often difficult to match projects and treatments to the goals. Ranking systems are much easier to explain in simple terms which elected officials and the public can understand. Optimization techniques also usually require substantial long-term data and powerful computers. However, heuristics (algorithms that approximate optimal solutions) are being used to overcome the computer limitations.

Priority Model Evaluation and Modification

Many methods for prioritizing pavement projects have just been presented. Whichever method is used within an agency's PMS, the priority model needs to be periodically reviewed and adjusted. One effective way to evaluate how well a priority model is working is to compare the PMS recommended project list for the previous year with the list of projects that were actually completed. While these lists will never match up 100 percent due to outside factors that the pavement management software does not take into consideration (such as utility and construction projects, results of project level engineering analysis, growth and changes in traffic patterns, political influences, and practical constraints), some degree of correlation should exist between the two lists. The next chapter shows how adjusting the priority model will affect the final recommended project list.

Establishing A Feedback Loop Within A PMS

Throughout this chapter, the reader has been advised to periodically review and update the models used within its pavement management software. The establishment of a feedback process will assist with this calibration process. Further, feedback information can be used to check the accuracy of design procedures, to evaluate the cost effectiveness of different rehabilitation and maintenance techniques, and to support research projects (such as evaluating the impact of utility cuts on pavement performance).

During the initial implementation of a PMS, processes should be established that allow for continual feedback of information into the PMS. In addition, a schedule for conducting periodic reviews of the pavement management software models to make sure that they still reflect original assumptions on costs, conditions, and organizational policies should be established. These activities are crucial to verifying and improving the reliability of a PMS.

Feedback Process and Annual Calibration Schedule

The feedback process is essentially a manual activity. It will vary depending upon the agency, however the following activities are usually conducted. These activities should be conducted at least annually.

1. At the completion of each pavement maintenance or rehabilitation project, store the final cost information in the PMS database. Use this information to verify the accuracy of the cost information that is being used in the PMS software models to estimate the cost of different repair alternatives. Adjust the costs used within the models as needed based upon the actual project cost data.
2. At the completion of each pavement inspection cycle, compare the actual pavement conditions with those predicted by the pavement management software. With time, performance models can be systematically calibrated using data from pavement condition surveys and construction records, thus improving the reliability of and confidence in PMS recommendations.
3. Perform an annual check of whether maintenance and rehabilitation treatments being considered by the pavement management software are still applicable by comparing the treatments recommended by the software with the treatments actually used in projects during the past year. Over time, some repair types may be identified as not providing adequate

performance and other repair techniques may become feasible. Adjust the feasible repair selection identification models within the pavement management software as necessary.

4. Each year, compare the actual projects rehabilitated with those recommended by the pavement management program. If these do not match fairly well, the pavement repair needs identification models and the prioritization models need to be adjusted. Keep in mind, however, that an agency will never obtain 100% correlation between the pavement management recommendations for projects and the projects actually completed. This is due to the fact that factors not usually accounted for within a pavement management software program, such as utility projects and political realities, impact the ultimate selection of projects.

A Case Study: City of Tacoma (22)

The city of Tacoma began its pavement management efforts in 1982 and has been refining and improving its PMS ever since. The pavement management software the city uses permits the agency to either use default parameters when performing analysis or to define agency-specific parameters. Over the years, the city has been working on establishing its own agency-specific parameters.

The PMS software allows the city to define its own repair alternatives and performance models. To date, the city has concentrated primarily on developing its own decision tree which specifies the repair types that it wants the PMS software to consider under specific conditions as presented in Appendix A, Case Study #9.

The city's decision tree is broken down by pavement surface type, functional classification, and condition. For example, ACP pavements are separated from PCC and BST pavements in the decision tree. Underneath each of these surface types, the decision tree is further broken down by functional classification. For example, ACP pavements are broken out into principal arterials, collector arterial, local access, and so on. Finally, each of the surface type/functional classification combinations are divided by condition index.

For each of the resulting surface type/functional classification condition combinations, the city has defined the primary rehabilitation strategy it considers appropriate and an alternative maintenance strategy that it would recommend applying if there were insufficient budget available to fund the primary rehabilitation strategy. In addition to specifying the type of repair, the software allows the user to specify the unit cost of the repair and to control how the condition index of the pavement will be impacted by applying the repair.

The city developed the decision tree using several resources. First, the experience of the maintenance and engineering staff pertaining to what repair types work best under what conditions was taken into account. Second, the life of the different repair types was estimated using a combination of actual experience with the roads and looking at the historical construction information in the PMS database. The unit cost information was obtained by reviewing bid sheets.

While the city of Tacoma has developed a decision tree for use in its PMS program, it is constantly refining it. For example, the city hopes to replace functional classification with actual traffic classification at some point in the future. In addition, the unit costs of the different maintenance and rehabilitation activities change over time and the decision tree needs to be updated.

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The performance models which are used in the PMS software to predict future pavement condition can also be modified by the user. At this point, the city of Tacoma only has one good inspection data point in its database. Therefore, each segment is assigned a performance curve by fitting a default curve (for functional class and pavement type) through the last inspection/age data point.

In the future, when the city has completed another inspection cycle, there will be multiple data points available for use in model development. At that point, the city will first attempt to fit a curve to the data using regression analysis. If the resulting curve is unsatisfactory (based upon its criteria), the city will elect to use the default curve fit through the latest inspection/age point. Since data points can be from distress surveys, expected life, or construction histories (CI assumed 100 at last construction date), or any combination thereof, the city has flexibility in how it can define its performance models.

Summary

Until an agency has enough information to calibrate its PMS software, the use of default parameters is acceptable. However, the data analysis and development of recommendations performed with the program will be much more accurate and reliable once agency-specific parameters have been developed and entered into the software.

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4:P:DP/PMAG

Chapter 4 Analyzing Pavement Management Data

This chapter covers the types of analysis that can be performed with pavement management software, and includes numerous examples of the different analytical approaches that can be taken. Chapters 3 and 4 are designed to be used in conjunction with each other. Chapter 3 provides the theoretical background necessary to understand Chapter 4.

Analysis Process

A PMS is a tool that can help the pavement manager respond to questions about the pavement network from the public, elected officials, upper management, and other agency departments. It also provides the pavement manager with the tools necessary to identify maintenance and rehabilitation needs and budget requirements. The pavement manager can use pavement management software to sort through and evaluate the pavement information collected and stored. Typically, the following types of analysis are performed:

- **Condition Assessment:** The overall condition of the network as a whole and the condition of individual segments are calculated using the distress data stored in the system. This information can also be used to calculate the rate of deterioration, cause of distress, and type of distress present in each segment.
- **Condition Prediction:** The future condition of the network and individual segments without maintenance and rehabilitation are calculated using performance models contained in the PMS. Future performance resulting from different maintenance and repair strategies can also be estimated.
- **Needs Assessment:** Segments needing repair in each of the analysis years are identified. Feasible repair treatments are evaluated and a recommended repair treatment and estimated repair cost are identified.
- **Budget Analysis:** The level of funding required to complete all the projects identified during needs assessment is compared to the available budget levels for each of the analysis years. Projects are prioritized in accordance with agency-specified objectives. These objectives can range from maintaining the system above a specified condition to obtaining the most benefit from the money spent.
- **Repair Program Adjustment:** Even after an agency has determined which funding strategy to use, the program recommended by the pavement management software requires adjustment by the pavement manager. Logical projects need to be grouped together in a common

repair year, and outside factors (such as upcoming utility work or residential development) need to be taken into consideration. Finally, project level analysis is performed to finalize the repair design and obtain accurate project costs.

- **Analysis of Various Futures ("What If"):** "What if," or impact analysis, can include several different activities. The results of different funding strategies (funding level, allocation of funding among different classes of roads, allocation of funding between preventive maintenance and rehabilitation) are compared based upon factors such as overall network condition, a backlog of needs, or future funding needs. The impact of delaying specified projects or funding alternative segments compared to those recommended by the pavement management program can also be evaluated.
- **Special Studies:** Special studies can be undertaken to evaluate such things as the performance of different maintenance and repair techniques.
- **Reevaluation of the Pavement Management Program:** On a regular basis, a pavement manager should also perform a feedback analysis. This involves reviewing the models used within the software and revising them as needed.

An example street network is used throughout Chapter 4 to illustrate the different activities that a pavement manager could undertake while preparing a pavement maintenance and repair program using a PMS. The example illustrates the process undertaken by an agency using priority ranking rather than true optimization (which requires a computer and complex calculations to perform). Basic information about the example street network is shown in the following table. ***Note:*** This is an example only. It does not contain real information.

Example Street Network Inventory Information

Street Name	*Segment Number*	*Pavement Area (sf)*	*Functional Class*	*Truck Traffic Volume*	*Surface Type**	*1996 Age*
Oak	10	100,000	Urban Arterial	High	PCC	20
Maple	10	4,800	Residential	Low	AC	5
Elm	10	50,000	Rural Arterial	Moderate	AAC	15
Birch	10	25,000	Urban Access	Moderate	APC	10
Birch	20	10,000	Urban Access	Moderate	AC	15
Pine	10	4,000	Residential	Low	AC	10
Pecan	10	8,000	Rural Access	Low	BST	7

*Where PCC = portland cement concrete; AC = asphalt cement concrete; AAC = asphalt overlay over AC; APC = asphalt overlay over PCC; and BST = bituminous surface treatment.

Condition Assessment

The condition evaluation data contained in the PMS are used to assess the current physical condition of each pavement segment in the database. A condition index (CI) based upon visual distress data is normally calculated for each pavement segment. These calculations are usually performed automatically by the pavement management software after the distress data have been entered. In addition to determining a CI, the visual distress data can be used to calculate the rate of deterioration and determine the cause of deterioration (load, environment, or other). Depending upon the pavement management software, these calculations may or may not be automatic.

Condition Index

The CI provides a general sense of the pavement condition and the magnitude of work that will be required to rehabilitate the pavement. A CI of 100 indicates that a pavement is exhibiting no visual signs of deterioration. A CI of 0 is essentially a failed pavement.

Type of Distress

The type of distress present provides insight into the cause of the pavement deterioration. Distress types are characterized as load-related (such as alligator cracking), climate/durability related (such as weathering and D-cracking), and other (distress types that cannot be attributed solely to load or climate/durability). Understanding the cause of distress allows a rehabilitation alternative to be selected that corrects the cause and thus eliminates its recurrence. Appendix C contains a table describing the primary cause of the different visual distress types.

Pavement Deterioration Rate

The deterioration rate helps identify those pavement sections that are failing faster than normal. It can be estimated by using the following equation:

$$\text{Deterioration Rate} = \frac{100 - CI_{\text{at last inspection}}}{\text{Pavement Age}_{\text{at last inspection}}}$$

Segments exhibiting higher than normal deterioration rates warrant close monitoring and further evaluation by the pavement manager.

To determine a normal deterioration rate, calculate all past rates on the network and examine them for a common trend. One way would be to take the overall average deterioration rate plus or minus one standard deviation.

Some agencies use a measure of the structural capacity of each segment, as determined by nondestructive testing using equipment such as a Road Rater or Falling Weight Deflectometer, in addition to visual distress data within their pavement management process. This information is used to help determine the amount of structural deterioration present and help prescribe the right repair technique. Please refer to *A Guide for Local Agency Pavement Managers* (1) for further information on the use of nondestructive testing data.

The following table shows the results of the condition assessment for the example network. This type of table can provide very useful information to the pavement manager. It summarizes the overall condition of each segment, describes the types of distress present, predicts the cause of deterioration based upon the distresses identified, and provides a quick estimate of how quickly each pavement segment is deteriorating.

Example Street Network Current Condition Information

Street Name	Segment Number	1996 CI**	Prominent Distress Types	Main Cause of Deterioration	Deterioration Rate (CI points per year)*
Oak	10	75	Patching; Spalling	Other	1.25
Maple	10	80	Block Cracking	Environment	4.00
Elm	10	70	Alligator Cracking	Load	2.00
Birch	10	65	Rutting	Load	3.50
Birch	20	45	Alligator Cracking; Rutting	Load	3.67
Pine	10	80	Flushing	Environment	2.00
Pecan	10	60	Raveling	Environment	5.71

*Calculated by: (100 - 1996 CI)/(1996 pavement age).
**Assumes a rating scale of 0 to 100 with 100 being the highest possible rating.

A pavement manager can develop the type of table shown above either manually or using pavement management software. The two (or however many the pavement manager wants to use) most prevalent distress types for each segment are listed. Appendix C, which contains a table describing the primary cause of the different visual distress types, can be used to assist in filling out the fifth column of the table. If an agency is using structural testing data, another column can be added to the table to show those results.

This type of table provides the pavement manager with a quick review of the current condition level of each pavement segment, how rapidly it is deteriorating, and what is causing the deterioration. This is all very useful information when prioritizing projects or selecting a feasible repair alternative.

Condition Prediction

As an agency develops a multi-year pavement maintenance and repair program, it needs to project pavement condition into the future. This is done through the use of performance prediction models. The simplest type of model is based upon the current condition of the pavement segment and its current age. As previously discussed, a deterioration rate can be calculated by dividing the drop in PCI since a segment's last construction or rehabilitation (100 - last inspection PCI) by the segment's age at the last inspection. For example, for Oak Street the rate of deterioration is (100 - 75) divided by 20, or 1.25 PCI points per year. This results in a linear deterioration model. In other words, for Oak Street the rate of deterioration would remain unchanged year to year, so that in four years the PCI would be 70. The deterioration rates shown in the above table are based on this type of model.

While this modeling approach is simple to perform and easy to understand, it does have disadvantages. Pavements rarely perform in a linear fashion. A pavement segment may show little deterioration for many years, but once deterioration does begin it can accelerate quickly. Chapter 3 discusses more reliable techniques for developing performance models

Needs Assessment

During needs assessment, pavement segments needing repair are identified and the recommended repair treatment is selected. A PMS program uses *Repair Needs Models* as discussed in Chapter 3 to identify which pavement segments should be considered for repair. These models often identify repair needs based upon criteria such as surface type, current pavement condition, traffic level, functional class, and rate of deterioration. Threshold values are set for the different criteria being used that determine when a treatment should be applied. If a pavement segment is identified as needing repair, *Feasible Treatments Models* as described in Chapter 3 identify which repair treatments would be appropriate to use to fix the segment.

Often, the determination that a pavement segment needs repair and the identification of feasible repair alternatives are performed simultaneously within pavement management software. One method used to identify repair needs and select feasible repair alternatives is a treatment matrix. An example treatment matrix is shown on the following page.

Please note that this matrix only considers major repair actions; preventive maintenance alternatives are not addressed. Preventive maintenance activities are usually applied on a periodic basis (such as crack sealing annually) until the pavement segment is projected to deteriorate to a point where rehabilitation is required. For further information on preventive maintenance, see Chapter 5.

Example Treatment Matrix

Allowable Functional Class	*Allowable Surface Type*	*Allowable Truck Traffic*	*Allowable Main Cause of Deterioration*	*Allowable Condition Index*	*Feasible Repair Type*	*Unit Cost (sf)*
Rural Local Access	BST, ACP, AAC, APC	Low	All but Load	50 - 70	Chip Seal	$2.25
All but Urban Arterials	BST, ACP, AAC, APC, PCC	Low, Moderate	All but Load	40 - 70	Thin Overlay	$3.00
All	BST, ACP, AAC, APC, PCC	All	All	0 - 70	Thick Overlay	$4.75
All but Local Access	ACP, AAC, APC, PCC	High	All but Environment	0 - 50	Recon-struct	$8.50

The following table summarizes the feasible first year repair needs for the example problem, based upon the treatment matrix just presented.

Example Street Network Needs Assessment and Feasible Repair Alternatives

Street Name	*Segment Number*	*Repair Needed?*	*Feasible Repair Alternatives*
Birch	10	Yes	Thick Overlay
Birch	20	Yes	Thick Overlay; Reconstruct
Elm	10	Yes	Thick Overlay
Maple	10	No	N/A
Oak	10	No	N/A
Pine	10	No	N/A
Pecan	10	Yes	Chip Seal, Thin Overlay, Thick Overlay

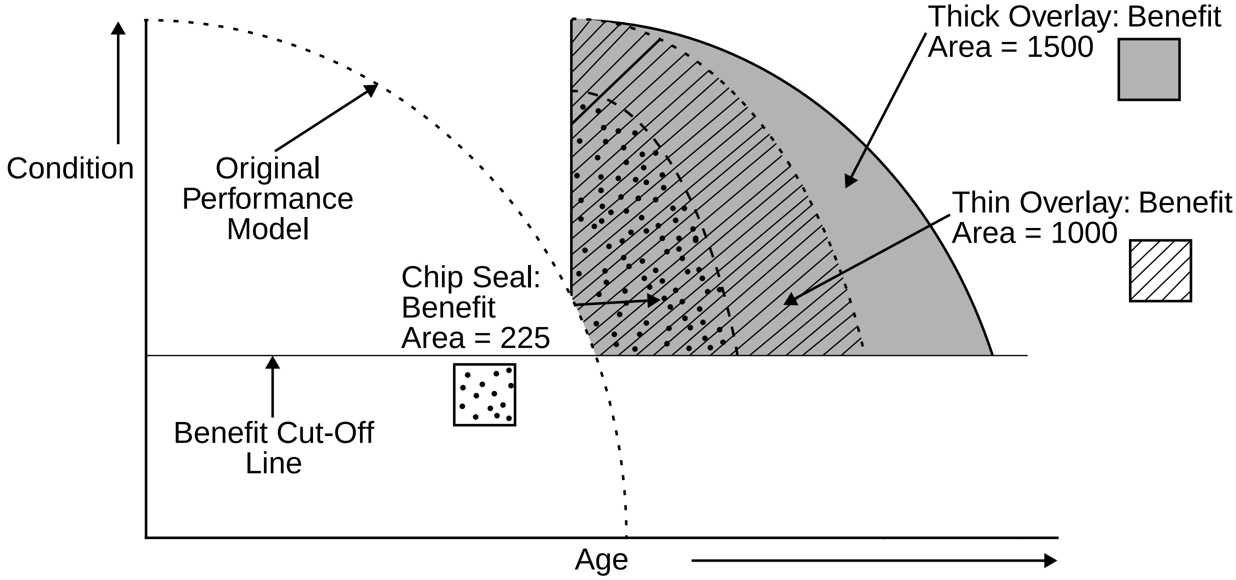
The next step in the needs assessment is to select the recommended treatment from the feasible repair alternatives. Several methods, described in the previous chapter, can be used to select the recommended treatment when more than one feasible treatment has been identified. Decision trees, initial cost, life-cycle cost, benefit-cost ratio, and cost-effectiveness are some of the techniques used in the selection process.

Keep in mind that at this point in the preparation of a pavement repair program, the analysis is being performed at the network level. The treatments identified are used primarily to assign a general repair level to each segment of pavement that has been identified as needing repair for budget purposes. Some will ultimately cost more money than estimated and others will require less. Project level analysis will be performed later in the preparation of the pavement repair program and the actual repair treatment type will be selected at that time.

For the example street network, the recommended repair type for each segment with more than one feasible repair type was selected using the cost-effectiveness technique. In this approach, the benefit of the repair alternative (defined as the area between the original performance curve and the performance curve of the applied repair type) is divided by the unit cost of the repair type. A cutoff condition level is often set using this technique, which simply specifies that below that condition level no benefit is assumed to be gained. For a road network, the cutoff is often set between a CI of 20 to 35.

For example, there are three feasible options for repairing Pecan Street: a chip seal, a thin overlay, and a thick overlay. Since the thin overlay has the greatest benefit relative to the cost (cost-effectiveness ratio = 333), it is the recommended repair type. This approach is illustrated in the following figure. The calculation of the benefit area is best done with the assistance of a computerized PMS.

Treatment	Cost	Benefit	Cost-Effectiveness Ratio
Chip	$2.25/sf	225	225/2.25 = 100
Thin Overlay	$3.00/sf	1000	1000/3.00 = 333
Thick Overlay	$4.75/sf	1500	1500/4.75 = 316



The results of the cost-effectiveness analysis for the example street network are summarized in the following table.

Example Street Network Recommended Repairs and Associated Costs

Cost-Effectiveness Ratio	*Street Name*	*Segment Number*	*Recommended Repair Type*	*Repair Cost*
316	Birch	10	Thick Overlay	$118,750
470	Birch	20	Reconstruct	$85,000
316	Elm	10	Thick Overlay	$237,500
N/A	Maple	10	Do Nothing	$0
N/A	Oak	10	Do Nothing	$0
333	Pecan	10	Thin Overlay	$24,000
N/A	Pine	10	Do Nothing	$0

*Not weighted by traffic.

Budget Analysis

At this point in the analysis process, a tentative work program identifying which segments require repair has been developed, recommended repair treatments and costs have been identified, and an estimated benefit calculated. Now, a budget analysis must be performed to determine which of the proposed projects can be funded. This analysis will reveal that available funding levels exceed project requirements, exactly match project requirements, or fall short of project requirements.

Project Ranking

Most agencies are faced with insufficient funding which necessitates the ranking of projects to determine which segment repairs have to be delayed until a future year. Or, the agency selects less cost-effective repair methods that have a lower initial cost.

Many methods of ranking projects are available, as described in Chapter 3. The following ranking methods are applied to the example problem for illustration purposes.

Subjective Ranking

One time-honored method of ranking is purely subjective. It involves someone ranking projects based upon his or her subjective opinion as to the condition of the roads. It is highly vulnerable to political and other outside interests. The following table illustrates how this process might rank the example network.

Example Street Network Ranking of Projects Using Subjective Ranking

Street Name	*Segment Number*	*Comment*	*Rank*
Oak	10	Road in front of mayor’s house	1
Pecan	10	Greatest number of citizen complaints	2
Birch	10	Highest priority of maintenance supervisor	3
Birch	20		4
Elm	10		5
Maple	10		6
Pine	10		7

Ranking Using a Single Condition Indicator

“Worst First” Ranking Using a Single Condition Indicator

In ranking using a single condition indicator, a single measure of condition is used to prioritize the projects. In the example problem, the condition indicator is the pavement condition index. If “worst first” prioritization is used on this pavement network, the ranking shown in the following table would result.

Example Street Network Ranking of Projects Using Worst First Ranking

Street Name	Segment Number	PCI	Priority Ranking
Birch	20	45	1
Pecan	10	60	2
Birch	10	65	3
Elm	10	70	4
Maple	10	80	N/A (no repair needs identified)
Oak	10	75	N/A (no repair needs identified)
Pine	10	80	N/A (no repair needs identified)

The "worst first" approach has the disadvantage of not considering the benefit received from the funds expended. In fact, costs and benefits are not considered at all. In the long term, this approach is usually very expensive, since it focuses work efforts on major rehabilitation projects. It is much more costly to fix a pavement segment once it has deteriorated to very poor condition. It does have the advantage of being simple and easy to understand.

Reverse Prioritization Ranking Using a Single Condition Indicator

In reverse prioritization, the highest priority is given to the pavement segments that an agency believes are at the point in their service life where repair will be most cost-effective. In this example, an agency has identified pavements with a CI between 50-70 as having the highest priority, 30-50 as having the second highest priority, and 0-30 as having the lowest priority. This prioritization approach results in the following ranking.

Example Street Network Ranking of Projects Using Reverse Prioritization

Street Name	Segment Number	PCI	Priority Ranking
Birch	10	65	1
Elm	10	70	1
Pecan	10	60	1
Birch	20	45	2
Maple	10	80	N/A*
Oak	10	75	N/A*
Pine	10	80	N/A*

*No repair needs identified.

Reverse ranking does not include an actual calculation of costs and benefits, however, it does indirectly try to account for the increased cost-effectiveness of repairing a pavement before it has deteriorated extensively.

Ranking Using a Combined Index

A combined index includes more than one ranking factor with each factor weighted by relative impact. For example, if condition and traffic were combined into a single index the agency could rank highest those pavement segments in the worst condition and serving the highest traffic levels. That way, the worst pavements that are used by the most people are ranked highest.

For the example problem, the agency felt that condition was the most important factor to consider in ranking, but that traffic levels were important too. Therefore, the agency gave the traffic index a 30 percent rating and the condition index a 70 percent weighting. (***Note:*** the weighting factors must total 100 percent). The traffic index needs to be on the same scale as the condition index for this approach to work, so for the example problem low truck traffic is assigned an 80, moderate truck traffic is assigned a 40, and high truck traffic is assigned a 10. To calculate the combined index in this case, with Birch Segment 20 used as an example, the following equation is used:

$$\text{Combined Index} = (\text{Condition Index} \times 0.7) + (\text{Traffic Index} \times 0.3)$$

$$\text{Combined Index} = (45)(0.7) + (40)(0.3)$$

$$\text{Combined Index} = 43.50$$

This ranking approach results in the following prioritization of the example network. Please note that in this case the smaller the combined index the more critical the segment.

Example Street Network Ranking of Projects Using a Combined Index

Street Name	*Segment Number*	*Condition Index*	*Traffic Index*	*Combined Index*	*Priority Ranking*
Birch	20	45	40	43.50	1
Birch	10	65	40	57.50	2
Elm	10	70	40	61	3
Pecan	10	60	80	66	4
Oak	10	75	10	55.50	N/A*
Maple	10	80	80	80	N/A*
Pine	10	80	80	80	N/A *

*No repair needs identified.

Note that this prioritization approach results in a different ranking of projects than the ranking by single condition index did. This approach is an improvement over the ranking by single condition index, because factors other than condition (such as traffic) can be taken into account. However, the combined index itself is often difficult to interpret and the method still does not consider costs or benefits.

Ranking Using Initial Cost

In this approach, those segments with the lowest initial repair cost are ranked highest. Initial repair cost includes all costs involved in completing the repair; however, it does not include any subsequent costs for maintenance of that repair. If this method is used, unit costs should be used to adjust for segment size (otherwise the smallest segments almost always are assigned the highest priority rankings).

For example, one section could be one mile long and the other 5 miles long. To adjust for the different areas, the total cost of the repair is divided by the area of pavement being repaired to come up with a unit cost of repair. The results of this ranking method when applied to the example street network are shown in the following table.

Example Street Network Ranking of Projects Using Initial Cost

Street Name	***Segment Number***	***Area (sf)***	***Total Cost of Repair***	***Unit Repair Cost*****	***Priority Ranking by Total Initial Cost of Repair***	***Priority Ranking by Initial Unit Repair Cost***
Pecan	10	8,000	$24,000	$3.00/sf	1	1
Elm	10	50,000	$237,500	$4.75/sf	4	2
Birch	10	25,000	$118,750	$4.75/sf	3	2
Birch	20	10,000	$85,000	$8.50/sf	2	4
Oak	10	100,000	N/A*	N/A*	N/A*	N/A*
Maple	10	4,800	N/A*	N/A*	N/A*	N/A*
Pine	10	4,000	N/A*	N/A*	N/A*	N/A*

*No repair needs identified.
**Unit repair cost is calculated by dividing the area of the segment by the total cost of the repair.

Note that the results are different if total initial cost is used rather than initial unit cost. Ranking by initial cost has the disadvantage of not considering repair performance, future costs, or benefits.

Ranking Using Cost-Effectiveness

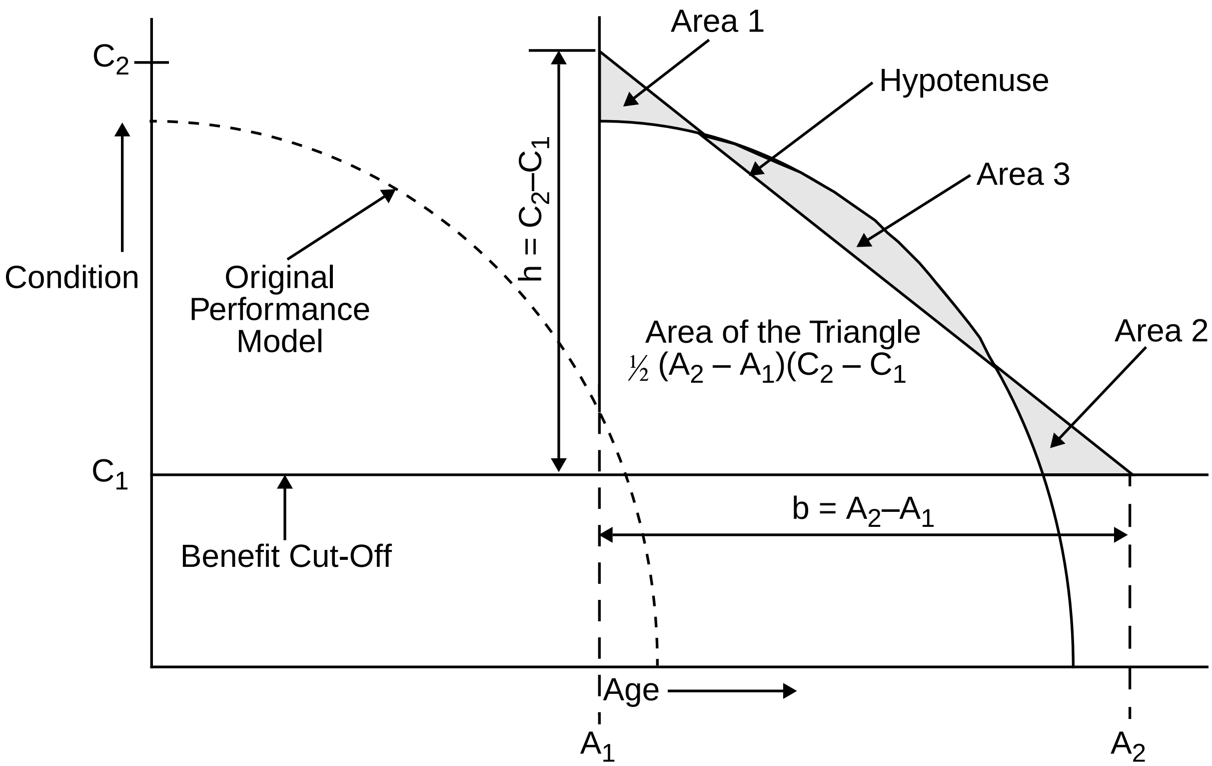
In ranking using cost-effectiveness, all costs and benefits from repairing each pavement segment are determined over the selected analysis period. The costs include construction costs, maintenance costs, and future rehabilitation costs. In this example, the measure of benefit is the area under a performance curve (as illustrated in Chapter 3). This assumes that the longer the pavement stays in good condition the more benefit will be accrued by the user. If the traffic levels served by segments being prioritized are not equal, as in the example problem, the cost-effectiveness rating must be weighted by traffic volume (otherwise, the lower-cost repairs on low-volume roads will usually be ranked above the higher-cost repairs on heavily traveled roads).

The results of this ranking method when applied to the example street network are shown in the following table. In this example, the benefit for a thin overlay is 1,000, the benefit for a thick overlay is 1,500, and the benefit for reconstruction is 4,000. These benefits were calculated using the area under the performance curves presented earlier in this section under needs assessment. Note that computerized pavement management software programs are usually used to perform these benefit calculations since they involve integral calculations; they are not normally done manually. For reference, a manual process of calculating benefit is described below.

If a curve is available, a rough estimate can be made by converting the arc under the curve to a triangle of approximate equivalent arc.

To do this, draw the hypotenuse of a triangle through the benefit curve such that the areas marked “Area 1” and “Area 2” are approximately equal to “Area 3” as shown in the following figure. The approximate benefit area is the area of the triangle formed by the hypotenuse, side “h” (formed by the vertical distance from the benefit cutoff line and the hypotenuse intercept, at “A_1”), and the side “b” (formed by the horizontal distance along the benefit cutoff line from “A_1” to the intercept of the hypotenuse with the benefit cutoff line) at “A_2:”

$$
\begin{aligned}
\text{Approximate Benefit Area} &= \text{Area of the Triangle} \\
&= \tfrac{1}{2}\, bh \\
&= \tfrac{1}{2}\,(A_2 - A_1)(C_2 - C_1)
\end{aligned}
$$



The agency in this example decided that traffic on high volume roads was most critical, with less of an important distinction being made between low and medium volume roads. Therefore, the agency set the traffic weighting factor at 1 for low volume roads, 1.25 for medium volume roads, and 2 for high volume roads.

Example Street Network Ranking of Projects Using Cost-Effectiveness

Street Name	***Segment Number***	***Benefit of Repair***	***Total Cost of Repair***	***Area (sf)***	***Traffic Weighting Factor***	***Cost Effec-tiveness*****	***Priority Ranking***
Birch	20	4000	$85,000	10,000	1.25	588	1
Birch	10	1500	$118,750	25,000	1.25	395	2
Elm	10	1500	$237,500	50,000	1.25	395	2
Pecan	10	1000	$24,000	8,000	1	333	3
Oak	10	N/A	N/A	100,000	2	N/A	N/A*
Maple	10	N/A	N/A	4,800	1	N/A	N/A*
Pine	10	N/A	N/A	4,000	1	N/A	N/A*

*No repair needs identified.

$$\text{**Cost Effectiveness} = \frac{[\text{Benefit Area} \times \text{Weighting Factor}]}{\text{Total Cost/Area of Segment}}$$

In this method, the higher the cost-effectiveness rating the more critical the work. This method has the advantage of considering both costs and benefits, which recognizes the fact that not all repair alternatives yield the same level of service to the public.

Actual Ranking Process

Once the segments have been ranked, regardless of the priority ranking technique used, the segments are selected from the top of the list to the bottom until the funds for the analysis year are used up. A check is made to make sure that all the funds are spent. For example, the third priority project may require $300,000 when there is only $250,000 left in the budget. Lower priority projects (in order of priority) are then reviewed to see if one of them can be funded for $250,000 or less.

When funds are exhausted, those projects not funded are moved into the next year. These projects are then considered along with those that were originally identified as needing repair in the second year. The same process described for the first year can be repeated for as many years as desired. This is a called a repeated single year prioritization. *Please note, this is not the same as true multi-year prioritization, where the benefit/cost of projects and treatments are considered in different years to find the best combination of segments to repair, the best treatments to apply, and the best time to apply the treatments. For more information on this, please refer to Chapter 3.*

In the example street network problem, the first year budget is $125,000. If the ranking by cost-effectiveness is used to prioritize the projects, then the following table shows which projects will be selected for funding during the first year and which will be delayed. Note that Pecan Street was funded, even though it had a lower priority ranking than Birch, Segment 10 and Elm Street. This is because there had to be a balancing act between available funds and the size of the project. The Birch and Elm Street projects were too costly for the budget remaining after the first priority project was funded. Unfunded projects would be delayed until later years when funding is available.

Example Street Network Final Project Selection

Priority Ranking	Street Name	Segment Number	Repair Cost	Accumulated Repair Costs if Projects Are Funded	$125,000 Budget Limit
1*	Birch	20	$85,000	$85,000	▼
2	Birch	10	$118,750	$203,750	
2	Elm	10	$237,500	$441,250	
3*	Pecan	10	$38,000	$479,250	
N/A**	Oak	10	N/A	N/A	
N/A**	Maple	10	N/A	N/A	
N/A**	Pine	10	N/A	N/A	

*Projects funded in first year. ($85,000 + $38,000 = $123,000 < $125,000 budget limit.)
**No repair needs identified.

Repair Program Adjustment

The pavement repair program developed up to this point should not be used directly but should be refined through further adjustment. Network level analysis identifies candidate projects and required levels of repair. The resultant program provides a sound basis for developing the final repair program, but manual adjustments do need to be made to the program. The pavement manager needs to review the program and perform the following actions:

1. Review the list and remove any projects that should not be included in the final program due to factors not considered by the PMS. For example, if a road segment is scheduled for an overlay next year and a large utility project will be conducted on the same segment in two years, the overlay project should be delayed until after the utility work is finished. Another common situation that necessitates the modification of the final program is when a road segment is scheduled for repair by the PMS, however, due to increasing traffic a decision has already been made to reconstruct and widen the road. Or, if a segment is already scheduled in a six-year program, the PMS output should be adjusted to reflect this.

2. Review the list and add projects that were not identified by the PMS but must be completed due to factors not considered by the PMS. For example, a road could be in good condition but require an overlay because of an expected or anticipated increase in truck traffic. Or, a road

may require widening due to a new development being built in the area. Or, a road may be deteriorating much faster than predicted by the PMS because it has become the chosen route for a concrete hauler due to bridge closures on another road.

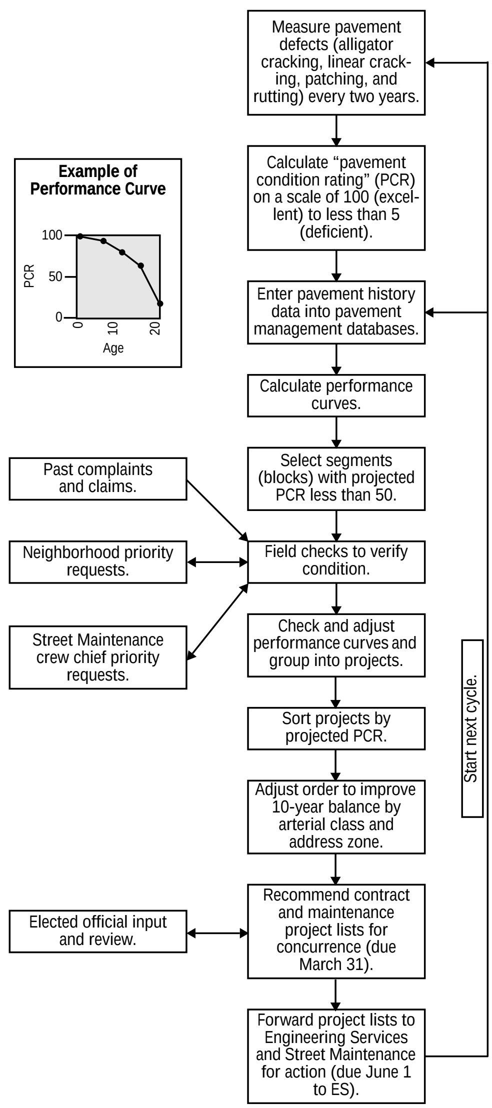
3. Review the list of projects that were identified for repair in the analysis year but were delayed until a future year because of limited funding. The agency may decide to use a less-cost effective repair type, with a lower initial cost, to repair some of these pavements that it feels cannot be delayed until funding is available for a long-term fix. In this situation, the pavement manager may be making a less cost-effective selection but he or she does it knowing the potential impact on the system and the eventual additional cost it will incur.
4. If the PMS resides in the engineering division, review the draft project list with the maintenance division. If the PMS resides in the maintenance division, review the draft project list with the engineering division. It is critical to obtain all interested parties' input in order to develop a final project list that everyone can accept.
5. Review the list and group logical projects together in a common construction year. It is not unusual for a PMS to recommend that one segment of a road be overlayed in one year and the adjacent segment to be overlayed two years later. It would make sense to group these projects together. Some agencies review their draft lists and group projects together in one region of the city or county for work in a single year. In residential areas, all the streets in a subdivision or neighborhood will probably not all be identified for repair in the same year. However, it may make sense to group these projects together to reduce the impact on the residents. If so, it may be necessary to move projects around in order to maintain an even workforce from year to year.
6. Modify the list as necessary to incorporate external considerations, such as political factors, into the final project list.
7. Conduct a project-level analysis to finalize the repair design and obtain accurate project costs.

A Case Study: City of Seattle (2)

The city of Seattle has 3800 lane miles of residential and arterial streets to manage, including both residential and arterial streets. It began its pavement management efforts back in 1984 via feasibility studies and developed conceptual designs for an infrastructure management and planning system. Since that time, it has implemented a PMS and uses it during the development of annual project lists.

The following flow chart shows the process the Seattle Engineering Department (SED) undertakes when developing its annual project list.

Arterial Asphalt Project Selection



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Each March, SED updates its project list for asphalt arterial pavements. The first step is to evaluate the condition of the pavements using a visual inspection. The asphalt arterials are visually inspected using automated distress data collection vehicles. This information is then input into the city's PMS on a block-by-block basis.

A pavement condition rating (PCR) is then calculated for each street segment. Any available pavement history data (surface type and last construction date) are entered into the database. The software is then used to develop performance curves.

The city is always working one year ahead with its program (for example, in March of 1996 they began finalizing the project list for 1997). The performance curves are used to estimate the PCR of the streets in the program year. The software is used to generate a list of segments (blocks) with projected PCR values less than 50 in the program year, along with their estimated PCR values for the next four years.

The pavement manager then conducts field checks on each of the segments identified on that list. During that field check, the pavement manager verifies the condition of the pavement. If the field condition does not correspond well with that predicted by the pavement management software, the database is reviewed to make sure that the last construction date has been entered. If it has not, it is obtained if possible and the performance curve is regenerated using this information. If the software is using a default curve for that segment because of limited data or a poor fit to actual data points, and the default curve that is being used does not reflect actual field performance for that segment, the pavement manager selects an expected life curve that he feels better approximates the deterioration behavior of that pavement.

During the field verification, the pavement manager determines where the logical project boundaries should be. For example, one block is on the list, the adjacent block is not on the list, and the block adjacent to that one is on the list (of pavements with a PCR less than 50). The pavement manager determines whether the block that is not identified as needing repair should be included in the project. To make this decision, the pavement manager looks at the field condition of the block and reviews a four year projection of its condition.

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Along with pavements with a PCR less than 50, the pavement manager also considers pavements that have been identified through citizen complaints, neighborhood priority requests, and street maintenance crew chief priority requests for inclusion in the final project list. This process is manual and by nature subjective. Segments are then grouped into logical projects.

The resulting project list is sorted by projected PCR. The project list is adjusted manually to improve the 10 year balance by arterial class and address zone. This recommended list is then provided to the elected officials for input and review. The final list is forwarded to Engineering Services and Street Maintenance for action.

"What If" Analysis

The true power of a PMS lies in its ability to permit the pavement manager to quickly examine the consequences of different strategies. To take full advantage of this power, the process described up to this point is often repeated many times to examine the results of changing different parameters, such as the budget or the prioritization approach. The pavement manager runs the program and evaluates the impact of each strategy, in terms of items such as overall network condition, backlog of needs, and future fund needs.

Typical "What If" Questions

Financial "What If" Questions

The major variable that is altered during the evaluation of alternate strategies, or scenarios, is the budget. Usually, an initial analysis is run with an unlimited budget to find out roughly how much money would be needed to complete all the projects identified during the needs assessment. In an unlimited budget scenario, many projects are identified for the first year of the repair program with dramatically fewer allocated for repair in later years. This is because the unconstrained budget assumes there is enough funding to not only address all of the needs developing during the first year but also all of the "backlog" work outstanding from previous years. This is not normally feasible for two reasons: a) the initial year budget will usually far exceed available resources, and b) uniform yearly budgets are more acceptable than budgets that show extreme variability year to year. However, this analysis scenario does provide an excellent baseline for future comparison with other budget scenarios.

In addition to running an unlimited budget scenario, an agency often runs a zero budget analysis. The zero budget analysis is used to show the impact of performing no pavement repair on the overall condition of the network. It provides a benchmark for other, more realistic budget scenario results. In addition, it underscores the importance of continually maintaining the pavement system.

After the unlimited budget and zero budget analysis have been performed, more realistic budget scenarios are analyzed.

Network Condition "What If" Questions

Another type of analysis often performed with a PMS is to use the program to estimate the annual budget levels required to maintain the pavement network at a given condition level. Several local agencies interviewed during the preparation of this guide noted that they often run this type of analysis. These agencies have established with their local board or council what overall CI is acceptable for the road network, and they run analyses to determine what funding levels are required to support that overall condition level.

Other "What If" Questions

A pavement manager can evaluate the impact of changing variables other than funding levels. For example, one of the questions often asked is "How much of the budget should be allocated to preventive maintenance, stopgap maintenance, and rehabilitation?" By running through several analyses where the percentage of funding allocated to the different activities is varied, a pavement manager can determine a good split among these work types.

The methods used to prioritize projects are also common analysis variables. For example, running one analysis using the "worst first" approach to priority ranking and then comparing it to the results of another analysis using cost-effectiveness to rank the same projects would be useful in showing that the cost-effectiveness ranking approach maintains the pavement network in better condition than the "worst first" approach over a multi-year period.

Other types of "what if" analysis include an evaluation of what would happen to the overall network condition and funding requirements if the agency's maintenance strategies are modified. For example, what would happen if an agency increased the amount of money it spent on preventive maintenance activities, such as crack sealing. Another type of "what if" analysis studies the effect projected traffic changes would have on network condition and required maintenance and repair budgets? The type of "what analysis" that can be efficiently conducted by an agency will depend upon the type of pavement management software being used and the type of information stored in the pavement management database.

Techniques to Evaluate the Impact of Different "What If" Strategies on a Pavement Network

The overall impact of a given analysis strategy on the pavement network can be looked at in many ways. The most effective presentation approach to use with each of these will be discussed in Chapter 6, Communicating the

Recommendations of a PMS. The following information is summarized, in part, from the *Pavement and Road Surface Management for Local Agencies Course Notebook* (3).

Network Condition

The condition of the pavement network is a basic way to evaluate the impact of a given scenario. If the condition increases with time, this is an indicator that the system is improving. However, there are other measures of system health that should be evaluated along with overall network condition. Also, keep in mind that elected officials and the public may not understand what change in condition is significant.

Condition Categories

The percent of pavement segments in different condition categories (i.e., excellent, good, poor, and failed) provides useful information that is more readily understood by elected officials and the public. For example, an agency could use this technique to show that under one funding level the percent of arterials in poor condition over the next 5 years is steadily increasing, whereas under another funding level the percent in poor condition is steadily decreasing. This way of looking at the impact of a given strategy provides an excellent counterpart to expressing the impact in terms of overall network condition, because it is possible for the overall condition of a network to be improving, while the percent of pavement in failed condition is also increasing.

Backlog of Needs

A backlog of needs is another way of analyzing the impact of a given strategy on the network. Usually, a backlog of needs is defined as the segments which are identified in the needs assessment as requiring repair but which are not funded for repair. In the example street network problem, this would include Birch-1 and Elm-1 because they were both identified as needing repair but were not funded for repair.

When evaluating backlogged projects, the amount of miles of these projects is usually reviewed. If the number of backlogged projects increases over time, then the agency will likely find itself in a situation where more and more roads can only be repaired using major rehabilitation techniques, such as reconstruction, because the time in their life cycle when more cost-effective rehabilitation techniques (such as an overlay) would be effective has long been passed.

Deferred Funding Needs

Deferred funding needs refer to the amount of money that would be needed to fund the backlog of projects described above. This is simply the sum of the estimated costs of those projects carried forward from previous years. If deferred funding decreases over time, the overall condition of the network is probably continuing to improve. Looking at deferred funding is a good check to make even if the PMS analysis shows that the overall network condition is improving over time, because there could be a few projects that are being continually deferred due to their high cost. In the example street network problem, the deferred funding needs are $356,250 in the first year.

Stop-Gap Maintenance

Stopgap maintenance is used to describe repair activities that are applied to keep a section in serviceable condition until the needed funding becomes available. An example of stopgap maintenance would be applying a chip seal to a road that needs a structural overlay. While stopgap maintenance can hide distress for awhile, it is not generally cost-effective. For example, a chip seal placed on a road that is structurally deficient will mask the pavement deterioration for a short period of time; however, it will rapidly deteriorate because it did not address the cause of the pavement deterioration (structural deficiency). The pavement will soon deteriorate to the same condition level as before the chip seal. Another type of stopgap maintenance commonly used at the local agency level is extensive patching of a road that needs an overlay. Patching keeps the road open to the traveling public; however, it is a temporary repair that becomes expensive over the long run.

If an agency stores information on the type of maintenance it performs on its pavements, it can track the amount of stopgap maintenance being performed. If the number of miles that have been treated with stopgap maintenance increases, the agency will know that the system is probably getting worse over time. In addition, the money that is spent on stopgap maintenance is not being spent on more cost-effective, long term repairs. An analysis of the number of miles that have been treated with stopgap maintenance will also provide an agency with an indication of the amount of pavement needing more permanent repair when funding becomes available.

Remaining Service Life

Some agencies find that the remaining life of the existing network and changes in remaining life with different “what if” strategies are useful because they provide a general sense of how much work is required now and in the future. In general, remaining service life refers to the amount of time before a pavement segment reaches an unacceptable condition. If the remaining service life is short for much of the pavement network, it means that considerable work is needed now. By plotting the percent of the network with different quantities of remaining service life over the next several years, an agency can quickly visualize when large amounts of work are going to be needed in specific periods of time.

Special Studies

A PMS can be used to perform special studies, if data exist in the database to support these studies. For example, an agency might have a policy of chip sealing its rural access roads every seven years. The agency could use the PMS to evaluate whether the seven-year cycle was appropriate, by looking at such things as the condition prior to applying a chip seal and the condition prior to applying the next chip seal seven years later. If the condition prior to the second chip seal is significantly lower than it was when the first chip seal was applied, the agency might consider shortening its chip seal cycle.

A Case Study: City of Renton (4)

The city of Renton has found that its PMS has many more uses than just providing information during the preparation of the city's pavement maintenance and rehabilitation program. For example, the city recently used the data stored in its PMS to justify a request for funding from the State of Washington to repair a street that was used as a haul route during a State construction project. The city also uses its PMS database to assess what type of repair utility companies are required to implement after installing waterlines in a street.

The city of Renton is responsible for maintaining Houser Way. During 1995 this street was used as a haul route by construction vehicles during the rehabilitation of the "S-curves" on Interstate 405. The city of Renton was able to use the visual distress data stored in its PMS to show that Houser Way deteriorated much faster during the time it was used as a haul route than would have been expected under normal traffic conditions. The visual condition rating of the road before and after being used as the haul route (as documented in the PMS) was compared to the pavement condition that was predicted by the PMS to occur under normal traffic conditions. The State of Washington agreed with the findings of the city of Renton, and provided $30,000 to be used for the repair of Houser Way.

The city of Renton has also used its PMS database to assess the potential impact of the installation of longitudinal water lines in existing streets. If the current condition of the pavement, as identified by the last visual inspection data contained in the PMS database, is above a given condition index, the utility company is required to overlay either one half or the entire width of the roadway (depending upon the location of the utility trench).

A Case Study: Jefferson County (5)

Jefferson County was aware that it had a problem with excessive flushing on some of its roads. The county was concerned about the safety of these roads, since under wet conditions pavements with a significant amount of flushing can become slippery. The county needed to identify roads where this problem was occurring in the most cost-effective manner possible.

Since Jefferson County rates each segment for flushing during its visual surveys and stores this information in its PMS database, the county was able to use this information to create a flushing index. The county assigned a flushing index of 3 to segments with high severity flushing, a 2 to segments with medium severity flushing, a 1 to segments with low severity flushing, and no index to those segments where no flushing was observed. By listing the segments by descending flushing index, the county produced a list of those segments with flushing so they could include this information in its engineering analysis prior to developing their chip seal program.

Reevaluation of the Pavement Management Program

The incorporation of a feedback process within the PMS is described and encouraged in Chapter 3. Feedback information can be used to continually improve the models used within a PMS. Further, feedback information can be used to check the accuracy of design procedures, to evaluate the cost-effectiveness of different rehabilitation and maintenance techniques, and to support research projects (such as evaluating the impact of utility cuts on pavement performance). Examples of feedback analysis follow.

Pavement Performance

Over time, pavement performance models can be further refined and made more specific. This process was described in Chapter 3.

Pavement Design

The Engineering Division can use data stored in a PMS, along with other needed data, to evaluate how long different pavement designs are actually lasting in the field. In order for this type of analysis to be conducted, the pavement management database must contain information on when a pavement was constructed, its original pavement design, its original design life (in terms of years or traffic loads), and its CI versus age or CI versus traffic loads. The agency can then compare expected design life with the actual condition versus age or traffic. If the agency finds that a given design type performs differently in the field than anticipated, the pavement performance models in the PMS can be adjusted to more accurately reflect actual field performance.

Pavement Repair Techniques

The Engineering and Maintenance Divisions can use data stored in a PMS, along with other information to evaluate the performance and cost-effectiveness of an agency's pavement repair techniques. To do this, the agency should maintain basic repair information over time to allow analysis. The type of information needed would include: when a repair was applied, what condition (CI, structural condition (if available) and type of distress present) the existing pavement was in prior to repair, what type of repair was applied, how much the repair cost to apply, historical CI versus time or traffic loads for the entire life of the pavement repair, and the CI when the pavement with the repair was rehabilitated again. This information can be used to estimate the annual cost of the repair and determine the repair life.

Pavement Research

The data contained within a PMS can be used to support special research studies. For example, many local agencies are concerned about the impact utility cuts have on their pavement network's long term performance. If utility cut information is stored in the PMS database, it can be reviewed in conjunction with pavement performance data over time to evaluate in objective terms what impact utility cuts do have on pavement performance.

Planning Horizons

The budget planning process can occur on several different planning horizons. Planning horizons are often predicated on the planning requirements of the agency and those who mandate planning activities. Requirements in Washington include the six-year plan, the three-year TIP, and the Annual Program.

There are three planning horizons often used by a local agency: short-term, medium-term, and long-term. Since programs extending past six years are tentative at best due to funding, industrial and population growth, and other unknowns in the future, one practical approach is to develop a 6- to 10-year program, but only fix the first two or three years of the program. Each year, the program is updated. This approach is sometimes referred to as using a fixed short-term horizon. During the update, the projects being updated are projects for years 2, 3, 4, 5, and 6.

Short-Term Horizon

The short-term program is normally one to three years. An agency prepares this program with the intent to formulate it into a final budget proposal and work program.

Medium-Term Horizon

The medium-term program is often developed for 6 years. Since it may take several years to move a project from conception through actual completion, this is the horizon that many agencies concentrate on. To apply for Federal or State funding, a project must be in a 6 year program.

Long-Term Horizon

The long-term program can be 5 to 20 years, depending on the agency's desires. Long-term horizons are primarily used for evaluating the long-term impacts of decisions, such as greater or lesser levels of funding. Periods beyond 5 years are not typically used for the actual programming of projects. Because of the amount of analysis required in preparing a long range program, a computerized PMS is normally used.

Summary

While PMS are very powerful tools that assist an agency in developing multi-year pavement repair programs and budgets, they are not infallible. Because not all factors (utility projects, traffic growth, political impacts, and so on) are included in an analysis, some manual manipulation of the pavement repair program produced by the PMS is required by the pavement manager. In addition, comprehensive and accurate determinations of all benefits and all costs associated with different repair strategies is just not possible. A pavement manager should understand the limitations of the PMS being used and understand that the recommendations provided by a pavement management program must be combined with the experience and sound judgment of the agency to formulate a final repair program.

Chapter 4 References

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5:P:DP/PMAG

Chapter 5 Incorporating Preventive Maintenance Into the Pavement Management Process

Funding levels for pavement maintenance and rehabilitation are often much too low to meet the needs of local agencies. Therefore, agencies must find ways to stretch every pavement dollar they receive. Preventive maintenance is one very cost-effective tool that an agency can use to preserve its pavement network. This chapter discusses the use of preventive maintenance and its role in the pavement management process.

What Is Preventive Maintenance?

Preventive maintenance has been defined as "… an organized, systematic process for applying a series of preventive maintenance treatments over the life of the pavement to minimize life-cycle costs (1)." A preventive maintenance strategy is based on the concept that applying periodic treatments at appropriate times in a pavement's life is less costly than applying one treatment at the end of a pavement's life (2). Preventive maintenance programs are designed to slow pavement deterioration.

Preventive maintenance is a planned activity, unlike corrective maintenance. Corrective maintenance is used to eliminate a pavement distress that is causing a safety or traffic problem (such as a large pothole). Preventive maintenance is generally cyclic in nature and is intended to stop some distresses before they occur (such as weathering) and to slow the development and progression of other distress types (such as non-load-related cracking).

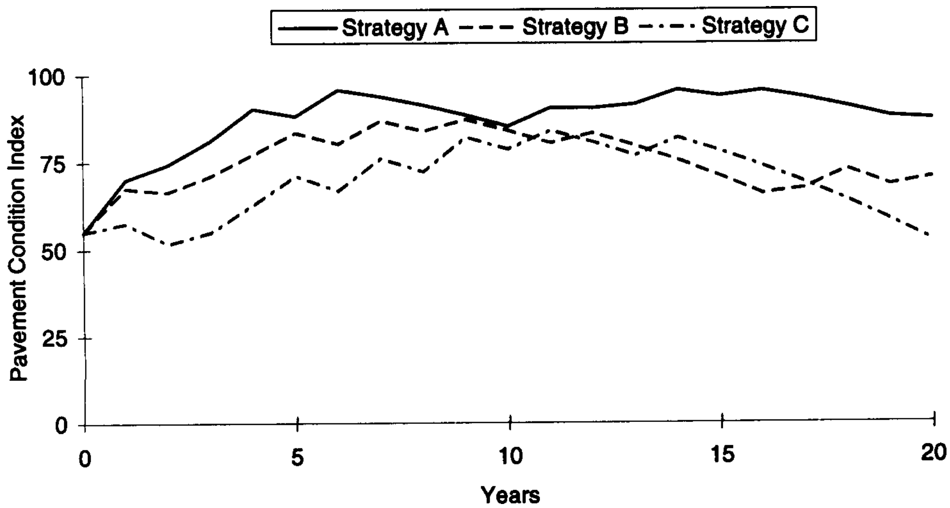
Benefits of Preventive Maintenance

A good pavement preventive maintenance program can reduce the need for corrective maintenance, extend pavement life, provide a better level of service, and result in lower life-cycle costs. Other benefits include improved safety, travel time savings, reduced tort liability claims, and reduced vehicle and operating costs (3).

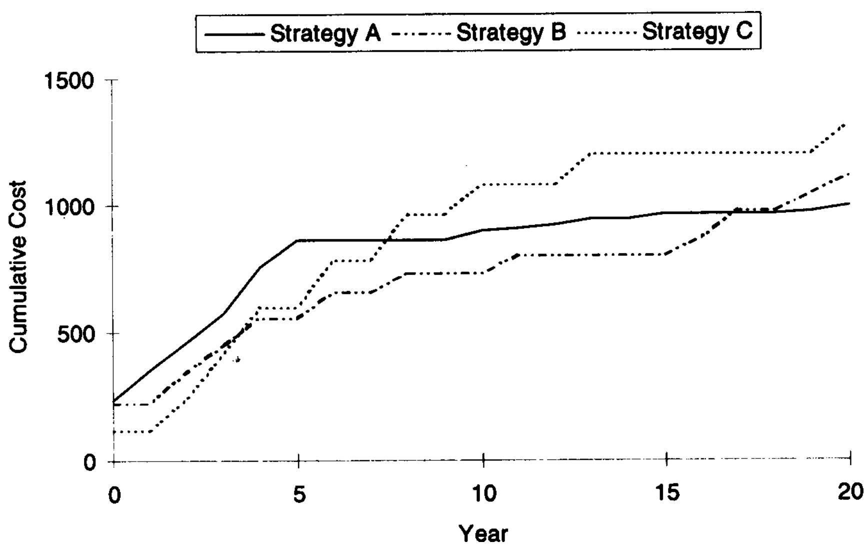
To illustrate the benefits of a preventive maintenance program, an example was prepared for use in a one-day workshop on Pavement Maintenance Effectiveness - Preventive Maintenance Treatments (2). Three pavement repair strategies were evaluated to determine which provided the best service level and the lowest life-cycle costs. The strategies were applied to the same pavement network, which had an even distribution of pavements within each pavement condition range (100 to 90, 89 to 80, and so on). The pavement strategies are shown in the following table.

Strategy	***Preventive Maintenance***	***Rehabilitation***	***Reconstruction***
A	CI ≤ 80	CI ≤ 40	CI ≤ 20
B		CI ≤ 40	CI ≤ 20
C			CI ≤ 20

The following figure shows the average condition over time for each of the three strategies. Strategy A provides the highest CI levels, demonstrating that preventive maintenance increased service life.



The following figure shows the cumulative costs for each strategy. It shows that the cost for preventive maintenance is initially higher. However, as the network quality improves, the cost of the preventive maintenance decreases.



This example demonstrates that preventive maintenance treatments are effective at both improving the quality of the pavements and reducing the costs of pavement preservation.

The purpose of preventive maintenance is to extend the life of a pavement. Preventive maintenance is not effective in a situation where a pavement is failing structurally, or due to problems such as poor drainage or a failed subgrade. In these cases, the underlying problem needs to be corrected and preventive maintenance is not the appropriate solution.

Cost-Effectiveness of Preventive Maintenance

Appendix D describes a process to demonstrate the cost-effectiveness of preventive maintenance, reproduced from NCHRP Synthesis 223(1). It is a generic process that does not require a detailed knowledge of each segment in the pavement network.

Typical Preventive Maintenance Techniques to Address Common Pavement Problems

The following table (1,2) lists the more common pavement problems that can be minimized or avoided by preventive maintenance treatments, and the commonly used preventive maintenance treatments. It also identifies some distress types that cannot be effectively treated with preventive maintenance. This list does not dictate which repair alternatives an agency should utilize in a given situation, but provides insight into which alternatives other agencies have found cost-effective. A basic primer on pavement preventive maintenance has been reproduced in Appendix E.

Pavement Type	Common Pavement Problems	Preventive Maintenance Treatments
Flexible	Alligator Cracking	Not a good candidate for preventive maintenance.
	Bleeding	Sand Seal; Chip Seal; Micro-Surfacing
	Block Cracking (low to moderate)	Chip Seals; Thin Hot-Mix Asphalt Overlays; Thin Cold Treatment
	Edge Cracking	Crack Treatment
	Patching	Extensively patched pavements are not good candidates for preventive maintenance.
	Polished Aggregate	Thin Cold Treatment; Chip Seal; Thin Hot Mix Overlay
	Potholes	Not a good candidate for preventive maintenance.
	Rutting — Due to Unstable Asphalt	Not a good candidate for preventive maintenance.
	Rutting — Due to Densification of Pavement	Fill ruts with micro-surfacing or strip chip seal, then thin cold treatment or chip seal
	Shoving	Not a good candidate for preventive maintenance.
	Transverse, Longitudinal, and Reflection Cracking (low to moderate)	Crack Treatment
	Weathering and Raveling	Fog Seal; Thin Cold Treatment; Chip Seal
Rigid	Blow-Ups	Drainage Improvements
	Joint Faulting	Retrofit Load Transfer
	Pumping	Joint and Crack Sealing

Note that the repair techniques listed in this table are only preventive if they are applied early in a pavement's life cycle, prior to significant deterioration. For example, joint sealing a rigid pavement after extensive joint damage has occurred due to incompressibles is not a preventive maintenance activity. Joint sealing on a cycle basis to prevent the loss of joint sealant material, which will help deter joint damage, is a preventive maintenance activity.

Preventive Maintenance Techniques for Flexible Pavements

There are many preventive maintenance techniques available for use on flexible pavements. These include crack sealing, fog seals, chip seals, thin hot-mix overlays, and thin cold-mix treatments. Except for crack treatments, all of these preventive maintenance techniques provide a new wearing surface and are designed to minimize adverse environmental impacts. The use of each of these is described in this section of the guide.

Crack Seal

Crack sealing applies sealing material directly into the cracks in the pavement surface. The sealing material prevents or reduces the intrusion of water and incompressible materials into the pavement thereby reducing the rate of deterioration.

Crack sealing is not an appropriate treatment for all cracks. High density and high severity cracking cannot be cost-effectively treated with crack sealing (2). Cracks due to load-related problems, such as alligator cracking, may benefit from crack sealing during early stages in their development; however, unless the structural deficiency causing the cracking is corrected, the benefits received from crack sealing will be short lived.

Fog Seal and Sand Seal

A fog seal is a light application of diluted asphalt emulsion sprayed directly on the surface of the pavement. Fog seals are intended to reduce the oxidation of the pavement surface and seal minor surface cracks and voids. They are normally applied to pavements with low to moderate weathering or raveling (2). Fog seals are not effective when applied to pavements with large cracks, low skid resistance, rutting, shoving, or a structural deficiency (2). A sand seal consists of a fog seal followed with a light covering of sand.

Chip Seal

A chip seal consists of a sprayed application of asphalt binder followed by a layer of aggregate. They can be placed in either single or multiple layers. They provide several benefits, such as providing a new wearing surface, waterproofing the surface, sealing small cracks, protecting the original surface from solar radiation, and improving surface friction (2).

A pavement should be structurally sound before considering a chip seal as a preventive maintenance treatment, since a chip seal does not increase the structural capacity of the pavement. Chip seals do not correct surface irregularities, and should not be used on pavements with more than 0.4 to 0.6 inches of rutting (2). Pavements with high severity bleeding are not good candidates for chip seals.

Thin Hot-Mix Asphalt Overlay

Thin hot-mix asphalt overlays are a blend of asphalt cement and aggregate laid and compacted at a high temperature, just as conventional overlays. However, a thin hot-mix asphalt overlay is 1.25 inches or less thick (1). Thin hot-mix asphalt overlays are often classified according to aggregate gradation (dense-graded, gap-graded, and open-graded).

Thin hot-mix asphalt overlays are used to seal the pavement surface, improve ride quality, and improve skid resistance (2). They are particularly effective in correcting surface irregularities and unlike chip seals, there is no stone loss. Like chip seals, however, they do not appreciably improve structural capacity; therefore, pavements must be structurally sound before a thin hot-mix asphalt overlay is an appropriate choice for preventive maintenance.

Thin Cold Seals

Thin cold seals are asphalt emulsion with aggregates, mixed at the job site in specially designed mixing units (2). Slurry seals and micro-surfacing are examples of thin cold seals.

Slurry Seals

A slurry seal is a mixture of asphalt emulsion, well-graded fine aggregate (sand), mineral filler (in most cases), additives as needed, and water. Slurry seals are used to seal minor surface cracks and voids, slow weathering and raveling, and improve surface friction characteristics (2).

Slurry seals are not effective when placed on pavements with large cracks that move under traffic. Slurry seals should also not be placed on unstable pavements, which are often indicated by shoving and excessive rutting.

Micro-Surfacing (1,2,3,4)

Micro-surfacing is basically a type of slurry seal that is composed of polymer-modified asphalt emulsion, 100 percent crushed aggregate, mineral filler, water, and field control additives as needed. Micro-surfacing can be placed in a thicker layer than a slurry seal due to the increased stability of the mix.

Micro-surfacing is primarily used for improving surface friction and filling ruts. Micro-surfacing is an appropriate treatment for ruts if the pavement is stable. If the rutting is caused by an unstable paving layer or subgrade, micro-surfacing will correct the problem for a shorter period of time. Micro-surfacing has also been used to correct weathering and raveling, to address flushing (bleeding), and to fill cracks and voids.

Micro-surfacing is not effective when placed on a pavement exhibiting large cracks that move under traffic. The pavement should be stable and structurally sound before micro-surfacing is considered as an appropriate treatment.

Preventive Maintenance Techniques for Rigid Pavements (1,2,3)

There are only a few preventive maintenance options for rigid pavements. The first option is to reseal the joints as needed and seal other cracks (if wide enough to permit the application of a sealant) as they develop. Sealing joints and cracks stops surface water and incompressible materials from entering into the pavement. Water infiltrating under the slab can contribute to pumping, which can cause voids to develop under the slab leading to loss of support. Incompressible materials in joints and cracks can lead to blowups, joint deterioration, and spalling. If the pavement is badly deteriorated, sealing cracks and joints may not be effective.

Another preventive maintenance option for rigid pavements is filling the voids under the pavement with a grout material. The material is applied under pressure through holes drilled in the concrete slab. Left uncorrected, voids under a slab can lead to loss of support and eventually result in faulting and cracking of the slab. Subsealing does not correct faulting or improve load transfer efficiency, so it is often performed as part of a restoration process that can include grinding and retrofitting of dowel bars.

Retrofitting dowel bars to restore load transfer is another preventive maintenance technique used for rigid pavements. Retrofitting dowels reestablishes load transfer across joints and cracks. This improves pavement performance by reducing faulting and corner breaks.

Performance of Preventive Maintenance Treatments

The performance of preventive maintenance treatments depends on many factors. The condition of the pavement prior to the application of the treatment, environmental factors, traffic conditions, pavement cross-section, drainage and shoulder conditions, type of preventive maintenance performed and the materials used, quality of the application, and the weather conditions and time of year when the treatment is applied, all affect the performance of a preventive maintenance treatment (1).

For an agency to implement an effective preventive maintenance program, it needs to understand how the different treatments perform. The following table summarizes the published information on the performance of specific preventive maintenance treatments (2). Because so many factors affect the performance of preventive maintenance treatments, each agency will have to determine how well the different maintenance treatments perform on its pavements. Appendix D describes a process to demonstrate the cost-effectiveness of preventive maintenance.

Treatment	***Pavement Age at Time of First Application (years)***	***Frequency of Application (years)***	***Observed Increase in Pavement Life (years)***
Crack Filling	5 to 6	2 to 4	2 to 4
Single Chip Seal	7 to 8	5 to 6	5 to 6
Multiple Chip Seal	7 to 8	5 to 6	5 to 6*
Slurry Seal	5 to 10	5 to 6	5 to 6
Micro-Surfacing	9 to 10	5 to 6	5 to 6
Thin Hot-Mix Overlay	9 to 10	9 to 10	7 to 8

****Note:*** Many Washington local agencies have observed an increased pavement life of 7 to 8 years for multiple chip seals.

The timing of a preventive maintenance treatment is critical to its performance and cost-effectiveness. If the treatment is applied after significant amounts of pavement distress are present, it will not be cost-effective. Each agency needs to monitor the performance of preventive maintenance treatments placed at different points in a pavement's service life to identify the most cost-effective time to apply the treatments.

Role of Preventive Maintenance in Pavement Management

Many agencies rely on the experience of its maintenance and engineering staff when determining the performance of different preventive maintenance treatments and identifying when a preventive maintenance treatment should be applied. However, the use of a PMS can greatly facilitate the development of a preventive maintenance program and improve its effectiveness.

A PMS can provide objective information to identify the pavements that would benefit from preventive maintenance, to select which preventive maintenance treatment should be applied and when it should be applied, to track how well pavements that have received preventive maintenance are performing, and to calculate how much the different treatments actually cost. A PMS can be used to estimate the resource requirements (labor, equipment, and material) needed to conduct a preventive maintenance program and to calculate the cost-effectiveness of different preventive maintenance strategies.

The use of preventive maintenance can help maximize the benefits received from a PMS, by helping an agency break the "fix the worst pavements first" cycle. One very effective strategy is to first apply preventive maintenance to those pavements that are still in good enough condition to benefit from it, and then use remaining money to start fixing the pavements that are in very poor to failed condition. The Kansas DOT adopted this strategy and found that after four years a marked improvement in the condition of its pavement network had occurred and its overall costs for pavement maintenance and rehabilitation had started to decrease (1).

How to Use Your PMS to Develop a Preventive Maintenance Program

A PMS can be used to help develop and manage a preventive maintenance program. The data contained in a PMS can be used to identify cost-effective preventive maintenance treatments and estimate the impact of applying different preventive maintenance strategies. A PMS can also be used to identify the pavement segments within a road network that would benefit from preventive maintenance, and to help establish a schedule for preventive maintenance. Finally, a PMS can be used to monitor the performance of different preventive maintenance treatments.

Develop a Preventive Maintenance Strategy

- *Identify cost-effective preventive maintenance treatments*. If available, use the data stored within a PMS to determine which preventive maintenance treatments are cost-effective and to estimate the extension in service life provided by the treatments (see *Monitoring Performance* in this section for more information). If the information is unavailable in the database, or if the agency has not used preventive maintenance in the past, estimates of increased service life due to the application of preventive maintenance treatments can be made using experience and the results of any neighboring agencies that have used preventive maintenance (1).
- *Determine under what conditions the identified preventive maintenance treatments should be applied*. Based upon experience with the different treatments, and any available performance data on preventive maintenance treatments placed under different conditions available from the PMS database, identify under what conditions each should be considered feasible. Factors such as pavement type, existing pavement condition (overall CI and type of distress present), traffic levels, and environment should all be considered (2). Identifying the appropriate timing for preventive maintenance is critical to the success of the overall strategy.
- *Develop Overall Strategy.* The potential benefits of preventive maintenance can only be obtained if the treatments are applied on a consistent schedule. In addition, treatments must be applied to structurally sound pavements. Also, pavements that are not exhibiting significant amounts of environmental distress, such as raveling and block cracking, will not benefit from preventive maintenance (2). An effective preventive maintenance strategy usually does not contain just a single preventive maintenance treatment applied at a single point in a pavement's life. For example, an agency may develop a preventive maintenance schedule that includes a fog seal when the pavement is a year old, crack sealing every two years, and a surface treatment at six years.

Develop a Preventive Maintenance Manual

Once a preventive maintenance strategy has been adopted, it is recommended that an agency develop preventive maintenance guidelines and document them in a manual (3). This manual should contain the following topics:

- description of different pavement types (such as ACP and PCC) and the mechanisms that cause them to deteriorate,
- photographs of different types of distress,
- descriptions of the cause of the different distress types,
- lists of suitable treatments to address the different distress types (including a discussion on the importance of early repair to maximize the benefits of preventive maintenance),
- performance standards for applying the different treatments, and
- instructions for how to evaluate the most cost-effective action for a given situation.

Identify Pavement Segments to be Included in Preventive Maintenance Program

Once a preventive maintenance strategy has been adopted by an agency, the data stored in the PMS can be used to identify pavement segments that would benefit from preventive maintenance. The selection criteria that are identified in the preventive maintenance strategy (such as overall pavement condition, type of distress, type of pavement, and so on) are applied to the data in the PMS database. Since pavement age is often used to schedule preventive maintenance actions, that information should also be accessed from the PMS database.

Monitor Performance of Preventive Maintenance Treatments

It is important to monitor the performance of the preventive maintenance treatments being used. This information is used to determine the life extension provided by the treatments, evaluate the cost-effectiveness of the different preventive maintenance treatments, update the cost of various treatments, and adjust an agency’s preventive maintenance strategy as warranted (2).

The information needed to evaluate the performance of preventive maintenance treatments can usually be collected and stored as part of the pavement management process. The following type of information should be collected and stored in the PMS database for this purpose:

- as-built data on the existing pavement (pavement layers, thicknesses, material types),
- traffic data (historical and post-application of preventive maintenance treatment),

- condition and age of pavement prior to application of preventive maintenance treatment,
- data on the design and application of the preventive maintenance treatment,
- condition data collected after the application of the preventive maintenance treatment, and
- cost data.

How to Break the Reactive Cycle Through the Use of Preventive Maintenance

While many local agencies acknowledge the benefits of preventive maintenance, few have implemented preventive maintenance programs. At the state level, however, preventive maintenance programs have seen increased acceptance over the past decade.

There are two techniques that state highway agencies have used successfully to implement and support preventive maintenance programs that could be applied by local agencies. The first is to build preventive maintenance right into the design approach. A schedule is established before actual construction or rehabilitation work is even begun, and money is set aside just for preventive maintenance. The second technique is to commit a certain percentage of pavement funds to preventive maintenance, and to use those funds only for preventive maintenance activities even during times of very constrained budgets.

Summary

Pavement preventive maintenance is an important tool that should be seriously considered by agencies, particularly those facing a pavement network where their pavements are reaching the end of their design lives. Used consistently and applied in a timely manner, preventive maintenance treatments can improve the quality of the pavement network and extend pavement service life. A PMS can provide the information needed to develop a preventive maintenance program and monitor its performance.

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6:P:DP/PMAG

Communicating the Recommendations of a Pavement Management System

A PMS can be an effective tool for communicating pavement maintenance and rehabilitation needs to all levels and divisions within an agency, to elected officials, and to the public. If a PMS is not being used to serve as a basis for these communications, its full potential is not being realized. This chapter covers the different approaches an agency can use to prepare presentations for different users of pavement management information.

Users of PMS Recommendations

There are many groups that contact the pavement manager, seeking information about the pavement network. Upper management often has questions about overall network condition and projected needs of the pavement system. Design staff want to know how different rehabilitation and maintenance techniques are performing. Private citizens ask why one road is being fixed whereas another road in apparently worse condition is not being repaired. The pavement manager can use a PMS to respond quickly to these varied queries and present information in the format most readily understood by the group requesting information.

Maintenance Division

The Maintenance Division's primary use of a PMS involves the identification of pavement areas requiring maintenance. A PMS can provide information on where maintenance is needed, identify what type of maintenance activity is appropriate, and provide an estimate of the quantity and cost of the work to be performed. Often, the information from the PMS is used by the Maintenance Division to drive chip seal programs; less frequently, it is used to develop crack sealing and patching programs. Over time a PMS can provide insight into which maintenance techniques and materials are performing well and which are not.

The Maintenance Division usually accesses PMS information annually, during the preparation of its annual maintenance program. Following are tables that contain the type of PMS information a Maintenance Division would use.

1996 Proposed Maintenance Plan

Road ID	*Segment Number*	*Segment Area (sf)*	*1996 CI*	*Maintenance Required*
Route 34	10	40,000	65	Patching and Chip Seal
	20	60,000	85	Crack Seal
Elm Street	10	90,000	70	Patching and Crack Seal
Route 10	10	100,000	75	Crack Seal and Slurry Seal
	20	25,000	80	Crack Seal

1996 Crack Sealing Plan

Road ID	*Segment Number*	*Amount of Crack Sealing Required (lf)*	*Estimated Cost of Crack Sealing*
Route 34	20	3,000	$300
Elm Street	10	10,000	$1,000
Route 10	10	15,000	$1,500
Route 10	20	500	$50

A map of the street network that highlights the areas requiring maintenance, and the type of work to be performed, would also prove useful for the Maintenance Division.

Engineering Division

The Engineering Division uses PMS information to develop pavement rehabilitation (overlays and reconstruction) programs. It may also use PMS data (traffic data, condition data, structural data, and construction history information) during the development of rehabilitation designs. In addition, the Engineering Division can use a PMS to perform special studies, if the data are available to support them. For example, the Engineering Division can use PMS data to track the performance and cost of different construction and rehabilitation designs. This information can then be analyzed to identify the most cost-effective designs and construction techniques to use in the future.

The Engineering Division usually uses PMS data during the preparation of its overlay and rehabilitation programs (typically performed annually); however, it may also request specific information on an ad hoc basis that it needs in a relatively short time period. The Engineering Division often requests detailed data which are best presented in a tabular format. Following are two different types of tables that have been requested by Engineering Divisions.

Major Collectors by Pavement Condition (1)

(excerpt of report provided by Skagit County Pavement Manager to Design Engineer)

Road Name	Road Number	From MP	To MP	Pavement Type	Func. Class	Last CI	CI Year
Allen West	36300	00.000	00.390	BST	07	24	1996
		00.390	00.576	ACP	07	36	1996
Fir Island Road	40200	01.800	02.300	ACP	07	69	1995
Alger Cain Lake Road	53540	00.430	01.350	BST	07	82	1995
Bow Hill Road	21200	03.280	03.620	BST	07	91	1995

ACP Roads with Condition Index ≤ 70

Road Number	From MP	To MP	Pavement Type	Last CI	Age at Last CI	Primary Distress
10310	01.704	02.118	ACP	60	7 years	L&T; Edge Cracking
30650	00.000	00.080	ACP	40	15 years	W&R; Alligator Cracking
44010	01.005	01.760	ACP	50	10 years	Rutting; L&T
50630	00.000	00.260	ACP	30	13 years	Alligator Cracking; Rutting
61320	00.000	00.100	ACP	45	16 years	W&R; L&T; Patching

Planning/Programming/Finance Division

The Planning/Programming/Finance Division uses the recommendations of a PMS as an aid in planning by formulating repair programs and budgets using the information contained in the PMS. It may also use a PMS to coordinate road projects being undertaken for reasons other than poor pavement condition (such as road widening or realignment projects) with projects being recommended by a PMS.

The Planning/Programming/Finance Division normally does not want highly technical nor detailed information from the PMS. Summary tables, graphs, and maps are much more useful to these personnel. This division often only uses PMS information once a year, during the preparation of annual and multi-year programs and budgets. Examples of the type of information and format appropriate for these users of PMS information are illustrated below.

Proposed Three-Year Arterial Asphalt Resurfacing List (2)
(patterned after report prepared by City of Seattle)

Year of Proposed Overlay	Street Name	From	To	Last CI	Area (sy)	Cost (per sy)	Total Cost, 1996 Dollars
1st	Broad Street	North Way	South Way	45	7563	$35.22	$266,387
1st	Beach Avenue	NE 10th	NE 20th	55	5357	$49.97	$267,705
2nd	Beth Drive	Wall Street	Market Street	40	5732	$49.97	$286,427
2nd	30th Ave. NW	10th Street	15th Street	35	5861	$20.47	$31,919
2nd	Main Street	1st Street	5th Street	50	8406	$32.03	$269,201
3rd	Front Street	NE 20th	NE 25th	50	13,193	$31.77	$419,115

Roads with a CI from 56 to 75 (1)
(excerpt of report provided by Skagit County Pavement Manager to the Transportation Planner)

Functional Classification	Last CI	Length (miles)
07	71	0.510
07	68	0.274
07	63	0.560
08	70	0.609
08	66	0.070
08	65	1.000
09	75	0.340
09	74	0.875
09	62	0.260

Roads by Pavement Type (1)

(excerpt of report provided by Skagit County Pavement Manager to the Transportation Planner)

Pavement Type	Last Condition Index	Length (miles)
ACP	71	0.510
ACP	66	0.340
ACP	57	0.130
ACP	58	0.274
ACP	73	1.000
BST	62	0.340
BST	74	0.875
BST	69	0.300
BST	59	0.320

All Roads: Paving and Rating Dates (1)

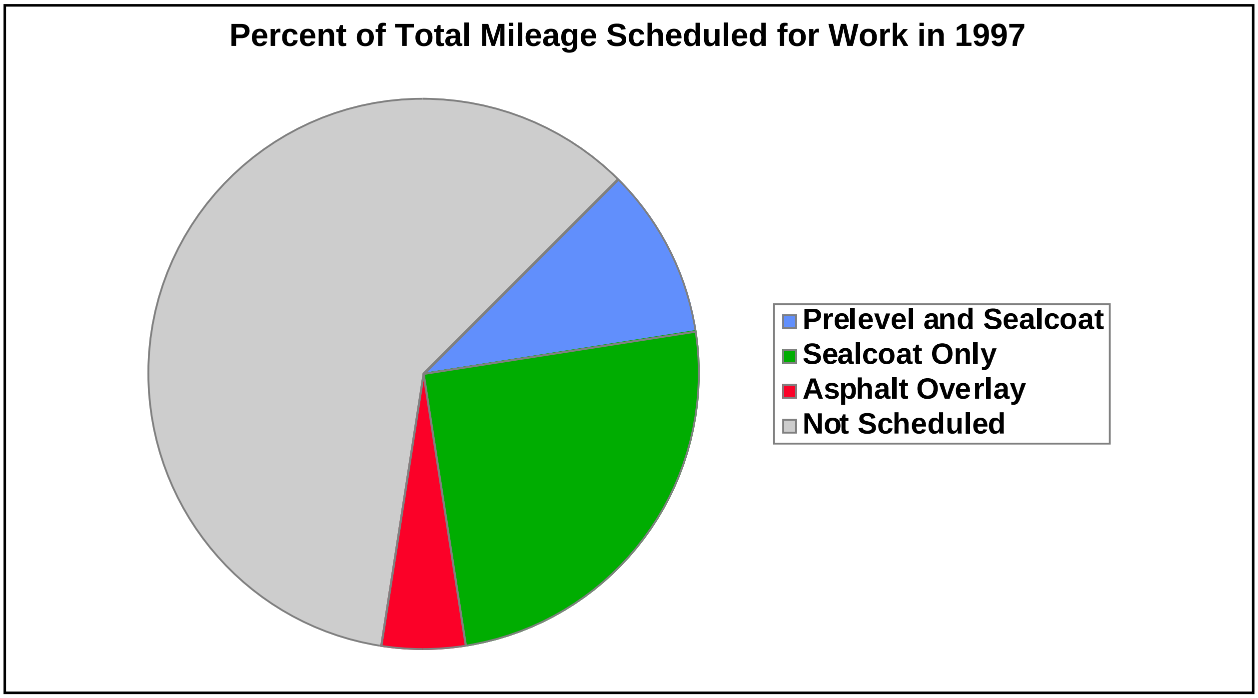
(excerpt of report provided by Skagit County Pavement Manager to the Transportation Planner)

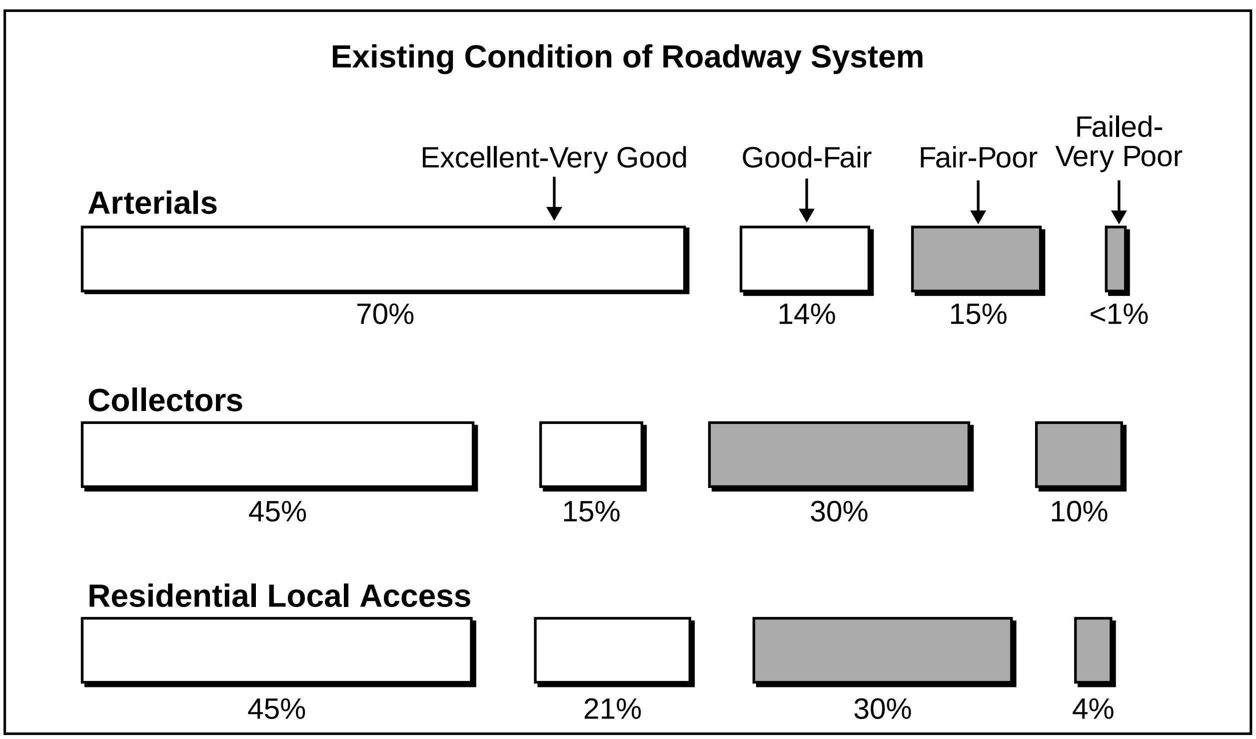
Road #	Road Name	From MP	To MP	Width	Pvt. Type	Paving Year	Last CI	CI Year
00500	Legge Road	00.000	00.250	18′	BST	1993	70	1996
04130	Knapp Road	00.000	00.130	24′	ACP	1973	57	1996
04350	Lee Road	00.090	00.110	12′	BST	1988	48	1992
05550	Morford Road	00.903	01.290	19′	BST	1989	68	1995

Management

A PMS provides management with the means to rapidly evaluate the impact of different funding strategies on the overall pavement condition of the network. Toward that end, pavement managers are often asked by management to run multiple “what if” scenarios with a PMS to evaluate how different funding strategies affect the condition of the pavement network. This information provides decision-makers with a sound basis for developing pavement repair programs and budgets.

Management also uses a PMS to develop presentations for elected officials and the public. Typically, management needs the information presented in highly visual graphics and maps. Management usually requests information annually during the preparation of annual work programs; however, management may also require specific information on short notice. Following are a few examples of the types of PMS output that management would find useful.





A Case Study: City of Olympia (3)

In a city, one of the users of PMS information is the Public Works Director. The Director is usually knowledgeable in the area of pavement management and can understand technical information; however, the constraints on the time of a person in this position mean that data need to be presented in a concise manner.

The city of Olympia Public Works Department conducts an annual pavement condition survey. The Department reports the results of the survey to the Public Works Director in the form of a memorandum and an accompanying oral presentation. The memorandum, which is reproduced in its entirety in Appendix A, Case Study #3, is succinct. It contains two pages of text (including tables) and three pages of charts. During the oral presentation, the information presented in this memorandum is greatly expanded.

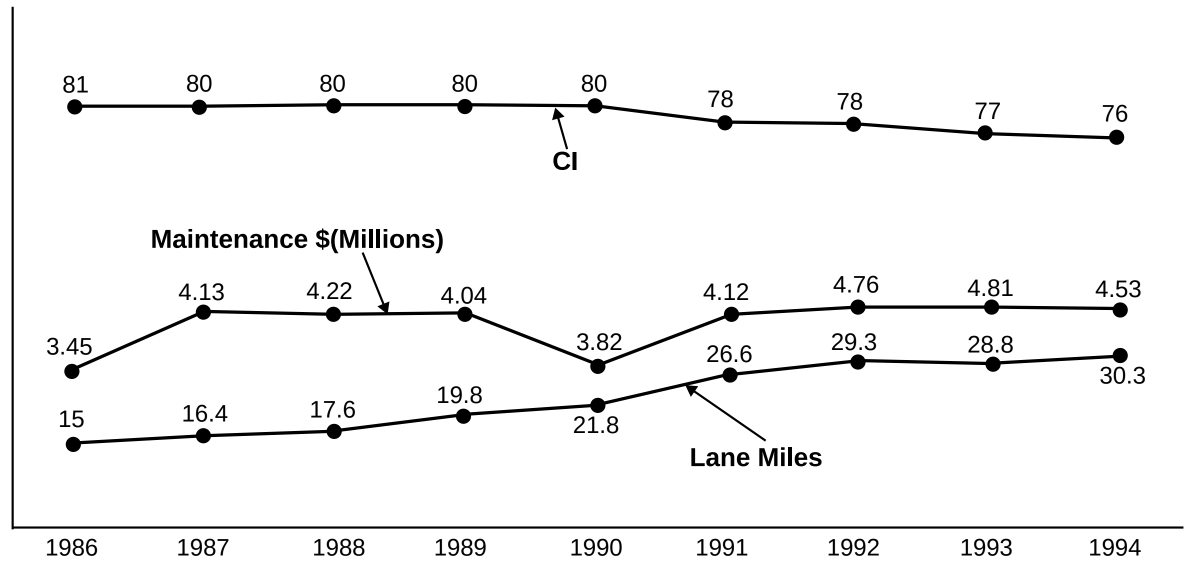
Note that the purpose of the memorandum is to summarize the current condition of the pavement network. It is not a budget report nor a proposed project listing. The graphics, particularly the second chart, illustrate very effectively the current condition of the pavements versus historical condition levels. This information sets the stage for the presentation of a needs report at a later date.

Elected Public Officials

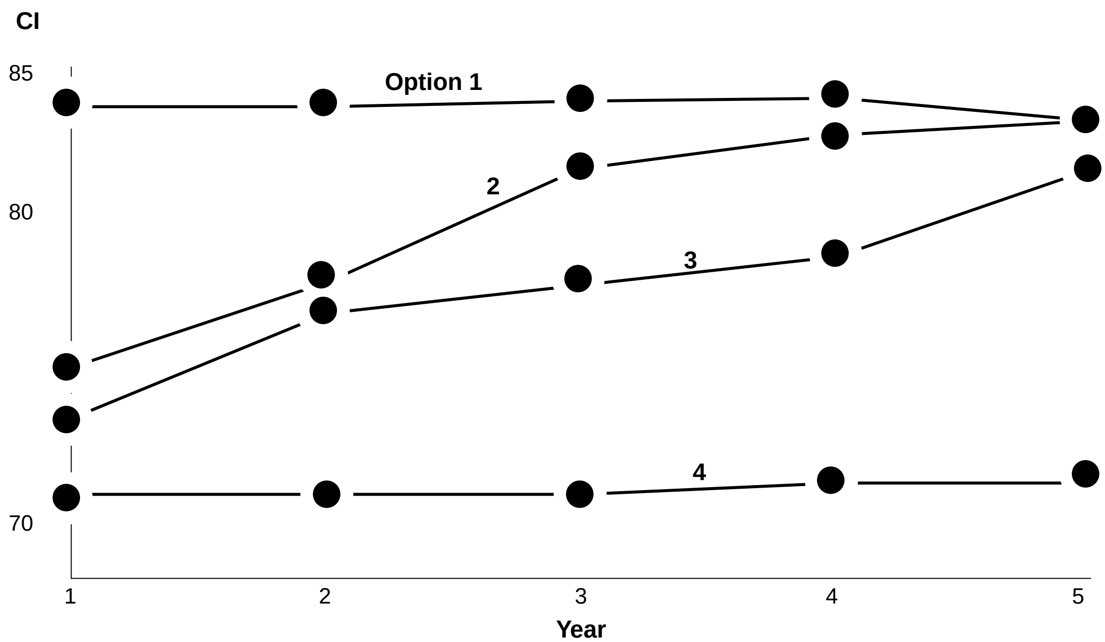
Elected public officials include legislative bodies, county boards, and city councils. PMS information helps them evaluate the immediate and future impact of their funding decisions on the overall condition of the pavement network. Elected officials can also use the recommendations of a PMS to weigh the needs of the pavement network with competing programs, such as social services and education. Usually PMS information is presented to elected officials on an annual basis, during the presentation of proposed pavement repair programs.

Elected officials serve short terms (often 2 years) but pavement decisions should be made on a longer time horizon (minimum 5 years). There is sometimes a tendency for elected officials to support short-term solutions (inexpensive in the short run but often expensive in the long-run) versus long-term solutions (inexpensive in the long-run, but more expensive initially). A PMS can be used to show the impact over time of continually selecting short-term solutions over long-term solutions, by analyzing overall network condition over time, backlog of needs (amount of pavement in unacceptable condition) over time, and future funding requirements.

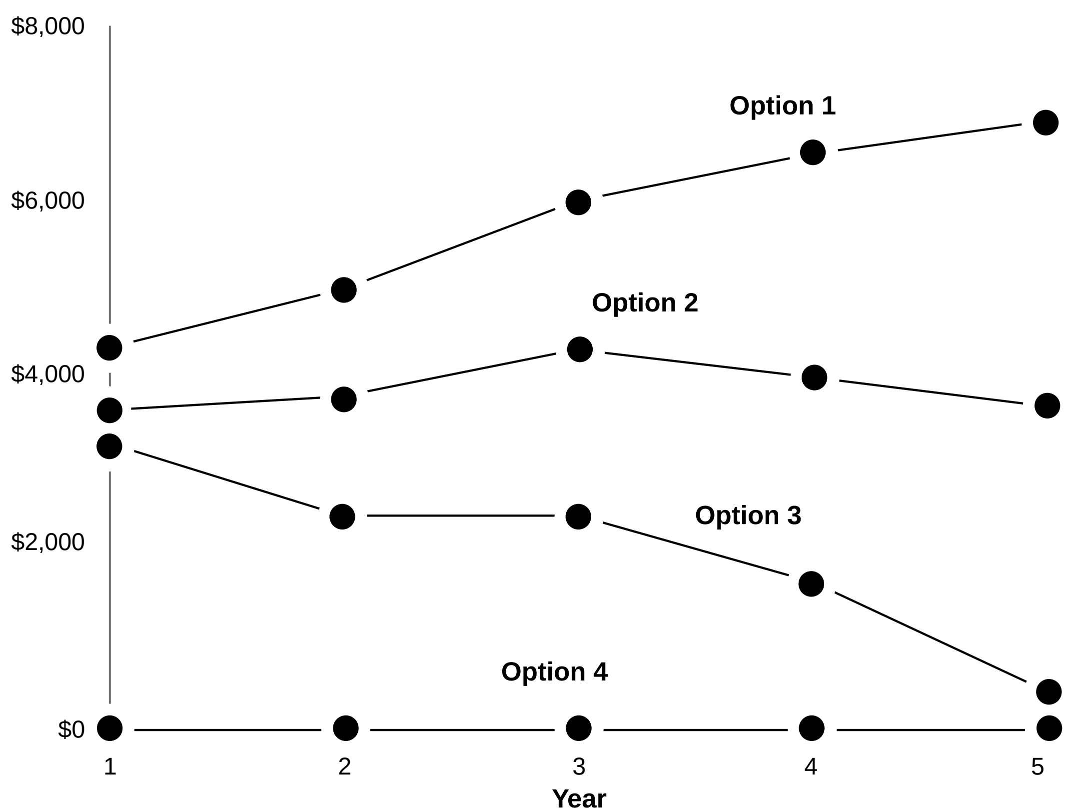
For example, elected officials usually want information about how different funding levels will affect the overall condition of the pavement network. They usually want to know the “bottom-line” impact of decisions made. Often, summary data presented in a highly visual manner works well with this audience. Examples of the types of information presented to elected officials follow.



Lane Miles vs Maintenance Dollars vs CI

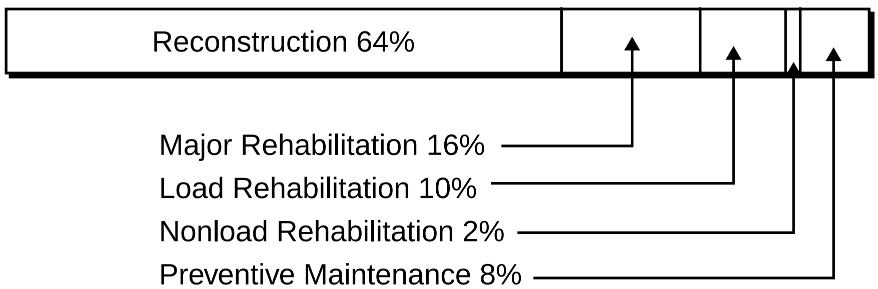


Impact to the Network CI with Various Rehabilitation and Preventive Maintenance Options



Impact to the Network by Options for Deferred Maintenance

Percent of Actual Expenditures Over Past Ten Years



Percent of Proposed Expenditures for Next Five Years

A Case Study: City of Renton (4)

The City of Renton Department of Public Works has used pavement management for nine years to identify pavement maintenance and repair needs, prepare annual budgets, and communicate the impact of different pavement maintenance and repair strategies and budgets on the condition of the street network. Many factors have contributed to the success of pavement management in Renton, including the Department of Public Works' efforts to communicate effectively with the city council.

The Renton Public Works staff have found that one of the keys to effectively communicating pavement needs to a city council is to design the presentation to match the needs of the audience. In Renton, this means keeping a number of things in mind. First, the staff remind themselves that the mayor and city council members are not employees of the Department of Public Works. Because of this, the council members do not have access to the same types of information that Department of Public Works staff may have and they are not as familiar with the operations of the department, including street maintenance.

Second, the staff must remember that in addition to being elected officials, Council members are tax paying members of the local community. It is from this perspective, rather than that of a city staff member, that the Council views recommendations by the Department of Public Works. Any presentation made to the council must address this point of view.

Third, the department must respect the council members' time so that the length of council meetings is reasonable. With this in mind, the department prepares material to distribute to the council prior to the meetings. That way, the presentations can concentrate primarily on summarizing the recommendations made and addressing any questions or concerns that Council members might have.

The Department of Public Works staff take the time to understand the council dynamics, which change over time depending upon the members of the council and the fiscal and political climate. The department makes a concerted effort to monitor the council, because the makeup of the council will directly impact the type of presentation tools that will be most effective. For example, one year, the council wanted very detailed information to make the decisions regarding road projects. The department responded with detailed information about the pavement budget needs and deterioration trends. Another year, the council requested brief, bottom-line only, presentations. In response, the department prepared graphical summaries that presented only the information needed.

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Wherever possible, presentations to the city council are made by department staff members closely involved with the day-to-day activities involved in developing the maintenance and rehabilitation recommendations. These staff members have earned a high level of credibility with the council members over the years.

The department believes that the communication of pavement needs is most successful when done in an environment of trust and credibility, where all participants work together as part of a team. The Department of Public Works has worked very hard to develop this partnership with the council. The department's use of a consistent and objective process for evaluating and managing its pavements for nine years has contributed to this environment. Through continuous (though often informal) discussion with the department, the council understands the process that is used to prioritize pavement maintenance and rehabilitation projects, and the basic concepts behind it.

Although the department now enjoys a level of trust and understanding with the council, efforts to establish this climate began with the implementation of the pavement management system. As soon as the system was being implemented, the Public Works Department gave a presentation to the city council on pavement management: what it is and how it will be used within the department.

Each year since, the department makes the offer to give a similar formal presentation on pavement management concepts; however, this offer is frequently turned down since many council members serve for many years and have already been exposed to the concepts of pavement management. Council members who have served for a number of years often serve as liaisons between department staff and new council members so that time at council meetings is not spent reviewing the concepts of pavement management. Instead, the presentations focus on reviewing the recommendations of the Department and addressing any questions that council members may have.

The City of Renton Department of Public Works often structures its annual pavement program presentation in the following way:

1. *The Department determines the best way to present the program to the council. It is at this time the department considers the current council members and selects the presentation approach that will be most successful in communicating pavement needs. The same type of information is presented every year; however, the way it is formatted and presented changes.*

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2. *The department develops the presentation. The basic order of the presentation remains the same year to year.*

   A. *First, the department staff tell the council how they spent last year's money. The department usually prepares maps that show the location of the projects completed, along with the cost of each project. The department also prepares a map that shows the condition of the pavement network, based upon the most recent inspections available.*

   B. *Next, the department shows the current overall condition network on the generic curve illustrating the cost to repair a pavement versus the condition level of the pavement (discussed earlier). Early on in the city of Renton's pavement management efforts, the department and the council agreed on the condition level they wanted to maintain for the pavement network.*

   C. *Finally, the department identifies the current needs of the system and the associated repair plan and budget for addressing those needs.*

Every effort is made to keep the presentation short and simple. Extensive backup material is provided prior to the meeting and is used to address any detailed questions that are asked during the meeting. Throughout the presentation, the Public Works Department tries to communicate the information in ways the city council can understand. For example, when explaining the future consequences of deferring maintenance the department will compare that to deferring work on a home's roof and the potential impact that would have.

Pavement management has been very successful in the city of Renton. This is due in part to the ability of the Department of Public Works to communicate the concepts and benefits of pavement management, and timely pavement maintenance and rehabilitation, to the city council.

Community Associations and Groups

Many different community groups use PMS information. Residential groups use PMS information to monitor how an agency plans to maintain the pavements within a given residential area. Groups representing the interests of bicyclists use PMS information to monitor road projects from the perspective of trying to integrate bicycle paths or lanes into upcoming projects wherever possible. In a similar manner, groups representing pedestrians monitor projects from the perspective of the pedestrian, trying to ensure that safe passage for pedestrians is considered during the design of a road project.

The pavement manager often uses the PMS as a public relations tool in its dealing with the public. For example, a pavement manager can use a PMS to quickly respond to public queries about why one road is not being fixed whereas another one is. Many local agencies interviewed during the preparation of this guide cited that this was one of the most important ways they use their PMS.

Highly visual formats, in the form of maps and graphics, work best to convey information to the public. The information presented should be simple. Easy to understand, and nontechnical. This information is often requested on an annual basis when the local agency presents its annual work program; however, the public frequently makes ad hoc requests for pavement management information throughout the year which the pavement manager needs to respond to in a timely manner.

A Case Study: City of Seattle (2)

The city of Seattle tries to involve the public in the pavement management process whenever possible. One example of this was the Neighborhood Priority Conference held in January 1996. During this meeting, the neighborhoods were presented with a list of streets that the city of Seattle had identified as needing work. The neighborhood associations then provided their input on the prioritization of that work.

Other Groups

There are many other groups that use PMS information. For example, the trucking industry depends upon roads for the efficient and cost-effective transportation of goods. In addition, taxes are assessed on the trucking industry based upon the amount of damage they inflict upon the road system and load restrictions may be placed upon roads based upon pavement management data.

A Case Study: Thurston County (5)

Thurston County has the right to limit or prohibit classes, types, or weights of vehicles which travel on County roads. The following memorandum is distributed to explain the process.

Subject: Haul Road Agreements

Contractors planning to use Thurston County roads for transporting any item, including but not limited to products, equipment, materials, and/or supplied over the county roads must apply for a Haul Road Agreement. The Haul Road Agreement shall be completed for existing, new and expanded hauling operations of 10 loads or more that may cause accelerated deterioration of county roads. These hauling operations shall include but not be limited to: pits and quarries, logging, contractor, and developers.

It is in the best interest of the citizens of Thurston County regarding both safety and expenditure of funds that county roads be restricted to protect them from accelerated rates of wear due to intensive use, by trucks and other heavy equipment.

The county may limit or prohibit classes, types or weights of vehicles which travel on county roads pursuant to RCW 36.75.270 and 46.44.080;

The county and the contractor anticipate that as a result of the contractor's use of county roads, accelerated deterioration may occur. Thus, repairs or improvements may be required and additional maintenance expenses may be incurred by the county.

The county is authorized to issue Haul Route Permits under the provisions of RCW 36.75.270 and 46.44.080.

A utility company can use PMS information to time its utility projects in conjunction with major pavement repair projects. By working together, utility companies and local agencies can avoid situations where a road is rehabilitated one year only to be torn up the following year to allow the installation of cable or some other type of utility.

Developers are also users of PMS information. A local agency often uses pavement management information to establish the specifications that roads leading into a new development have to meet.

Summary of Users of Pavement Management Information

The following table summarizes much of the information presented so far. It outlines the different users of PMS information, their level of technical understanding, their use for the information, the type of information they need, and the presentation format that will most effectively relay the information to each user.

Table of PMS Presentation Information

User of PMS Information	Level of Technical Understanding	Use for PMS Information	Type of Information Needed	Recommended Format of Presentation	Frequency of Information Requests
Pavement Manager	High	Prepare M&R programs; answer ad hoc queries; perform feedback analysis.	Detailed, technical data on all aspects of PMS.	All formats used by pavement manager.	Daily.
Maintenance Division	Variable	Identify where maintenance is needed, what type of maintenance is needed, and obtain estimate of quantity and cost of work; evaluate performance of different maintenance techniques.	Specific data showing location of needed work, estimated quantity of work, and cost of work.	Maps showing where work is needed; lists identifying type of work and estimated cost of work.	Annual for maintenance plan; ad hoc for other queries.
Engineering Division	Medium to High	Track performance and cost of rehabilitation techniques; assist in rehabilitation design.	Traffic data, CI data, structural data, construction history data.	Tables and lists of information.	Annually for rehab. design; ad hoc for other queries.
Planning/ Programming/Budgeting	Low to Medium	Assist in preparing annual and long-term programs and budgets.	Summary information showing what work is needed, along with cost of work.	Tables and lists of information.	Annual.
Management	Low to Medium	Perform “what if” analysis; develop presentation materials for Councils and Boards.	Summary information showing impact of different repair and funding strategies.	Graphs, figures, and maps.	Annual for work plan and budget; ad hoc for other queries.
Elected Public Officials	Low	Understand impact of different pavement maintenance and rehabilitation strategies and budgets.	Summary information.	Highly visual graphics and maps.	Annual.
Community Associations and Groups	Low	Understand what local agency is doing to fix the roads; understand why agency is fixing some roads and not others; used as a public relations tool.	Summary information.	Highly visual graphics and maps.	Ad hoc.
Trucking Industry	Low	Understand how load restrictions are developed; understand how haul damage is assessed.	Summary information.	Highly visual graphics.	Seasonal; ad hoc.
Utility Companies	Low	Coordinate utility work with local agency’s pavement repair projects.	Summary information.	Maps.	Annual.

Educating the Various Audiences

Regardless of the group for which the pavement manager is providing information, it is important to educate the audience on pavement management concepts. While it may not be possible to educate all the groups that use PMS information, it should be attempted with elected officials at a minimum. This step is often overlooked, but it is critical to provide this background information prior to presenting the results from pavement management analyses. Otherwise, the audience may become confused by the basics of PMS and not understand or trust the results being presented.

Introducing PMS concepts to the various users of PMS information can take the form of small presentations over a period of time or the distribution of informational flyers. One easy way to familiarize groups with PMS is to introduce each step of the PMS process as it occurs. As important milestones are met, such as the completion of condition data collection, they are presented. The effort expended to educate the audience will yield a large reward, as the users of the PMS information grow to understand and trust the recommendations made with the PMS.

Chapter 2 of this guide provides detailed information on the types of training that are appropriate for the different users of PMS information, along with example training outlines.

Developing A Working Relationship With The Audiences

In close association with educating the audience is developing a relationship with that audience. Usually, establishing this relationship is a gradual process. At first, the pavement manager is often a provider of practical information. Over time, as the pavement manager gains credibility and trust, the relationship transitions to the point where the pavement manager is playing an integral role in the management of pavement resources.

The following is a sequential process that may be followed to develop a working relationship with divisions within an agency, with the public, and with elected officials.

1. Prior to implementing a PMS, establish a steering committee (as described in *A Guide for Local Agency Pavement Managers* (6)). This committee should include representatives of the pavement management group, maintenance, engineering, budgeting/programming, and any other groups that will use or be impacted by the PMS. If possible, involve a City Council Member or Board of County Commissioner. The steering committee will establish direct communications among the groups that will be impacted by the PMS. It will also give the different groups a sense of ownership of the system.

   During implementation meet with this committee monthly or weekly, as conditions warrant, to inform the group of the progress being made and resolve any problems encountered. These meetings are often an hour to an hour and a half long during the first year of implementation. Continue to meet with the steering committee after implementation is completed on a quarterly basis to make sure the system is continuing to provide the type of information the different users require.

2. Make a presentation to the City Council or Board of County Commissioners. During this presentation, establish the reasons for implementing a PMS and present a schedule and work plan for completing the implementation. As PMS implementation proceeds, give a 2 to 3 minute presentation every couple of months to inform the Council or Board of the progress being made.
3. Develop a newsletter (1 page flysheet) describing the objectives and benefits of pavement management. This newsletter will also outline the key milestones of the pavement management effort. Distribute this to the public. Contact the local newspaper to have an article published describing the pavement management efforts being undertaken.
4. Analyze data as needed to support the different users of the PMS: Maintenance Division, Engineering Division, Programming/Planning/Finance Division, Management, and Elected Officials. Work with each user individually to find out what kind of information would assist them in their jobs.
5. Present pavement repair recommendations to the Council or Board.
6. Conduct public meetings as the pavement maintenance and rehabilitation program is developed to present the projects. Investigate alternative methods of communication, such as placing the project list on the Internet.
7. When pavement repair work is being done on a street, distribute a newsletter via mail or door hangars. This letter should outline the reason for the work being done and explain any details that the residents should be aware of (such as estimated beginning and end dates of the work and any parking or access restrictions that will be in place during the project).
8. Quarterly newsletters can be prepared and distributed to neighborhood associations identifying projects.
9. Once PMS is implemented, meet quarterly with the steering committee and representatives of users of the PMS in the agency to evaluate whether the PMS is meeting everyone's needs and how it can be continually improved. During these meetings, the pavement manager should find out what he or she can do for each user to make their jobs easier. It is important for the pavement manager to respond to any requests as quickly as possible and to maintain a service-oriented attitude.

Developing A Presentation

Putting together a presentation usually involves the following critical steps.

1. **Identify the target audience, both in terms of knowledge level and size.** A single presentation approach does not work for every audience; presentations need to be tailored by considering the level of technical detail required by the audience and the time available for the audience to review and evaluate the provided information.

   Audience Size

   A presentation to a small group can be relatively informal and one-to-one discussions and eye contact are possible. A large group (greater than 50 people) usually means that the presenter will be at the head of the room lecturing with a microphone. Only limited interaction is possible in this environment.

   Audience Make-Up

   If the presentation is being made to superiors, it is important not to lecture to the audience and to make recommendations that are backed up with facts. If the audience is comprised of peers, use an approach that stresses sharing of information and tries to draw the audience into the presentation by asking them to share their expertise and experience. During a team meeting, use "we" language and remember the cardinal rule of sharing success and taking responsibility for any blame. If the presentation is being given to a special interest group, focus the presentation around the concerns of that group (7).

2. **Select the presentation format.** The presentation of PMS information and recommendations can take many different forms. Oral presentations are frequently used to communicate information. Press releases and information brochures are used to reach a broader audience. Detailed reports are developed for groups requiring in-depth data and analysis results.

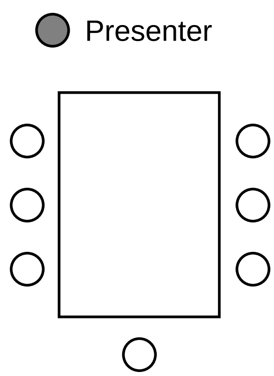
   If the engineering or research division asks the pavement manager for information about the performance of different pavement repair techniques, detailed information providing technical data and statistics pertaining to performance versus age or traffic is appropriate. On the other hand, if upper management wants to evaluate the impact of several different funding scenarios, the pavement manager may find that less detailed and to the point information that underscores the important results is an effective presentation approach. Graphical formats work well with upper management. For presentations to the public, information needs to be presented in a highly visual way, using a combination of graphics, maps, and photographs, that people who are not technical experts in pavement management can understand.

3. **Select the information to present.** When preparing a presentation, select only the information the audience needs. Be concise. There is often a temptation for the pavement manager to present too much information. That is because the pavement manager is often proud of the PMS and wants to show what it can do. In addition, the pavement manager has a thorough understanding of PMS concepts and may forget that most audiences do not. How the information is presented is often more important than what information is presented. The audience is often pressed to make a quick decision to address an immediate need and the information provided to them needs to be clear and focused, so that an answer can be made quickly.

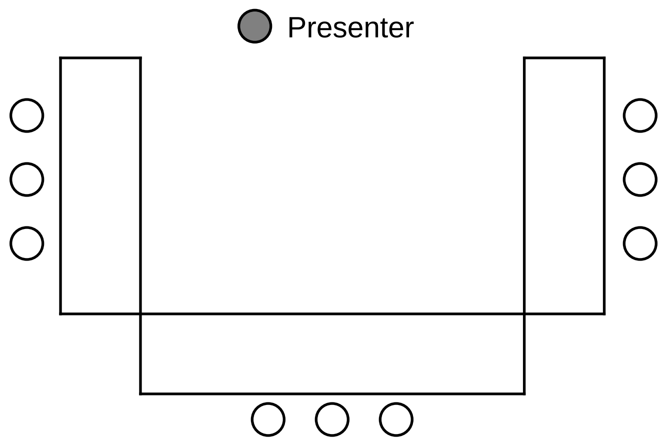
4. **Prepare presentation materials.** There are two types of presentation materials that need to be prepared: visual aids to use during presentation and handouts to distribute to the audience. These are discussed in the next section of this chapter.

5. **Set up the room.** There are several options available for setting up the presentation room (7).

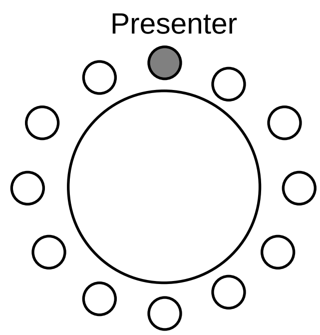
   - Conference Style: The audience can sit around a conference table, with the presenter standing at the head of the table. This approach works well with audience sizes of 4 to 16 people. It allows easy interaction among participants and is conducive to a working session. If this approach is used, be careful when presenting visual aids because it is easy to block the view of someone in the audience.



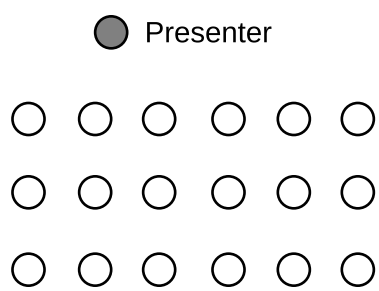
   - U-Shaped Style: In this approach, the tables are organized in a "U" shape. This approach works with audiences of 4 to 16 people. While it does allow for big group interaction, participants often find it difficult to talk to people that are not seated on either side of them. Encourage participants to speak up and discourage side discussions.



- Circular Style: The circular style is similar to the conference style, except that a round table rather than rectangular is used. It is limited to about 10 people. There may be trouble giving the audience an unobstructed view of visual aids.



- Classroom/Lecture Style: In the classroom style, the presenter is at the front of the room and chairs (with or without tables) are lined up in front of the presenter. This style is more formal and can accommodate almost any size group.



6. **Rehearse.** If possible, rehearse in the room that will be used for the presentation. Have notes available to refer to, but do not read your speech (unless you are quoting something). Practice maintaining eye contact with the audience and remember to concentrate on the audience, not your

visuals. Speak clearly, avoid a monotone, and make sure you can be heard all the way in the back of the room. Most important, be yourself and try to move around if possible. (7)

7. **Arrive early.** Go through a checklist before the presentation to make sure everything will go smoothly.
   - Check any audiovisual equipment that will be used.
     - Make sure extension cords and extra projection bulbs (if needed) are available.
     - If 35 mm slides are being used, make sure the projector is in focus and that the slides are in the carousel correctly and in the right order.
     - If there is a microphone, check to make sure it is working.
     - If a computer or VCR will be used during the presentation, make sure everything is working properly.
   - Check the temperature of the room.
   - Make sure there are enough seats available.
   - Arrange for someone to control lights.
   - Get a glass of water and set it where you can easily get to it.
   - Check your appearance, take deep breathes, and try to relax. It often helps to greet people as they come into the room to establish a rapport with the audience.

Presentation Materials

A variety of media can be used during presentations, including handouts, overhead transparencies, 35 mm slides, and videotapes, to help communicate the recommendations of a PMS. Different visual aids can be presented using these media, including tables, charts, maps, and photographs. Each is very effective in the appropriate situation and can make a presentation come alive.

Presentation Media

Handouts

Handouts that include copies of visual aids can be distributed to the audience. Since these handouts can sometimes compete for attention during the actual presentation, it may be better to distribute them at the completion of the presentation.

Overhead Transparencies

Overhead transparencies are best for small to medium audiences (4 to 20 people) (7). They provide the flexibility of allowing you to change the sequence of your presentation at the last moment by rearranging or omitting transparencies. You can also use a marker to write on the transparencies during the presentation. Overhead transparencies can facilitate an interactive presentation.

The key to making effective overhead transparencies is to make sure that the text can be read all the way in the back of the room. It is recommended that the minimum height of the smallest letters be 3/16" (6 point in Word Perfect, Times Roman font) (8). One good test is to place the transparencies on the floor and if you can still easily read them the type is large enough. Another good hint is to never use more than 7 words per line or 7 lines per page. If you use color, limit it to three colors maximum and avoid red and green which are difficult to read. (7)

Slides

35 mm slides are effective with medium to large audience sizes (20 to 50 people) (7). Since the room is normally darkened during a slide presentation, the speaker does not command the attention that he or she does when using overheads and there is the potential for the audience to doze. In addition, once the presentation has begun the speaker is confined by the sequence of the slides and cannot modify them as the presentation goes along.

There are several tips you can follow to make clear, legible slides (7,8).

- Limit the slide to only one idea.
- Remove any details that are not needed to relay the message. For example, cut out any decimal places that are not necessary, substitute symbols for words (such as a $) where possible, delete footnotes, and omit sources. Keep it simple.
- Use contrasting colors. Light lettering on a dark background or dark lettering on a light background work best. Never use light lettering on a light background or dark lettering on a dark background.
- Never show more information on one slide than can be assimilated in 30 seconds.
- Use no more than 10 to 15 words on a table.
- Use no more than one or two broad-line curves or bars on a graph.
- For computer-generated slide images, the minimum character size should be 6 point Times Roman font.
- Use a duplicate slide if the same slide needs to be referred to again during the presentation.

Videotapes

Videotapes are very useful in situations where you want to dramatize. For example, a videotape of traffic whizzing by, cars hitting potholes, cars waiting in a traffic jam caused by road construction, and water splashing underneath the wheels of a vehicle is very effective in relaying the impact of pavement condition on the traveling public. Videotapes are also very useful for training. When deciding whether or not to use a videotape in a presentation, keep in mind that videotapes provide very poor audience involvement and should be limited to no more than 25 minutes in length.

When preparing a video, there are some key factors to keep in mind.

- Lighting is critical.
- To show pavement distress, you need to use a high quality camera, with a zoom lens and steady cam function.
- Use a tripod.
- Move camera in slow moving motions (no jerks).
- Stay on a subject for longer than you'd expect (10 to 15 seconds).
- Learn to fade in and fade out.
- Use a reference point (for example, a pencil) in the shot for perspective.
- Use a good TV screen to present the videotape (high definition, if possible).

Visual Aids

Tables

Tables are very useful in situations where an extensive amount of detailed information has to be presented. They are most effective when supporting detailed analysis and providing technical information. When in-depth information is required on a segment by segment basis, a table is usually the best format for presenting the data. Frequently, engineering and research groups will request information in this format.

Tables are most effective when incorporated into written reports or other documents, where a reader can take the time to fully assimilate the information. Tables are least effective when used during a presentation, particularly if the presentation is being made to nontechnical audiences. It is hard for an audience to understand all the information contained in a table in a short amount of time and it can distract the audience from concentrating on what the presenter is saying. If tables have to be used in a presentation, they should be simplified as much as possible and the key factors that are being illustrated with the tables need to be highlighted.

Examples of tables that are frequently developed as part of PMS presentations include the following:

- **inventory listing**, providing information such as segment location, name, surface type, physical dimensions, age, and traffic designation.
- **condition listing**, providing information such as segment location, segment name, surface type, age, traffic designation, visual condition index, and structural condition.

- **maintenance listing**, providing information such as segment location, segment name, year of maintenance activity, maintenance type, and maintenance cost.
- **budget listing**, providing information such as the total amount of money proposed for different repair types or the amount of money to be spent on different road functional classifications.

Tables are either produced directly with the PMS software, through the use of word processing software, or through spreadsheet software. The following table is representative of one that a pavement manager would include in a budget report. Many examples of other typical pavement management tables have been presented earlier in this chapter.

	Year 1	Year 2	Year 3	Year 4	Year 5	5-Year Total
Total Projected Revenues (10%)[1]	1,041	1,145	1,260	1,386	1,525	6,357
Revenues to Pavement Repair (31%)[1]	323	355	390	430	473	1,971
Front Loaded						
Recommended PMS Program Five Years	4,442	746	1,083	377	372	7,020
Repair Program Surplus (Deficit)	(4,119)	(391)	(693)	53	101	(5,049)
Spread Evenly						
Recommended PMS PMS Program Spread Evenly	1,404	1,404	1,404	1,404	1,404	7,020
Repair Program Surplus (Deficit)	(1,081)	(1,049)	(1,014)	(974)	(931)	(5,049)

[1]Note the two key assumptions: a 10 percent revenue growth rate (which is less than the average annual growth rate from 1987/88) and 31 percent of revenues going to pavements for patching, sealing, overlays, and rehabilitation. The average seven-year revenue total of $860,571 was used in 1988/89 and was increased to reflect 1990/91 in year 1 above.

Five-Year Roadway Related Revenue/Pavement Repair Summary Table ($, Thousands)

Charts

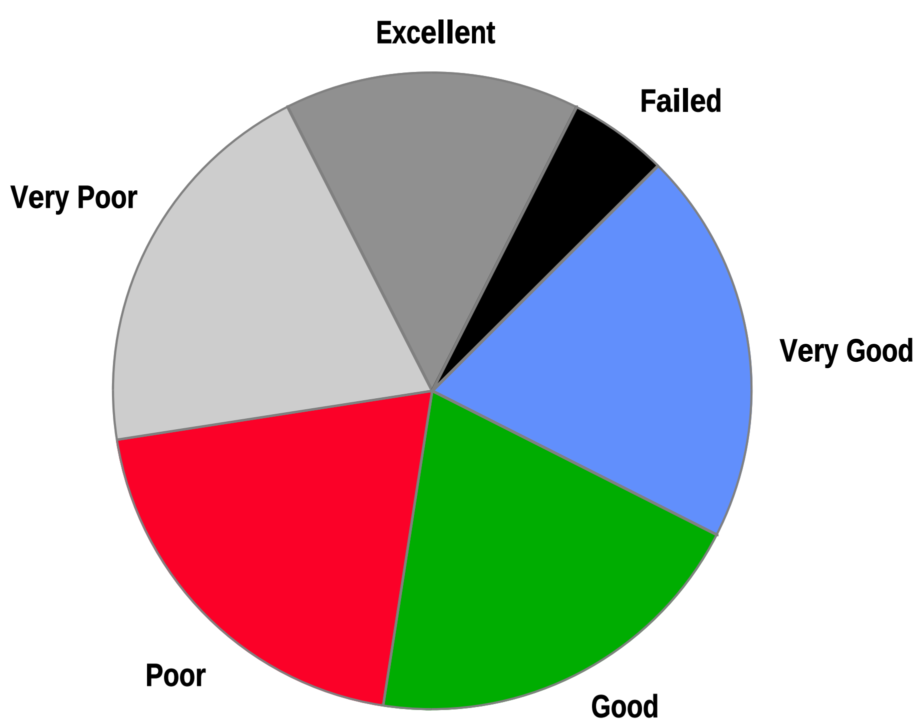
Charts cannot adequately communicate all the information that a table can. However, well-designed charts are much easier for an audience to understand and can be used to really emphasize the points that need to be made. Charts are an excellent choice for presenting information to nontechnical audiences, such as elected officials and the public. In addition, charts are very effective in both written reports and in oral presentations.

There are five basic chart forms: pie chart, bar chart, column chart, line chart, and dot chart (scatter chart) (9).

Pie Charts

Pie charts work best for relaying information that shows the size of each part as a percentage of the whole. For example, the percent of the roadway network that is in good, fair, and failed condition is a component comparison.

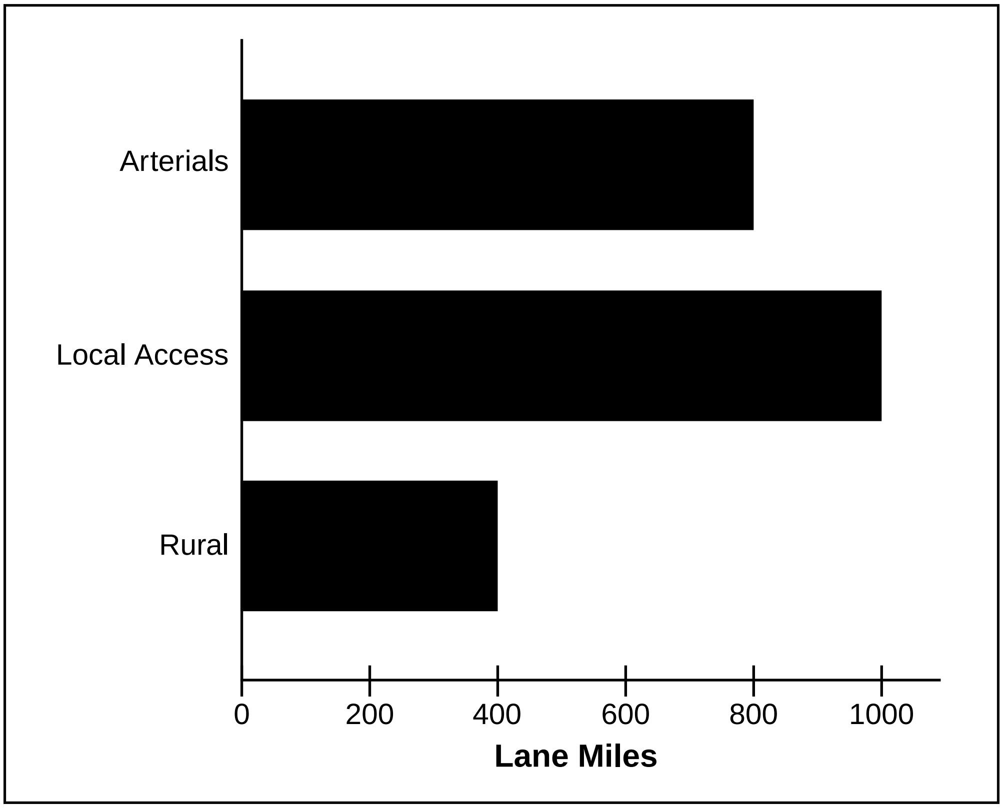
To make the most of a pie chart, limit the pieces of the pie to 5 or 6. If you have more than 6 pieces, use the 5 biggest and then group the rest into an "others" category. The viewers eye is accustomed to measuring in a clockwise motion, so position the most important segment against the 12 o'clock line (9). To draw attention to a piece, use contrasting colors or interesting shade pattern.



Percent of Pavement Area by Pavement Condition

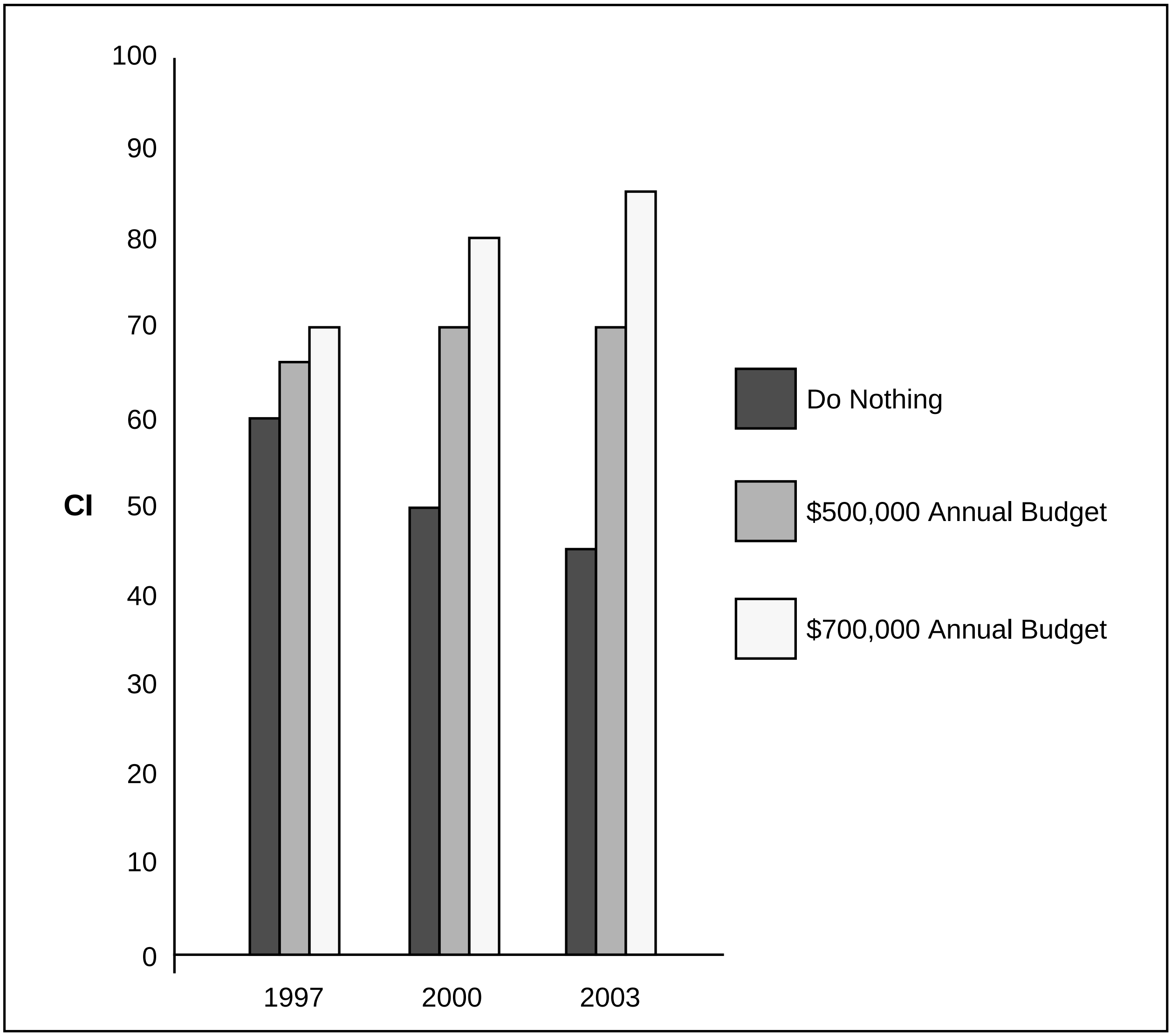
Bar Chart

Bar charts are used to show how things rank. The vertical dimension is not a scale in a bar chart; it is used to label the items being ranked. In preparing bar charts, make certain that the space separating the bars is smaller than the width of the bars (9). Use the most contrasting color or shading to emphasize the important item.



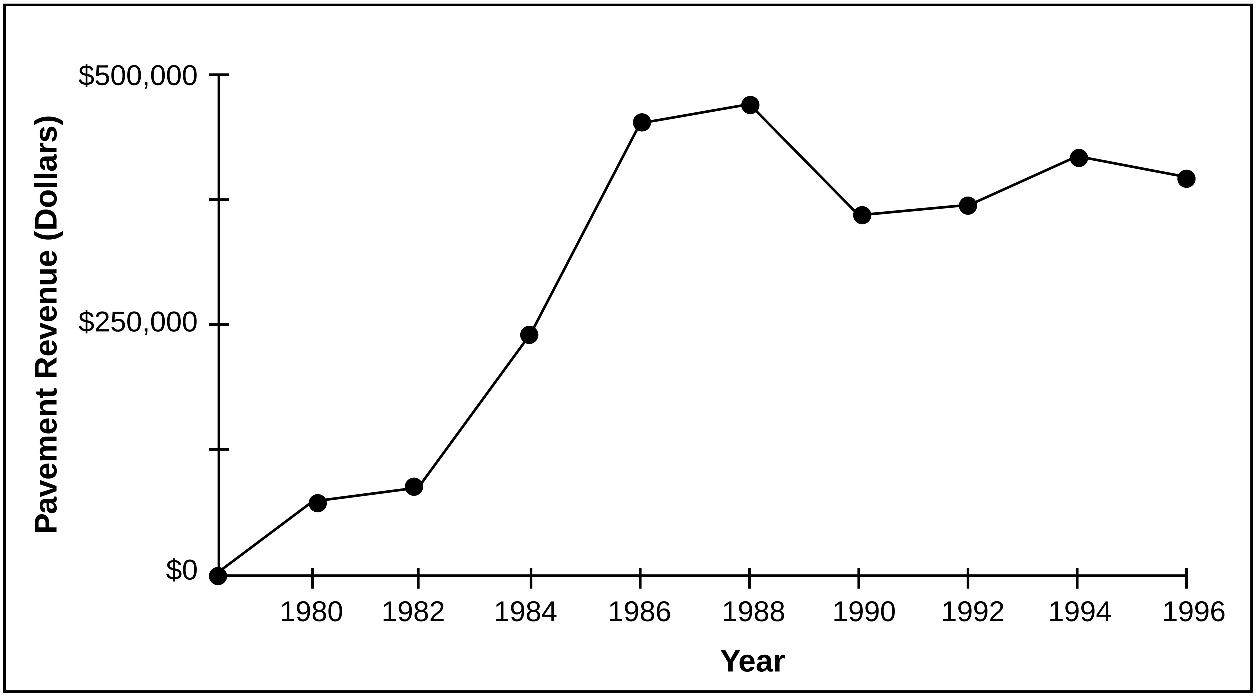
Column Chart

Column charts are useful when showing how items change over time. If there are more than 7 or 8 items being evaluated, use a line chart instead. For column charts, make the space between the columns smaller than the width of the columns (9). Use color or shading to emphasize one point in time more than others.



Line Chart

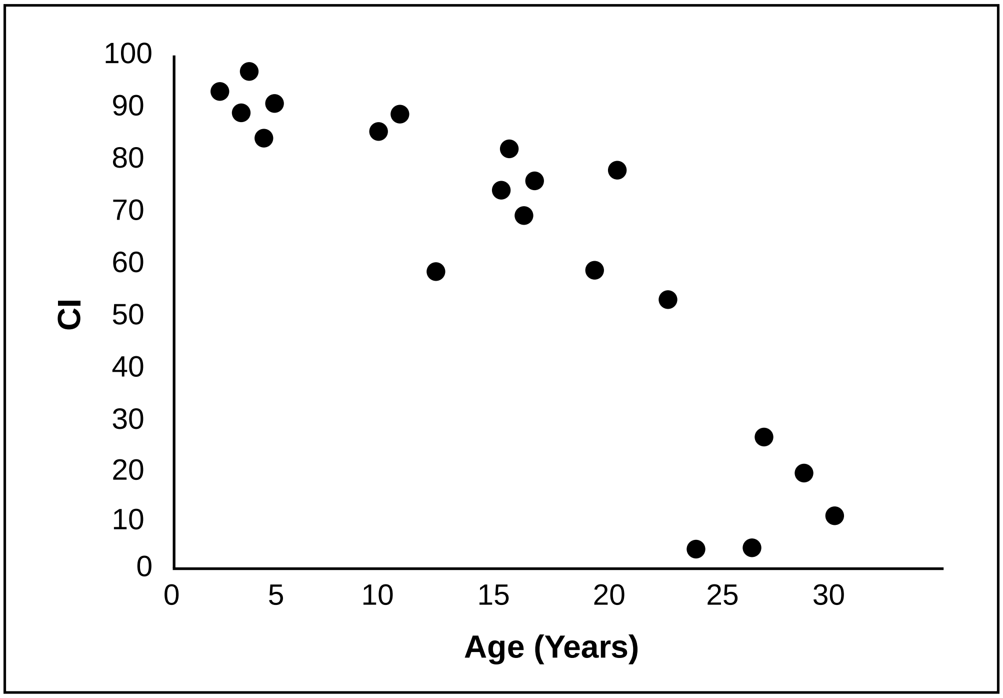
Line charts are useful for showing how items change over time when there are over 7 or 8 items being evaluated. They are also useful for showing how many items fall into a series of ranges. A grouped line chart compares the performance of two or more items. The challenge is deciding how many trend lines can be viewed simultaneously before the chart becomes too confusing.



If the line chart is being used to show how many items fall into a series of ranges, it is best to use groups of equal sizes and to select a number of groups that brings out the pattern of the distribution (too few will hide the pattern and too many will break it up) (9).

Dot Chart

Dot or scatter charts work well to examine the relationship between two variables. Data series are often examined using this type of chart.

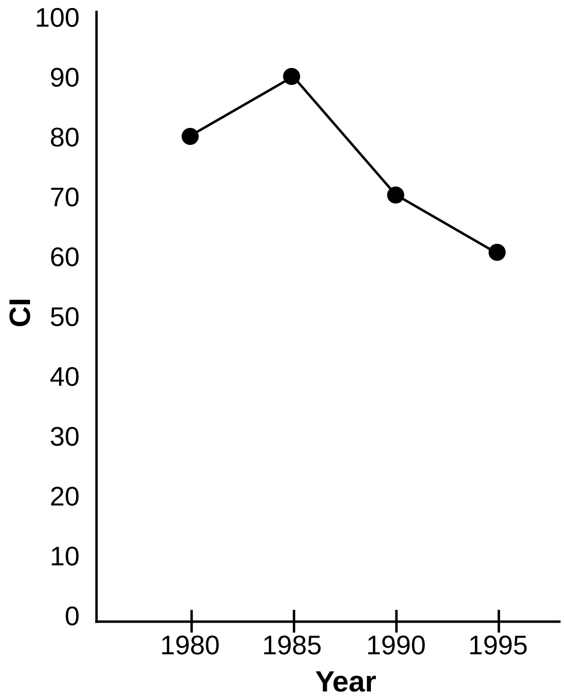


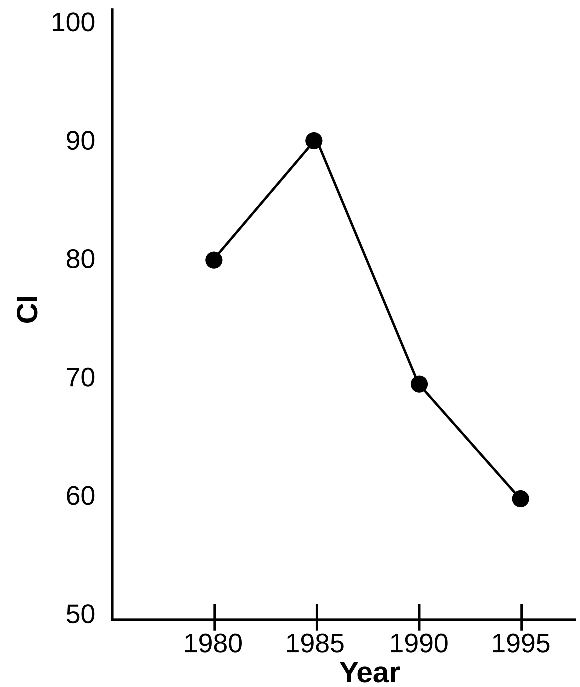
General Guidelines for Preparing Charts

Some general guidelines and hints for preparing effective charts follow:

- Put just enough information on the chart to illustrate the point you are trying to make.
- If the chart will be used in an overhead or 35 mm slide, remember to keep it much simpler than one you would use in a report or handout.
- If a chart is being prepared in color as a slide or overhead, and you will be reproducing it in black and white to include in handouts, make sure that it reproduces well on paper.
- Black, white, and one other color is about all that a viewer can easily assimilate.
- Clear, detailed, and thorough labeling should be used.
- In time-series displays of money, deflated and standardized units of monetary measurement are nearly always better than nominal units (10).
- If presenting a series of charts, remember that any differences blurs changes in the data. When doing a comparison from chart to chart, keep everything the same except what you are comparing.

- Be honest with the reader about the information you are presenting on the chart. It is easy to distort charts and make them misleading by using the wrong scale or changing the scale part way through the chart. An example of how using different scales with the same set of data can change the way a viewer interprets the information is presented below.





Graphics are produced directly with a PMS, through manual or computerized drafting, through the use of spreadsheet software, or through presentation software. There are many books available that provide instructions for developing effective graphics, including *Say it With Charts (9)*, *The Visual Display of Quantitative Information* (10), and *Envisioning Information* (11).

> *A Case Study: Thurston County (5)*
>
> *Pat Carroll*
>
> *Thurston County has been involved in pavement management for many years. During that time, it has periodically been asked to explain the benefits of using pavement management. The County prepared a series of highly effective graphs to assist during presentation on pavement management and its benefits, which can be found in Appendix A.*

Maps

Maps are very effective for displaying a single type of information (such as projected pavement condition) on a geographical basis. They are particularly powerful when used during presentations to upper management, elected officials, and the public.

When preparing a map, make it as simple as possible. Eliminate extraneous information and subdue any support information. Use a common sense approach to color. For example, if you are preparing a pavement condition map, red is usually used to identify pavements in very bad condition and yellow and orange are used to identify pavements approaching bad condition. Blue is used to identify a river or lake, and black is often used to identify a road.

Examples of maps that can be used during PMS presentations include the following:

- map of pavement network color-coded by segment surface type
- map of pavement network color-coded by traffic designation
- map of pavement network color-coded by current condition
- map of pavement network color-coded by future condition under a given funding scenario
- map of pavement network color-coded by deferred projects under a given funding scenario
- map showing projects scheduled for a given year

Maps are produced directly through the use of the PMS, through manual or computerized drafting, or through the use of geographical information systems (GIS). An example of a map follows.

Photographs

Photographs are often overlooked when putting together a PMS presentation. However, there are some situations where photographs can be invaluable. For example, an audience may not understand what different condition index values really represent. A series of photographs showing pavement segments in various conditions will convey this information much more effectively than verbally trying to describe the meaning of condition index values.

The film, lighting conditions, lens, filter, depth of field, and composition all affect the type of photograph taken and its quality.

Film

The first decision to make when taking photographs is whether to use color or black and white film. Color film is recommended, unless the photographs are going to be reproduced in a black and white document. Color provides more referencing information to the viewer and is more forgiving of the photographer. However, color photographs do not reproduce as well in black and white documents as black and white photographs do.

To adequately show fine details, such as cracks and surface texture, use high resolution, professional film (such as Kodak Tmax 100 or 400). The number indicates the speed of the film, the lower the speed, the finer the grain of the film and the better the resolution. Lower speed film is particularly important if the final photograph will be enlarged. However, lower speeds do require more light.

Use slide film for overhead presentations or where the photo will be reproduced in color.

Lighting Conditions

When shooting photographs, keep the sun to your back or to your side. Be aware of your shadow and make sure it does not end up in the picture. Distress in pavement or any fine detail will show up better if you take the picture with the sun is shining at an angle and approximately 90 degrees from your side. If taking general black and white photographs, those not highlighting texture detail, light overcast conditions are better since contrast is decreased.

Lens

There are three basic types of lenses: a wide angle lens, a normal angle lens, and a telephoto lens. A wide angle lens has a focal length < 40 mm and it makes things look farther away. For a 35 mm camera a normal angle lens has a focal length of about 50 mm (our eyes have a focal length of about 50 to 55 mm). A telephoto lens has a focal length > 70 mm and compresses the view making things look closer than they are.

Be aware that lenses can distort information. A wide angle lens can make a pavement look better than it is by expanding the view over a broader area. A telephoto lens compresses depth and enhances irregularities by making them look closer together thereby, making a pavement look worse than it is, i.e., corrugations, sags, and humps.

Filters

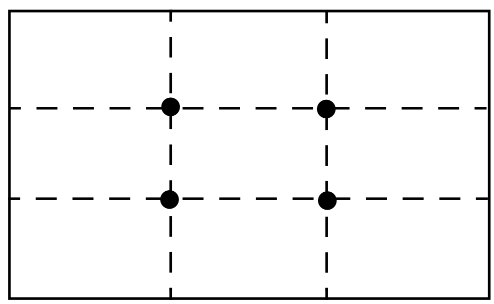
When taking black and white photos, a dark yellow or dark red filter helps increase the contrast in the sky, make the photo more natural looking, and bring out more detail. For color photos, UV or skylight filters cut haze and make the photo sharper. In extremely bright sunlight, consider using a polarizing filter (automatic focus cameras require a circular polarizing filter). A polarizing filter decreases reflection and makes color richer.

Depth of Field

The size of the aperture opening (F-stop) directly relates to how much of the picture will be in focus. Smaller openings (F16 or lower) will give longest depth of field. Smaller F numbers have larger openings and shorter depth of field. For a general purpose photo, to maximize focal length yet still keep the picture stable, set the shutter speed at 1/125th of a second, then adjust the light meter with the F-stop (if no traffic is in the picture, you can set shutter speed to 1/60th of a second). If your camera is automatic and has a "hyperfocal" setting use that setting.

Composition

Visualize how your photo will appear before actually taking the picture. One useful tip regarding photograph composition is to imagine the view finder divided into thirds, both vertically and horizontally as shown:



Place the subject of the photo along one of these lines with the center of the subject at one of the intersections. If the horizon is in the picture, place it along the top horizontal line to accent the foreground or along the lower line to accent height. If the subject fills diagonally across the frame, try to compose it go through the two intersection points diagonal to each other.

Use of Color (12)

Color is a powerful tool that can be used to highlight the point you are trying to make and to add variety to a presentation or document. Following are some tips for using color:

- Use color sparingly for maximum impact.
- Use color to explain, not to decorate.
- Use high-contrast colors to draw attention to major points. The reader will look at the brightest area first.
- Use color to differentiate (i.e., pie charts) or to highlight (i.e., map identifying upcoming projects).
- Avoid using complementary colors, such as red and green, since they appear to vibrate when viewed together.

- Keep color choices simple. Two colors plus black is about as much as a reader can easily remember.
- Use a common sense approach to color and stay with accepted color representations. For example, blue for water and red for pavements in bad condition are typical color representations.

Reports

A pavement manager is often called upon to prepare written reports, either in conjunction with a presentation or as a stand-alone document. It is not possible to present examples in this chapter of all the types of reports that a pavement manager might be asked to prepare. Therefore, a Budget Options Report has been selected for illustration purposes since it is one of the most common and important report types that a pavement manager is asked to produce.

A Budget Options Report presents pavement needs and discusses different funding options. The basic purpose of writing a Budget Options Report is to better assess the adequacy of a local agency's revenues to meet the pavement repair needs identified by their PMS. If written well, a Budget Options Report is a tool that the pavement manager and upper management can use to promote (1) the implementation of a multi-year street rehabilitation program; (2) the development of a preventive maintenance program; and (3) the generation of additional revenue to make street networks cost-effective to maintain.

A Budget Options Report is most effective if it contains pertinent information presented in a manner that is easy for upper management, elected officials, and the public to follow and understand. While every local agency customizes a Budget Options Report to meet its specific needs, the basic structure and components of the report usually remain the same.

Appendix F and Appendix I of *A Guide for Local Agency Pavement Managers* provide detailed instructions for preparing a Budget Options Report. Appendix E and Appendix F of this guide contain samples of Budget Options Reports prepared for two different audiences: a public works department and a board or council.

A typical Budget Options Report outline follows.

Budget Options Report Outline

I. Project Description of Pavement Management System

   A. Introduction

   B. Statement of Purpose

   C. Background

   D. Steps Taken for Implementing Pavement Management

   E. Current Use of Pavement Management System

II. Summary of Findings and Recommendations

III. Pavement Management Budget Analysis

   A. Historical Revenue for Pavements

   B. Historical Expenditures for Pavements

   C. Pavement Budget Needs Analysis

   D. Projected Expenditures for Pavements Compared to Actual Budget Needs

IV. Alternative Budget Scenarios

V. Conclusions

VI. Recommendations

VII. Glossary

VIII. Appendix

A Case Study: Skagit County (1)

Vicki Griffiths

Skagit County has been involved with pavement management for over seven years. Even though pavement management has become an established activity within the agency, the County recognizes that it is important to continually promote the benefits of pavement management. Part of its efforts to do this include period presentations to the Board of County Commissioners on topics pertaining to pavement management. Excerpts of one of these presentations may be found in Appendix A.

A Case Study: Clark County (13)

Bud Cave and Dave Shepard

In 1986, Clark County Department of Public Works knew it was facing a crisis with respect to its roadway system. Population increases and industrial growth were fast outpacing funding for preserving the roadway system within Clark County. The Department of Public Works determined that the use of pavement management would help it identify the extent of the problem and develop a cost-effective plan to address the situation. But before the Department could proceed with the implementation of a PMS, it needed to convince the Board of County Commissioners that such an action was justified.

Clark County prepared a straightforward and highly effective report explaining why pavement management was critically needed within the County, which it presented to the Board of County Commissioners in April 1987. The basic components of the report included:

- *Overview*
- *Pavement Management Concepts*
- *Pavement Deflection Testing*
- *Network Findings and Justifications*
- *Funding*
- Recommendations

A copy of this report may be found in Appendix A.

Summary

The pavement manager is the link between all of the agency's pavement information and all those trying to make decisions regarding the pavement system. A pavement manager must have a thorough understanding of what information he or she has available or can acquire to meet a user's needs. In addition, it is very important that the pavement manager be service-oriented and actively search out each user's needs. The pavement manager must find out what kind of information is needed by each user and how to package the information in a way that is most usable to them.

When a pavement manager consistently meets each user's needs by providing timely and reliable information, he or she quickly becomes an indispensable resource throughout the agency. The pavement manager can play a direct role in ensuring the effective and efficient use of agency roadway resources. In addition, the pavement manager has the tools available to keep the public informed and affect public relations in a positive way.

Chapter 6 References

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7:P:DP/PMAG

Chapter 7 Overcoming Application Challenges

This chapter addresses some of the issues that may stall, or even stop, continuing pavement management efforts within an agency. It discusses the institutional, technical, and funding challenges that often affect an agency and methods that can be used to successfully address these challenges.

Introduction

The implementation of a pavement management system is often one of the major efforts within an organization. Resources, including financial and staff, must be allocated to the implementation effort, as well as the pre-planning activities and training. Even after these activities are completed, the agency should not consider the system implemented until the recommendations being generated from the system are incorporated into the day-to-day decision-making process. In order to successfully accomplish this level of implementation, institutional and organizational issues that would normally create hindrances must be addressed early in the implementation process.

As the concepts of pavement management were first being implemented, many of the barriers that agencies encountered involved technical issues such as inadequate computer capabilities, inflexible software, or the unavailability of standardized condition rating procedures. Today, many of these technical barriers no longer exist. The most common implementation barriers now relate to institutional, or organizational, issues such as “turf protection,” lack of support for PMS, or lack of communication among users of the system.

Through careful planning and an awareness of possible application challenges an agency can successfully integrate its PMS into the decision-making process. This requires prudent planning before the implementation is begun, education and training throughout the agency, and improved communication among those affected by the system.

The types of issues that are discussed in this chapter are based in part on material presented in *Modern Pavement Management* (1) and the *Proceedings from the Third International Conference on Managing Pavements* (2).

Institutional Challenges (3)

Institutional challenges within an organization include situations in which agency personnel interfere with the adoption of a PMS due to internal issues. In most cases, institutional challenges fall into two major categories: those challenges due to personnel issues and those due to organizational issues.

Personnel Issues

Some of the most serious impediments to a successful PMS implementation arise from the interpersonal relationships of individuals within an agency. These types of issues are commonly referred to as personnel issues. They can be caused by a number of factors, as discussed in the following sections.

Conflicting Priorities

The individuals responsible for pavement management within an organization are often also responsible for a number of other responsibilities. Because of this arrangement, the PMS is frequently not given enough attention at regular intervals to really be incorporated into the decision-making process. This is further complicated by the fact that information from the PMS is often requested only one or two times per year; when budgeting information is needed or a specific piece of data about a road section is requested.

In order to minimize these types of problems, it is important that the agency conduct planning prior to the implementation of the PMS. It is important that before the system is implemented, the agency identify the level of support that will be required to implement and maintain the system. The agency should then match the operational requirements of the system to the resources available in terms of staffing and data requirements.

Frustration

The implementation of a PMS can also be hindered when the recommendations generated by the PMS are not followed due to political, or other, factors influencing the use of available funds. This is most common in organizations with very restricted funding levels or when the implementation of recommendations rests with other divisions of the agency. Eventually, the pavement manager can become so frustrated because the PMS recommendations are going unheeded that he or she stops using the system.

It is helpful for the pavement manager to remember that the primary purpose of the PMS, and any management system for that matter, is to provide objective, accurate, and consistent information to the decision maker so an informed decision can be made. The decision maker, on the other hand, must weigh a variety of other inputs that are often far less objective in nature when making a decision. As a result, the final decision is usually a compromise between the objective output of the PMS and the subjective influence of political and other factors that are as real and influential as the PMS outputs. The compromise developed through this process, and the fact that both subjective and objective considerations are taken into account by the decision making process, creates a positive influence on the decisions made to maintain the roadway network.

The pavement manager must learn to recognize the contribution of the PMS on the decision process and the benefit provided to the agency by the availability of the objective information. Over time, these benefits add up, the system gains credibility and acceptance, and reliance on the system recommendations will increase. With patience and perseverance, the pavement manager's efforts pay off, one step at a time. As one mayor of a Washington city told a conference of pavement managers, "We're glad you're here to tell us what we don't want to hear."

The acceptance of the PMS recommendations is enhanced when the PMS compliments current management processes, existing procedures, and political realities within the agency. This helps to ensure that the system is compatible with the existing processes and works to support the decision making process. A system that tries to dramatically alter existing processes, procedures, and policies, will most likely draw heavy opposition and not gain acceptance within the agency. Consideration should be given to incremental changes carried out over time and processed through a standing PMS steering committee.

Reliance on One Individual

Occasionally, the PMS implementation is spearheaded by one person within an organization. This individual is involved in the system development and implementation, and is often the only one who receives pavement management training. This situation can be detrimental to the continued use of a PMS. If the person who knows the system has poor communication skills or has a personal desire for power, others within the organization will either know nothing about the system or will be turned off by the efforts of the key individual. If the key individual should leave the agency, the PMS efforts could easily and quickly be abandoned. In any of these situations, the system will not be integrated into the decision process and no one else will know how the system operates.

This issue is best addressed by promoting education and training throughout the agency. Each individual who will be responsible for some aspect of the program, or who will receive information from the program, should receive training so that they understand the capabilities of the system and the importance of their contribution to the overall success of the program. The agency should work to ensure that each of the key players understands his/her role and importance in the pavement management process and receives recognition for contributing to the process. Each of the players must recognize that pavement management is a team effort that requires a contribution of resources by the departments and divisions in exchange for the benefits realized from the effort. In other words, pavement management is not a one-person show.

It is also important that cross-training be used to prevent the reliance on one or two individuals for the operation of the system. This way, if a number of individuals are familiar with some aspect of the program, the agency's PMS efforts will not be lost if key individuals leave the organization. Many organizations do not realize the importance of cross-training until it is too late and a key individual has left. For this reason, cross-training must be made a priority within the agency. In addition, the preparation of system documentation (as described in Chapter 2 of this guide) will prove very help during times of staff turnover.

If the PMS was implemented by a consultant, it is important that several agency personnel be involved in as much of the implementation as possible. Agency personnel can easily be involved in the data collection activities and model development as the system is being implemented as a form of excellent hands-on training. The agency should also request clear documentation of the system operations and any customized aspects to the program from the system developer so that individuals can find the answers to questions that arise as the system is used.

Fear of Exposure, Resistance to Change, and Turf Protection

Other institutional issues that can affect the success of a PMS implementation involve personal issues such as fear of exposure, resistance to change, or turf protection. People who have been responsible for selecting projects before the implementation of a PMS may be somewhat fearful that the PMS will expose their prior actions as incorrect or inappropriate.

Other people fear any type of agency change and are hesitant to accept the changes caused by the implementation of a PMS. This can be especially true if the PMS is perceived as being very complex and the project selection process is not understood. Individuals naturally wonder how the changes will affect their role within the organization and worry that they may lose power, responsibility, or importance. Because of this, efforts to integrate the PMS may be blocked.

Fear often leads to another personal challenge: turf protection. This occurs when individuals feel that their importance within the organization is being threatened, so they become protective of their “turf”. This is a serious problem because a PMS is most effective when it crosses formal and informal lines of authority and communication. Some people may view the pavement manager as gaining power due to the large amount of information available from the PMS and the pavement manager’s interaction with others to communicate PMS recommendations. This may worry people who perceive a loss of their power, leading to a breakdown in communication and cooperation. This is further aggravated when the pavement manager is new, inexperienced, or is given control over the affairs of the more “seasoned” and experienced employees.

Another problem frequently encountered is explaining to other divisions why a pavement manager may recommend fixing some roads before fixing others in worse condition. Maintenance staff, who handle citizen complaints and are out fixing the roads every day, might find it difficult to understand or support the decision not to fix the worst roads first.

Communication is the most effective way to address these types of issues. The pavement manager must strive to establish both formal and informal lines of communication throughout the agency to be truly effective. Formal lines of communication follow the organizational structure within the agency. Informal lines of communication do not typically follow the organizational structure, instead relying on communication channels that do not exist formally but make sense organizationally.

An example of an informal line of communication includes the link between the pavement manager and a design engineer. Although no formal communication link may exist, the design engineer can provide the pavement manager with important information about the designs being used by the agency. The two individuals may find it helpful to examine the performance information contained in the PMS database so that comparisons of actual performance measurements can be made with the expectations of the design engineer.

The formal and informal lines of communication should be used as much as possible to explain the pavement management concepts and processes to others within the organization. This should include formal presentations at meetings to management and funding authorities as well as training sessions for those who will use the system. Informal discussions are effective with individuals who will be influenced by the implementation of the PMS and other users of the system.

Some agencies have communicated the improvements to the organization that have resulted from the implementation of the PMS through internal newsletters to agency personnel. This has allowed individuals throughout the agency to understand the types of information the system will provide and its role in the project selection process. This type of information helps to offset some of the fear that may arise due to the implementation of a new computerized system.

It is also very helpful to involve all divisions that will be affected by, or will use, the pavement management recommendations in the pavement management process. This will serve to educate them on the philosophy behind pavement management and help them "buy into" the recommendations being made using the program.

Organizational Issues

There are also challenges that occur within an agency because of the structure or the existing policies and procedures of the organization. These issues frequently require the involvement of individuals at the management level to deter any negative impact on the success of a PMS implementation. Some of the common organizational issues are found in the areas of communication, reliance on other agency employees, and training.

Communication

Lack of communication is one of the most common organizational issues among the PMS developers, users, and beneficiaries. Communication problems occur most frequently in agencies that are large enough to support separate divisions, each working independently of the other with no formal lines of communication. The development and implementation of a PMS often requires that lines of communication be established among planning, programming, maintenance, and engineering divisions so that the system is designed to address the decisions most needed by the agency and the recommendations follow agency policies and practices. If these lines of communication have not been established prior to the PMS implementation, it is often difficult to establish them afterwards when the personal issues often arise.

Communication also becomes an issue as the project selection process takes place. In most agencies, each division feels strongly about their recommendations for the multi-year plan. The pavement manager, armed with justifications for the recommendations from the PMS may be perceived as holding most of the power in these meetings. Without strong lines of communication established, the project selection process can become a series of arguments between divisions rather than a cooperative effort to select projects that best address the agency's goals.

Interagency communication can be greatly increased following the implementation of a PMS by the exchange of information from one division to another. This communication can be enhanced by planning for the types of information each department or division will need prior to the implementation of the system. The pavement manager should ask each department or division within the agency what information is needed from the PMS and provide the information in a format that is useful. By becoming service oriented, the pavement manager can become a valued resource for information throughout the agency. In addition, the pavement manager should ask for input from other divisions whenever it could enhance the program or strengthen support for the program.

Communication is also important with individuals or organizations that are involved in funding pavement maintenance and rehabilitation projects. This type of communication is important on an ongoing basis to address continuing questions concerning current pavement conditions, maintenance and rehabilitation needs, and other pavement related issues.

In order to be most effective, the pavement manager must establish themself as a resource to these individuals and organizations, including city and county managers and boards. By supplying useful information on a regular basis, and being responsive to pavement-related questions in a timely manner, a comfortable rapport can be established. This will likely lead to positive interactions that benefit both the pavement manager as well as the manages and board.

It is also important that the city and county managers and board become familiar with the role of the PMS in the budgeting process. Each year, immediately prior to the project selection process, a brief overview of the pavement management process should be presented to city and county officials. Any project recommendations should be presented clearly and substantiated as much as possible; allowing the officials to evaluate the trade-offs between various options. The pavement manager should be prepared to respond to questions and inquiries form these individuals throughout the budget development period so that the pavement needs are adequately presented and considered.

Reliance on Other Agency Employees

In many agencies, the pavement manager is responsible for the maintenance of the pavement management system, but not the collection of inventory data that goes into the system. In this scenario, the pavement manager must rely on the quality of data collected by another individual who may or may not understand the overall importance of the data to the agency as a whole. Placing responsibility for data collection in the hands of an individual who does not appreciate the importance of accurate data could jeopardize the entire pavement management process. It is important that these individuals understand that they are critical to the success of the whole system. The system output is only as reliable as the input information they collect.

Ongoing training activities are critical to preventing this type of issue from deterring the success of the PMS within the agency. Cross-training individuals on various aspects of the program is important so that each individual understands his/her role within the process and the importance of quality data to the decision process. They must understand how critical their role is. Through regular discussions about the benefits provided by the PMS, individuals are more apt to reliably address their responsibilities. These discussions often include benefits such as improved responsiveness to agency personnel, better coordination with utilities or other agencies, overall improvement in network condition, or more objective decision making.

Inadequate Training

A lack of adequate training can adversely affect an organization in two primary ways. First, if the PMS responsibilities are delegated to an individual who does not understand the PMS process, or can not understand the analysis techniques, the system can not be expected to be integrated into the agency’s decision process or updated as needed to keep the models current. Second, if the individual responsible for the PMS does not fully understand the capabilities of the system, it can be expected that the full system capabilities will not be used or promoted throughout the organization. As a result, the full benefit of the PMS will not be apparent to the organization and the system will not be used as effectively as possible.

The lack of understanding of the system capabilities and responsibilities can also have a dramatic impact on the availability of future resources to support the system. Without a thorough understanding of the PMS implementation as an ongoing process, an agency may not allocate the resources necessary for data collection activities or the activities included as part of the feedback process. Agencies that have not programmed resources for the ongoing maintenance of the PMS will find that over time the system recommendations no longer make sense. As a result, the agency may stop using the PMS for assistance with the project selection process.

The importance of ongoing training efforts can not be stressed enough to prevent these types of problems. In addition to the formal and informal training efforts previously discussed, the agency must recognize the importance of external training opportunities such as courses, seminars, user group meetings, pavement management association meetings, and conferences. These opportunities provide an excellent forum for networking, sharing experiences, and bringing home new ideas and technology.

Communication is also important so that the necessary resources are provided to the pavement manager. In most agencies, management recognizes the benefits provided by the PMS and provides the funding necessary to operate and maintain the system. These benefits must be realized, and the PMS must be integrated into the decision process, for long-term funding to be provided.

Technical Challenges

In addition to institutional challenges, there are technical issues that continue to plague agencies. These issues often center around the use of an inappropriate system or unrealistic requirements that do not match the available resources. Other issues concern the PMS itself and the inherent limitations of its analytical capabilities.

Selection of the Wrong PMS

In order to provide an agency with effective recommendations for the development of multi-year plans, a PMS must fit the style and practices of the agency where it will be used. Otherwise, the system recommendations will not make sense to the agency and will not become an important part of the planning and programming process. In order to ensure that a PMS fits the organization, it is important that the agency carefully plan what information it wants the PMS to provide, the format for providing that information, and the level of resources it wants allocated to the entire process. Some of the issues that may arise within an organization that has not carefully planned its PMS requirements follow.

PMS Does Not Match Agency Needs

A PMS must meet the needs of the agency in order to become an integrated component of the agency's decision-making process. A system's decision matrix, or decision tree, must reflect the way the agency does business and must be updated quickly as policies and practices change. Any system that makes recommendations that do not fit the agency's policies and practices will rapidly lose credibility and be identified as an unnecessary activity that does not contribute to the overall process. For example, an agency may only consider the use of surface treatments on pavements with relatively low truck traffic. If the PMS recommends the use of a surface treatment on a pavement section with heavy truck traffic, the recommendation will be ignored and any other recommendations made by the system will be questioned.

In addition to fitting the policies and practices within an agency, the PMS must also address the agency's goals for the types of information to be provided by the system. If, for example, an agency sought a PMS to assist them in justifying budget requests to a city council, the agency must be sure that this information is communicated to the system developers and implementors. In some cases, PMS only provide assistance in selecting sections needing some type of maintenance or rehabilitation action, rather than evaluating the long-term impacts of decisions on the overall health of the network. An agency looking for budget justifications would not be satisfied with a system that merely selects projects without providing the long-term impacts of its decisions.

This type of information must be determined prior to the selection and implementation of a PMS, as much as possible. During the pre-implementation planning stages, the agency must identify the types of data that will be needed to support the system, the level of agency support that will be required to implement and maintain the system, and the types of information that will be needed in the decision process. After the PMS has been implemented, the pavement manager should periodically check with the users of the PMS information to make sure that the system is continuing to provide the information they need, in the format they need it in. If it is not, the pavement manager must make adjustments as needed.

Complexity of the PMS

The complexity of the system can also have a tremendous impact on the acceptance of a PMS within an organization. This often occurs because systems that are too complex may discourage potential users, especially if the system is too hard to understand or operate. Similarly, too simple a system may not be appropriate for an agency either, especially if the system lacks key functions that would prove beneficial to the agency. For these reasons, it is important that the complexity of the system be tailored to the appropriate level for each agency. For example, if an agency must be able to explain or recreate the project selection process, it may be most appropriate to select a system that provides a prioritization process rather than a truly optimized strategy. Agencies have found that prioritization methods are much easier concepts to explain than the mathematical probabilities involved in the optimization process.

Another factor that should be considered is that people are less intimidated by concepts and techniques that are easier to understand. Individuals who are less intimidated by the components of a PMS are more likely to adopt the system and use it to assist them with the project selection process. The selection of a highly complicated system may intimidate the people it was designed to assist. Many of the local agencies interviewed during the preparation of this guide felt that the complexity of their pavement management software is a significant roadblock to their using pavement management to its fullest potential.

It is important to point out that not all users of PMS information need to know the details of the process. In fact, it may be counterproductive to overwhelm some users with the intricacy of the PMS. The pavement manager needs to relay enough information to the user so that he or she is comfortable with the information and recommendations being provided by the system but not so much detail that the user is confused by what is being presented.

There are a number of ways to address the challenges caused by a system that is either too complex or too simplistic. First, the agency should evaluate the amount and type of data being collected to support the system. The agency should ensure that any data collected are important to the decision-making process and are being collected at a reasonable interval and level of accuracy for the way they are being used. Secondly, the agency must evaluate the number of performance models and treatment options considered by the system. In some instances, it may be better to simplify the number of models rather than be so detailed in the model development that they system stops being used. Finally, the agency should consider the approach being used for project and treatment selection. The complexity of the system should match the agency’s needs and resources.

Identification of What Data to Collect

Each agency can only commit a certain level of resources to the implementation and maintenance of a PMS. For that reason, it is important that the agency clearly defines goals for the PMS that fit within the agency constraints at the time of implementation and in the following years. Since data collection activities are often one of the most expensive aspects of a PMS, the agency must pay special attention to the data requirements of its system. Any system that requires more data than the agency can reasonably collect and maintain will eventually be unused as the agency gets further and further behind in its data collection requirements and the data in the system become outdated and the system loses credibility.

This type of information should be included in the pre-implementation planning process that the agency undertakes. The agency should identify the types of data needed to support the decision-making process and tailor the data collection plans and resources accordingly. The agency should ensure that only data that are absolutely necessary are collected and that data are only collected when needed.

Limitations or Incorrect Application of Analytical Capabilities

The final category of technical challenges involves limitations built into a PMS or the incorrect application of the PMS analysis tools. These challenges are often influenced by either improper planning prior to the selection of the system or inadequate training of the individuals using the PMS.

System Limitations

In some instances, the capabilities of the systems themselves can influence the ability of an agency to effectively integrate the PMS into the decision-making process. This can occur for a number of reasons, however one of the most common is the inability of the system to adapt to changes in technology or practices within the agency. One example of this type of limitation may exist in an agency that has performed manual condition surveys in the past, but wants to change to automated technology. The PMS must be able to accommodate this type of change or no current condition information will be able to be input into the system.

In addition to adapting to new technology, the PMS must be able to accommodate changes in the analytical components to meet changing trends, practices, or policies. This is especially important so that the deterioration models, rehabilitation alternatives, and costs used in the analysis continue to reflect existing conditions. If these components can not be changed, the system will not be applicable to a changing organization.

It is important that these types of issues be discussed prior to the selection and implementation of a PMS. By recognizing the types of changes that may occur in the future, an agency can build a certain amount of flexibility into their PMS system. Participation in conferences and user group meetings is an excellent way to keep abreast of the new technologies affecting pavement management and discuss ways of incorporating these changes into an existing system.

Inappropriate Use of the System

Other challenges can be caused by the inappropriate use of the system that has been implemented within an agency. These types of issues arise when the models are used inappropriately, such as using an asphalt deterioration model to predict the performance of a concrete pavement section, or when the models have not been calibrated or verified to reflect actual conditions.

Either situation will cause problems with the system recommendations which will eventually lead to a loss of confidence in the PMS and its eventual abandonment.

Occasionally the PMS is used inappropriately because of a lack of skills on the part of the individual using the system. This can occur when the system is fairly complex and has been inadequately explained or documented for the users. It is important that those individuals using the software and providing overall management of the system have the appropriate skills and be backed up by cross-trained support personnel whenever possible. Training should be provided on the philosophy behind pavement management as well as computer training on the operating system, the database application program, and the PMS software. A phone list, including the names and phone numbers of individuals proficient in the software, should be kept near the computer. Please refer to Chapter 2 of this guide for further discussion on training.

The agency should also verify that the system is not too complex for the resources and personnel available. Methods for verifying the appropriateness of the level of complexity were discussed earlier.

Funding Challenges

The last category of challenges concerns issues that relate to the availability of funding for the PMS or for the implementation of the recommendations made by the system. Some of the challenges caused by these factors are discussed below.

Inadequate Funding

Most agencies are faced with the dilemma of needing more money than is available to address all the needs within their networks. Because of this dilemma, many organizations initiate the implementation of a PMS to assist them in establishing priorities among the competing needs. In actuality, it is often difficult to implement the recommendations from the PMS because of the number of miles of pavement in poor condition that often receive the most public attention and have the greatest amount of liability exposure. However, the agency must realize that the continued practice of funding stopgap maintenance to maintain the pavements that are not being addressed adequately is a very expensive practice; one that will eventually cost the agency more in the long run and prevent the use of PMS-supported recommendations that could improve the condition of the network.

The users of a PMS within an organization that has limited funding must also realize that the agency can not always follow the PMS recommendations completely. There are often other, less objective, competing factors that affect the project-selection process. These factors may be driven by issues other than the financial implications and costs to the agency. These outside factors must be realized and be allowed to be incorporated into the decision process for the system to be truly effective. It should be recognized that the PMS does not make agency decisions. Instead, it presents objective information to the decision maker and measures the impact of different strategies. The PMS provides the information necessary to allow the decision maker to make an informed decision.

Agencies must also consider the implementation of a PMS to be an ongoing process that must continually have resources committed to it in order to provide the full range of benefits to the organization. Small to medium-sized local agencies often find it difficult to allocate dedicated funds to its pavement management activities; a factor that eventually contributes to the discontinued use of the PMS. Agencies must realize that the quality of the recommendations made by the PMS is directly related to the quality of the data stored in the system, the models used to analyze the data, and the ability of the pavement manager to use the system. Each of these aspects of the program require commitment on the part of the organization to the ongoing maintenance of the PMS.

In agencies with limited funding, it is important that the pavement manager do as much as possible to market the benefits realized by the agency because of the PMS as a method of promoting the funding of the system. The pavement manager can demonstrate the improved responsiveness to questions from throughout the agency by addressing questions as promptly and thoroughly as possible.

Additionally, the pavement manager can use information and graphics from the PMS to demonstrate the improvements that are possible to the agency's pavement network by following the PMS recommendations. The pavement manager can place an emphasis on the improvements in network condition that can be expected from various programs and the differences that will occur if other programs are followed. Using the PMS, the pavement manager can provide objective explanations to agency personnel, management, government agencies, and the public regarding why certain projects were funded and others were not.

The value of the PMS must be recognized by the agency for funding issues to be minimized. The pavement manager can play an important role in demonstrating the value of the system by providing as much information as possible to agency personnel who may benefit from information about pavement condition, deterioration rates, or special problems that have occurred.

Too Much Funding

Although not normally perceived as much of a problem, an agency with too much funding could easily find itself not using its PMS as an important part of its project selection process. In fact, the few agencies that face this dilemma often determine their projects by evaluating the number of projects they can "get on the street" within a particular timeframe rather than the effectiveness of one project over another. Although a PMS could still provide valuable information regarding the type of maintenance or rehabilitation that would result in the most cost-effective repair, these agencies frequently select the highest priority projects based on subjective assessments rather than an objective analysis and program a standard treatment that is used for almost any pavement deficiency.

Too much funding can sometimes cause another problem. A PMS may be used to procure increased funding for the completion of more pavement projects. However, if a corresponding increase in equipment and labor resources is not also obtained to support the additional workload, the agency could face a problem where it has a difficult time completing all the funded projects. In order to better project the staffing levels necessary to support various program levels, an agency must have good historical records that itemize the resources necessary to support different funding levels.

A Case Study: Clark County (4)

If a PMS has been used to obtain increased levels of funding for pavement maintenance and rehabilitation, it is usually perceived as a very successful management tool. Increased funding permits an agency to repair more roads or use long-lasting repair techniques. However, increased funding does have the potential to create some problems, as Clark County discovered during its 1995 construction season.

Clark County used its PMS to request and obtain an increase in pavement improvement funding of $800,000 (this increase was made possible by establishing an average PCI they felt constituents/public officials could live with and is documented in a case study presented in Chapter 7 of this guide). This increase in funding meant that Clark County was able to fund an additional 6 miles of overlay and 450,000 square yards of slurry seal. The County Operations Division was very pleased when it received this level of financial support during a time of tremendous growth in the region.

The only drawback in obtaining the requested increase in pavement funding was that it became extremely difficult to complete necessary pavement prep work prior to the contractor applying surface improvements. This resulted in a situation where it was difficult for county staff directing contracted pavement rehabilitation projects to get those improvements completed in a timely fashion. Clark County learned from this experience, and now programs its request for pavement funds by balancing in-house resources with outside contracted commitments.

In situations such as this, the pavement manager must still provide the agency with information regarding the consequences of various programs on the long-term health of the network. It is important that the agency understand the impacts of any decisions they make regarding pavement maintenance and rehabilitation programs so that agency goals can be achieved.

Lack of Continual Funding Support

As discussed earlier, a PMS can not remain an effective tool if the management of an agency does not continuously invest in the maintenance and operation of the system. This support must be allocated in terms of ongoing data collection efforts, continued training for the individuals responsible for the system, and the regular update of the analysis models and cost components. Agency management must recognize that this level of support is absolutely essential if the system is going to continue to make effective recommendations for the maintenance and rehabilitation of the pavement network.

As discussed earlier, in order to make a long-term commitment to the funding of a PMS, the agency must be able to see the benefits that the system provides. The pavement manager must make it a responsibility to demonstrate the types of information available from the PMS throughout the organization and the benefit of this information on the decision making process.

Summary

There are many different obstacles that can stand in the way of an agency implementing and utilizing a PMS. However, there are steps an agency can take to prevent, or overcome, these potential challenges. Following is a review of the recommendations made in this chapter for improving communication, education, training, and advanced planning.

Pre-Implementation Planning

- Match the operation requirements of the PMS to the resources available in terms of staffing and data requirements.
- Identify the data needed to support the decision-making process and tailor data collection plans and resources accordingly.
- Match the PMS to the current management process, existing procedures, and political realities within the agency.
- Identify important divisions and managers and keep them involved throughout the implementation process to gain their support.

Education and Training

- Make cross-training a priority within the agency.
- Become as involved with the PMS as possible, especially if it is implemented or maintained by a consultant.
- Request clear documentation of the software operations and any customize aspects of the program from the software developer.
- Develop an in-house guide that outlines the steps the agency undertakes to complete its pavement management activities.

- Take advantage of external training opportunities, such as course, seminars, user group meetings, pavement management association meetings, and conferences.

Communication

- Take every opportunity to explain the pavement management concepts and processes, during formal presentations, training sessions, and informal discussion.
- Develop good communication links with city and county managers and boards concerning the use of PMS.

Marketing PMS Benefits

- Demonstrate the improved responses to questions from throughout the agency by addressing questions promptly and thoroughly.
- Use graphics from the PMS to demonstrate the improvements that are possible to the agency's pavement network by following the PMS recommendations.
- Communicate the justification behind the projects selected and the differences that would have occurred had other projects been selected.
- Provide as much information as possible to agency personnel who may benefit from information about pavement condition, deterioration rates, or special problems that have occurred. Let people know the extent of information available form the PMS.

Chapter 7 References

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3. P. Sachs and R. Smith, “Roles for a Regional Transportation Planning Agency in Countering Local Agency Institutional Problems in Adoption and Use of Pavement Management Systems,” Proc., Third International Conference on Managing Pavements, San Antonio, Texas, May 1994.
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7:P:DP/PMAG

The pavement manager must keep abreast of new pavement management technology because the ability to accommodate change plays a large part in the long-term successful use of a PMS.

This chapter briefly reviews a sampling of new technologies which are beginning to impact the way agencies go about pavement management, or will within the next 5 to 10 years. It covers geographic information systems (GIS), the integration of a PMS with other management systems, new data collection equipment, new training methods, and the use of expert systems within a PMS.

Integration of PMS With Maps

In recent years, there has been an increased interest in linking pavement management systems to maps of the roadway network. This is due in part to the fact that it is often much easier to communicate some types of information about the road system using maps. In particular, these maps provide a way to display information that is easily understood by management, elected officials, and the public.

Two basic options are available to an agency if it wants to automatically display PMS information on maps. The first option is to develop an interface to the PMS database using automated mapping software, such as AutoCAD™. This method is relatively inexpensive and simple. It provides the user with the ability to display PMS data on a road network map; however, it provides little support for the analysis of data. It can also become very cumbersome and time-consuming to maintain this type of system.

The second option is to link the PMS to a Geographic Information System (GIS). A GIS is a computerized data management system which provides the ability to rapidly acquire, store, and access spatially referenced information. As a tool, GIS is a highly efficient means of combining several technologies — including advanced relational database management, global position systems (GPS), and computer-based mapping — to enhance the use of spatially based information. Combining PMS and GIS takes advantage of the strengths of each, linking time-dependent pavement data with geographic or location-based data. Linking a PMS and a GIS requires more expertise to implement and maintain than does the automated mapping option and can be expensive if an agency does not already have a GIS in place for the road network. However, with the increasingly widespread use of GIS in local agencies (for emergency 911 call routing or land record management, for example), it is becoming more feasible and common to link a PMS to a GIS.

Components of GIS

There are many different GIS software packages available; however, the basic structure of a GIS remains the same from program to program. There are three main components of a GIS: a geographical database, an attribute database, and a georelational data structure.

Geographical Database

The geographical database contains data that define the physical location of features, such as a segment of road. For such a road segment, its x-y characteristics are specified, effectively defining the geometry of the feature (three-dimensional characteristics can also be incorporated, and are important for such features as underground utilities). A complete database locates each individual feature as well as its relationship to other features.

Attribute Database

The attribute database contains the nongeographical data, such as segment names and pavement age, that describe a geographical feature. Whereas each feature has a unique set of geographical characteristics (x, y, and z coordinates), there can be many overlapping nongeographical characteristics. For example, there is only one road between two adjacent intersections but the name of that road may be assigned to many other features.

Georelational Data Structure

The georelational data structure links the locational and attribute data. This link establishes the relationship between the location of features in the geographical database and their corresponding descriptions in the attribute database. While the attributes may change frequently, such as every time a pavement is overlaid, the locational information should not. However, one of the advantages of a GIS is that the integration of the databases allows accommodation of changes in either the geographic database or the attribute database.

Approaches for Integrating GIS and PMS

Once an agency decides that it wants to pursue linking its PMS with a GIS, it has three general approaches available to it: total integration, PMS data export, and map export. These approaches are summarized in the table (1) presented on the next page.

Total Integration

Total integration involves implementing the PMS within the GIS software itself. This approach is not recommended in most cases because of several serious limitations. First, many GIS packages will work with only one database management system. That severely restricts the number of PMS software and GIS combinations that are feasible. Second, total integration results in a system that is often difficult to use, time-consuming to maintain, and inflexible. Third, matching the PMS analysis sections to the GIS map can be difficult unless the GIS has dynamic segmentation. In fact, many agencies that have followed this path only have the database component of a PMS. In many cases, no analytical models, such as deterioration models, are integrated into the package.

	Total Integration	PMS Data Export	Map Export
Approach	PMS and GIS integrated in common software	PMS data exported to GIS for linking to map	Map exported from GIS to PMS for linking to data
Map Maintenance	GIS	GIS	GIS
Data Export/Import	No export/import required	Disadvantage: PMS data requires export whenever data or analysis results change	Map requires export/import annually
Hardware Platform	Disadvantage: GIS and PMS restricted to common platform	Data transfer allows PMS and GIS to exist on different platforms	Map transfer allows PMS and GIS to exist on different platforms
PMS Software Flexibility	Disadvantage: Limited by GIS software speed and capabilities	No limitations on PMS software	No limitations on PMS software
Consistency of User Interface	Consistent interface between PMS and GIS portions of system	Disadvantage: PMS and GIS have different user interfaces	Consistent interface between PMS and GIS (PMS map display) portions of the system
Ease of Use for PMS Engineer	PMS engineer required to use GIS software — generally a more complex approach	Disadvantage: Data transfer and required knowledge of two systems adds complexity	Greatest ease of use for PMS engineer
Segmentation	Dynamic segmentation required in GIS	Dynamic segmentation required in GIS	Dynamic segmentation required in GIS
Divided Highways	Generally only single lines are maintained in a map	Generally only single lines are maintained in a map	Lines duplicated in PMS
GIS Access to PMS Data	All GIS users could access PMS data	All GIS users could access PMS data	Disadvantage: GIS users cannot access PMS data

PMS Data Export

PMS data export involves exporting data from the PMS database and importing the data into the GIS. Since the PMS and GIS are not part of the same program, they can use different software or even be on different operating platforms. An export utility in the PMS must be developed to make the transfer of data possible. Dynamic segmentation in the GIS is required to make this option work.

A disadvantage of this approach is that after every analysis performed with the PMS or after every update to the PMS database the user has to transfer data from the PMS into the GIS to refresh the information in the GIS prior to performing any graphical querying. For agencies that only access a PMS once or twice a year this may not be a problem. This is the approach that many local agencies in Washington State are using.

A Case Study: Thurston County (2)

A number of local agencies in Washington State have begun the process of linking agency maps to a PMS so that information about the agency's pavement network can be visually displayed. Thurston County has found that the process requires the involvement of a number of individuals from within the agency to ensure that the needs of the entire agency are met. For this reason, there are no standard procedures that can be followed by an agency interested in linking its maps to its PMS.

The Thurston County Geodata Center is assisting the Thurston County Department of Public Works with the link between the County maps and its PMS. The Geodata Center has been working with representatives from the Traffic, Design, Survey, and Maintenance Departments on a part-time basis for over a year on this project.

The first work on the project involved improving the quality of the Thurston County road network maps. This process involved taking information from the county's road inventory and matching the information to existing maps. In some cases, this meant adding features to the existing maps or modifying outdated information.

Once the County was satisfied with the quality of the road network map, it was tied to the County Road Information system (CRIS) segments. Thurston County found this step to be very time consuming, primarily because there was not a great deal of consistency in the location of the GPS coordinates for segment reference points. For example, sometimes the GPS coordinates were taken from one side of the road at the location of a pavement change and sometimes from the other side. This mixture of GPS coordinate locations required that Thurston County develop procedures to standardize GPS locations.

As the CRIS segments were matched to the road files, a number of discrepancies were identified. Each of these discrepancies required some field verification to eliminate the differences in the data. By the time this entire process is completed, Thurston County expects to have segments identified by GPS coordinates located in the center of the intersection so that dynamic segmentation techniques can be used to reflect different roadway characteristics.

Andrew Kinney of the Thurston County Geodata Center stated that the most difficult aspect of this process has been figuring out how to organize the information and reflect the data contained in the database. This required a number of meetings to discuss how each Department wanted the information presented.

A Case Study: The City of Tacoma (3)

The city of Tacoma has found that its GIS link to its PMS is an indispensable tool. When the city decided to implement the link, the first step it undertook was to investigate whether an existing street map existed that it could adapt to its purposes. It found that the planning department of the city had an ArcInfo™ streets coverage that it could use. While this coverage did contain more information than the pavement management group required (such as back alleys and unimproved right-of-ways), it was a relatively easy task to remove that information and saved the city the significant amount of money it would have had to spend to develop the maps from scratch.

The existing coverage usually broke segments with a node at every block (which matched the PMS database); however, there were segment breaks at census points and zip code breaks that did not match the PMS database. To resolve this problem, the city worked with a consultant to match up the PMS records to the street coverage and adjust the street coverage map as needed.

Now, the city of Tacoma can pull up a map of the city and query on PMS database elements. This link provides the city with more than just an automated mapping tool. The heart of GIS functionality is spatial analysis, and the city finds itself making use of this more and more. For example, recently the city needed PMS information on neighborhood council districts. Unfortunately, there were no fields defined in the PMS database identifying each segment's district. The city could have manually added that field to every segment in its PMS database, but that would have been very labor intensive. Instead, it found an ArcInfo coverage that the planning department had already developed with neighborhood council districts in it. Then, the city did an intersect between the planning coverage and the PMS coverage. This allowed the city to look at PMS data by neighborhood planning districts.

Map Export

Map export involves exporting a road/street network from the GIS and then importing it into the PMS. As with PMS data export, since the PMS and GIS are not part of the same program they can use different software and operating platforms. An import utility in the PMS must be developed to make the map file transfer possible. Dynamic segmentation is required to make this option work. This is the easiest approach for the pavement manager to use.

Benefits of GIS

There are many benefits of integrating a GIS with a PMS. Some advantages are:

- Ability to analyze pavement management data based on geographic location.
- Ability to display the results of database queries and pavement management analyses on a map of the roadway network.
- Ability to view pavement conditions and projected work programs on a map of the roadway network.
- Ability to view pavement conditions across other georeferenced information such as traffic, neighborhood soil conditions, zoning, etc.

Ability to communicate pavement management information using a format that is readily understood by management, elected officials, and the public.

Integration of PMS With Other Management Systems

A new research area that is being pursued is the integration of individual management systems, such as pavement, water, and sewer, into a municipal integrated management system (MIMS). To date, local agencies have developed and operated their various infrastructure management systems independently. The systems have separate databases that often have data fields in common, however, the location and identification information contained in the databases is often not the same for the different management systems. A MIMS would assist an agency in better managing the infrastructure. It would also eliminate duplication and inconsistencies in the collecting, processing, and storing of data.

While work in this area is still in the early research stage, the concept is considered feasible because the different infrastructure management systems have many components in common. The following elements have been identified as common to different infrastructure management systems: a central database containing inventory data, condition data, and location or geographical referencing information; analysis tools to evaluate needs and develop plans with established priorities; and reporting and graphics capabilities (4).

It has been stated that “The most important issue for developing an overall IMS is the creation of a centralized database that allows a flow of information to and from each subsystem and also from each activity, as needed. This results in a more comprehensive, efficient, and timely flow of information for the IMS as a whole and for each subsystem in particular.” (4) One approach to establishing the central database is using GIS as the platform. Since many utilities (water, sewer, telephone, cable, and so on) often occupy the same physical right-of-way as streets, a GIS would provide an excellent basis for integrating the systems.

Until the time that full MIMS are being implemented, it is important for local agencies to make sure that their existing separate infrastructure management systems can transfer information from one another when needed. For example, if an agency has a pavement inventory system that is separate from its pavement management system, these systems need to be linked in some way. It is easiest to transfer information when the two systems have location identifiers in common. However, even if the two systems use different identifiers, it is possible to transfer information through the use of conversion tables.

While it will probably be many years until local agencies implement full MIMS, the first steps have already been taken at some agencies. For example, some local agencies have integrated different inventory systems, such as sewers, electrical, pavement, water, sidewalk, and traffic signs, into a single inventory system containing a common database. These integrated inventory systems do not contain the data analysis capabilities that would make them true management systems; however, they do provide a common database for storing information about the infrastructure system.

New Measurement Technologies

A critical component of a pavement management system is the database, which contains information about the condition of the pavement segments in the road network. In recent years, developments in the techniques and equipment used to collect condition data have begun to significantly impact the pavement management process. It is expected that as these new measurement technologies continue to be developed and improved, their use in pavement management will become more widespread and accepted.

Automated Visual Distress Data Collection Equipment

Manual pavement distress data collection is very slow, labor intensive, and potentially dangerous. These restrictions often result in only a small fraction of a pavement network being assessed. Windshield surveys are faster and safer; however, the accuracy of the data collected is not as good as that collected during walking surveys. Since the accuracy of the condition data directly impacts the reliability of the recommendations made with a PMS, an agency must seriously consider the ramification of using the different data collection methods.

To maximize the benefits of distress data collection, timely and frequent appraisal of pavement condition is needed, which is often too expensive and time consuming to be done by manual methods. Also, if the inspectors are not well trained or experienced, the manual survey results may involve a high degree of variability and may have a low repeatability. In order to address these problems, faster, safer, and more cost-effective methods for collecting visual distress data are currently being developed.

Automated distress data collection equipment can range from the use of laptop or handheld computers for distress data entry to fully equipped pavement inspection vehicles capable of simultaneously measuring roughness, rutting, and capturing images of the pavement surface.

Visual Distress Data Entry Devices

Historically, the results of field inspections have been recorded using paper and pencil. Recent technological advances have made possible many alternate methods for data acquisition: portable computers, bar-code readers, handheld computers, voice recognition systems, optical mark readers, and programmable calculators. All these methods offer the potential for reducing data collection time, data entry time, redundant data entry, and reducing data entry error.

Bar-code readers, voice recognition systems, and optical mark readers are being investigated by the military for possible use in inventory and distress data collection. Local agencies and consultants have concentrated on developing distress data entry devices using laptop computers and handheld computers. In Washington State, several agencies have developed their own portable devices which have proven to be very useful in the field, reducing data collection time and almost eliminating the time required to enter the field data into the PMS.

A Case Study: Kitsap County (5)

Kitsap County manages 915 centerline miles of paved local access roads, collectors, and arterials. The collection of visual distress information on this network of roads was very costly and time-consuming when performed manually using pencil and paper to record the distresses identified during the inspections. This situation led Kitsap County to investigate the possibility of using new computer technology to speed up the data collection and data entry time.

Prior to 1995, Kitsap County evaluated its roadway network using pencil and paper to record the distress types, quantities, and severities identified during the visual inspections. The inspections were conducted by two teams (each with two summer help employees). The entire road system took two years to complete, with the inspections normally being conducted May through September. As the distress data were collected, another summer help employee entered the information into the PMS. All in all, it took five summer help employees to collect and enter the visual distress data into the PMS.

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Kitsap County attended a presentation by a pen-based notebook computer vendor in 1993 that sparked interest in developing a way to collect visual distress data using a pen-based computer. A pen-based computer allows all data entry to be performed using a pen as a pointing device; no keyboard is required. The pen-based computer can accommodate a keyboard, however, for times when its use would be faster.

Kitsap County purchased its first pen-based notebook computer in late 1993 (which it replaced late in 1995 with a more powerful pen-based notebook) and agency staff experimented with writing a data collection software program using Access™. The results were promising; however, with all the other responsibilities of agency staff it was felt that an outside programmer was really needed to write a usable software program in a reasonable amount of time.

Kitsap County now had to find a way to fund the hiring of a programming consultant. Since the data collection device would be used to perform quality control on the collectors and arterials which were being evaluated using automated distress data collection equipment, County Arterial Preservation Program (CAPP) funds could be used to hire a programmer and to buy software and hardware. By realizing how CAPP funds could be used, Kitsap County was able to fund the development of a handheld data collection device.

The programmer went to work, and in the summer of 1995 the data collection device was beta tested. The testing process was slow, but it was immediately evident that the use of such a device was definitely quicker. Improvements were made to the program throughout the summer of 1995, and Kitsap County is now satisfied with the system.

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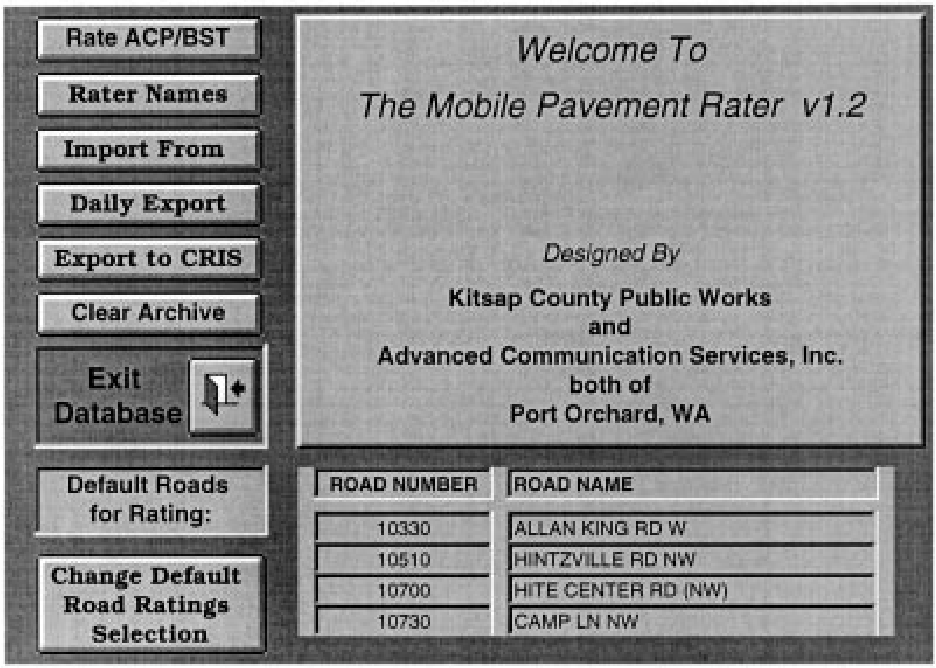
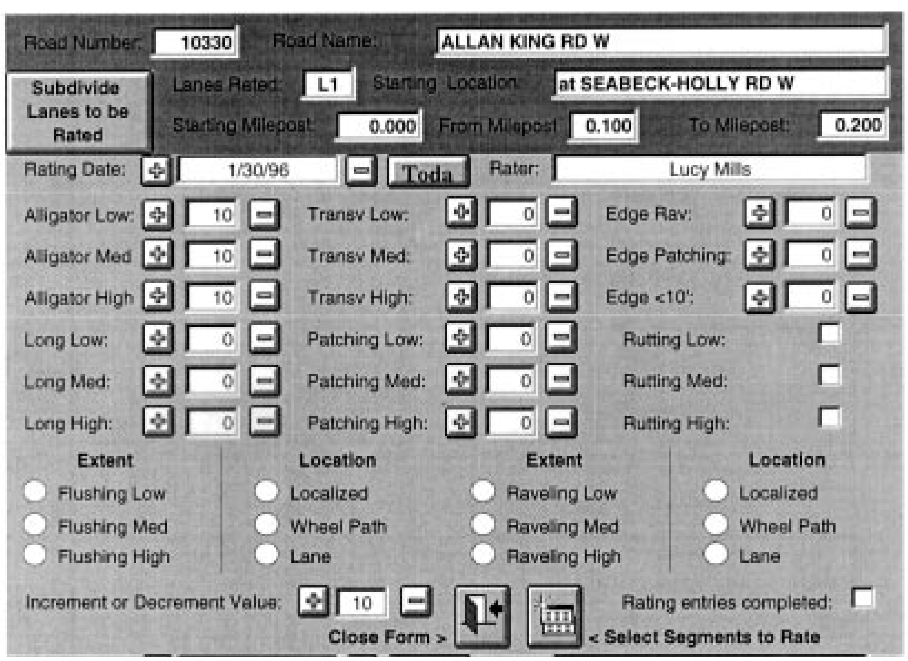
Following is the main menu for the software program that was developed. Also shown is the screen that the raters use in the field to enter visual distress data. All screens are designed to be very easy and quick to use, with only the pen-device needed. This approach greatly facilitates the collection of data in the field.





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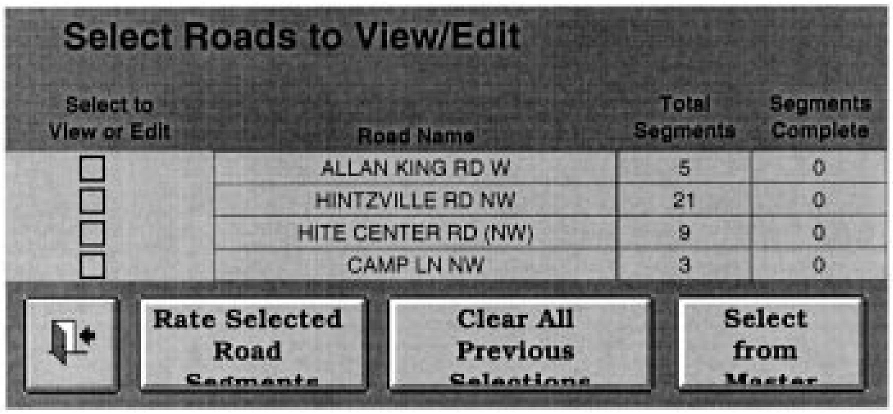

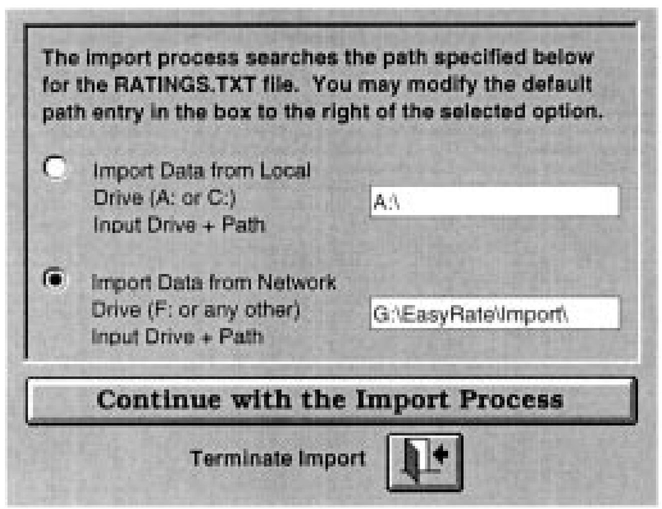

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Kitsap County's current rating procedure is to evaluate local access roads in 1⁄10 mile increments, using the pen-based system. One lane at a time is evaluated using a two-person rating team. As the team walks the pavement, one rater calls out the distresses and the other enters the information into the computer. An experienced team can rate both lanes at one time, with one rater calling out distresses in one lane and the other rater both identifying distresses on his or her lane plus entering the information. On low-volume roads, it is possible for one person to collect the information and enter it; however, it is much faster to collect the data with a two-person crew.

After the information on the local access roads has been collected in the field, the same software program that is used during the data collection converts the information into an ASCII file and it is uploaded into CRIS. The process of having to manually enter the collected information into CRIS has been eliminated. This resulted in the immediate reduction of one summer help employee (previously used to enter the visual data into CRIS) from the payroll. In addition, the two teams previously used for data collection (each consisting of two summer help employees) have been replaced with one team consisting of one permanent employee and one summer help employee.

The county uses a private vendor to collect videotape information on collectors and arterials and to evaluate that information. While this is safer and quicker than walking the roads and rating them, Kitsap County feels that close cooperation and supervision of the vendor is needed during this process. Kitsap County plans to spot-check the vendor results by manually inspecting selected areas using the pen-based computer system.

Kitsap County estimates that the cost of the system was $9,520 in 1995 dollars (computer $3,900; programmer $5,200; Access™ $300; and network card $120). Prior to the use of the pen-based notebook computer, Kitsap County estimates that it cost approximately $65 to $80 per lane mile to collect distress data and enter the information into CRIS. With the use of the pen-based computer, this cost has been reduced to $16 per lane mile for manual surveys on the local access road system. The $16 per lane mile cost is the 1995 cost and does not include any supervisory or quality control costs.

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Kitsap County is pleased with its pen-based notebook computer system. It may not be as flexible as collecting data using pencil and paper, but it has improved the overall efficiency of its data collection process by (1) having the computer do as much of the work as possible, such as the record keeping and calculations; (2) minimizing the amount of redundant data entry, which eliminated the need to hire a summer help to do just the data entry work; and 3) reducing data entry errors and editing time.

Automated Distress Data Collection Vehicles

Significant efforts have been made in recent years to develop automated equipment which is capable of capturing and preserving visual pavement distress data. Automated data collection equipment allows pavement distress data to be collected safely and rapidly. Many available systems allow the collection of data at speeds up to 65 mi/hr, and many can be operated during the night. Another advantage of automated data collection is that the condition of the pavement is recorded on film or videotape for future use and reference. The use of GPS and/or mileposting in these vehicles allows excellent location coordinates to be collected.

The objective of the automated systems is to collect pictorial data of the pavement surface. The systems include vehicles that travel over the pavement and document distress using lasers, video, cameras, or radar. Continuous strip (35 mm) photography techniques have been used throughout the world for years. High resolution continuous photographic records of the pavement are collected using this method. Another technology for image capture is using video imagery. Many automated systems collect rutting and longitudinal profile information as they record the visual information. In addition, cameras can be positioned to capture road inventory information, such as sign location and curb information, during the inspection.

Currently, manual data reduction processes are usually used to identify distress types, severities, and quantities from the collected video or photograph. The surface of a pavement is recorded and subsequently analyzed by a trained observer who conducts a manual assessment of distress at a workstation while viewing the video or photographs and records the results. While this technique is much safer than performing a manual survey (since it is done back in an office), it is still very labor intensive. This technique is more successful for some distress types than for others. Distress types involving depth perception, such as weathering and raveling in an asphalt-surfaced pavement, are difficult to identify from videotape or photographs. Other distress types, such as transverse and longitudinal cracking, can be measured quite accurately if a well-trained observer is evaluating the videotape or photographs.

New technologies are being developed and refined which may allow systems for distress processing and interpretation to be automated. The objective is to collect the photographic or videotape information and then use a computer to interpret the collected information, rather than a trained observer. These technologies focus on the application of computer vision and image processing techniques. Computer vision involves using sensors and computer to emulate human vision. In this case, the sensors are usually optically based, as in a video camera. Most processes being developed today involve four basic steps. First, a video image is captured. Second, that image is converted to a digital image. Third, the digitized image is preprocessed for noise removal and distress identification. Fourth, distress classification and quantification is performed using pattern recognition methods.

Digital imaging is the most common method used now to process visual images. A digital image is a mathematical representation of a normal pictorial image. There are several steps for processing images. First, the raw data are collected as analog images. Next, a digitized image is created for computer processing. Digitization involves the processes of sampling and quantization. Quantization refers to the discrete scaling of the illumination levels in the image to the gray scale values chosen for analysis. The digital image is defined only on a grid or array within the field of observation. The set of points comprising this grid is selected through the sampling process. Ritchie provides an in-depth discussion of this process in his paper, *Digital Imaging Concepts and Applications in Pavement Management* (6).

Once the raw data have been digitized, most systems go through the following steps to analyze the digitized image: filtering, segmentation, and feature extraction. Filtering (image restoration) separates signal from the noise and removes sensor bias. The image can then be enhanced. Segmentation allows the system to identify distinct objected in the scene. In other words, during segmentation objects of interest are extracted from the background. During segmentation, regions where the color or brightness levels are relatively uniform are identified. A variety of processing algorithms are available and have been implemented and adapted for enhancement and segmentation of digital images of pavement-surface condition. The most common means of segmentation is based on an intensity threshold, generally derived from histogram information. The histogram represents the number of image points that have a given intensity.

After segmentation, the features of interest are characterized and logged. During features selection, parameters are obtained geometrically, statistically, or through the use of transform techniques, to identify features that could be useful for image characterization and classification. Image registration is included to account for sensor attributes that could impact the image, such as velocity and attitude. Image classification attempts to match vectors of features against existing data to achieve a match and a detection for the original image or object. Current systems which provide automated distress interpretation are limited in capabilities, but substantial progress is being made. A paper by Mendelsohn, *Automated Pavement Crack Detection: An Assessment of Leading Technologies* (7) provides a good discussion of the problems that have been encountered using automated distress interpretation.

The processing of pavement images just described is based on the application of computer-vision and image-processing techniques. Recently, a new approach to identifying pavement distress is being investigated. It involves the use of artificial neural networks for pattern-classification. An excellent description of this research may be found in a paper by Kaseko et. al., *Comparison of Traditional and Neural Classifiers for Pavement-Crack Detection* (8) and a paper by Smith et. al., *Evaluation of Automated Pavement Distress Data Collection Procedures for Local Agency Pavement Managers* (9).

Other New Technology for use in Pavement Condition Evaluation

In addition to the automation of visual distress data collection and image processing, work is being undertaken in several other areas of condition evaluation. A very brief overview of some of the technology on the horizon is presented below. Since the equipment and techniques described are under constant development, the reader is urged to monitor publications to obtain the most current information available. One good resource that provides a framework for evaluating new technology is a paper by Al-Qadi et. al., *New and Old Technology Available for Pavement Management System to Determine Pavement Condition* (10).

Ground Penetrating Radar Testing

Ground penetrating radar (GPR) technology has been used for years to obtain pavement layer thickness values, to locate voids in the pavement system, and to measure moisture contents. However, the equipment has not gained widespread acceptance and use, partially due to the fact that it often does not provide sufficient accuracy unless extensive coring is conducted to calibrate the equipment. New GPR technology is being developed to provide more accurate layer thickness measurements without requiring core data calibration.

The ROAD RADAR™ is one example of traditional GPR equipment being adapted to provide a means to measure layer thickness without having to core the pavement to calibrate the equipment. According to a publication by Mesher (11) "…the ROAD RADAR™ SYSTEM … combines a novel hybrid multiple radar configuration with an extensive signal processing software environment to provide an accurate, user friendly environment for automated multilayer data interpretation."

Seismic Testing

Another type of testing equipment that is being researched measures the pavement response produced by high- and low-frequency pneumatic hammers. The equipment is being evaluated for use in measuring voids, moisture infiltration in asphalt pavement, and delamination of overlays.

The Seismic Pavement Analyzer (SPA, patent pending) is one such piece of equipment that uses this technology. It uses five accelerometers and three geophones to measure the pavement response induced by a large pneumatic hammer which generates low-frequency vibrations and a small pneumatic hammer which generates high-frequency vibrations. The equipment is mounted on a trailer that is towed behind a vehicle, similar to Road Rater and a falling weight deflectometer (FWD). This equipment is described in Nazarian, et. al. article, *Use of Seismic Pavement Analyzer in Pavement Evaluation* (12).

Skid Resistance Testing

New methods for measuring the skid resistance of pavement are being evaluated. Two methods, called the spin-up and spin-down methods, are showing potential for being able to obtain the skid number/speed relationship in a single pass and travel at posted speed limits. The method uses a locked-wheel tester to measure brake torque rather than friction force. In the spin-up approach, the test wheel is locked and the brake is released while the tester travels at constant speed. In the spin-down approach, the rolling test wheel is slowed down gradually to minimize inertial effects.

Laser Technology

Lasers are being used to measure longitudinal road profiles (both short and long wavelength variations), to detect rutting (transverse profile), and to measure various surface macrotexture deficiencies. Laser sensors operate by directing a light beam at an object and measuring the time it takes for the light to be reflected back to the sensor. Through the proper spacing of the sensors, these data are typically collected at or near posted speed limits, allowing the collection of large quantities of data with minimal disruption to traffic. Lasers are also being evaluated for use in measuring pavement deflection under moving loads, as discussed below.

Structural Testing

The current accepted practice for rapid structural evaluation of a pavement is deflection-based nondestructive testing, such as with a Road Rater and falling weight deflectometer (FWD). However, while it is cheaper and quicker than coring and destructive testing, NDT testing still obstructs traffic and requires frequent stops and starts. Prototypes of structural testing equipment capable of assessing a pavement's structural capacity at posted speed limits are being developed. Called "rolling weight deflectometers" (RWD), this equipment uses laser technology to measure the response (deflection) of the pavement to a moving wheel load. Current versions under development have successfully measured responses at 20 mph; it is anticipated that in several years the technology will exist to measure deflections at speed of about 50 mph.

Integrated Survey Vehicle

The ultimate piece of equipment would be a truly integrated survey vehicle. This vehicle would travel over the road at posted speeds and collect simultaneously information such as visual distress, roughness, structural capacity, and other features. Work on such a vehicle is going on today; however, it appears that it will take many years to fully develop this technology.

Use of Expert Systems

Another developing technology that is showing potential for use in pavement management is the expert system. An expert system is a computer program that uses knowledge and inference procedures to solve problems. It is designed to try to replicate the general thought process of a human expert in a particular field. Expert systems are more applicable in situations where a significant amount of human expertise and reasoning is needed to solve a problem.

An expert system is comprised of the following components (13):

Knowledge base: The knowledge base is the heart of an expert system. It contains the knowledge that is used by the system in solving problems. Two types of information are contained in the knowledge base: causal or factual knowledge of the application domain and empirical associations or rules. Only a person that is knowledgeable in the domain of a given program can define the applicable conditions and corresponding actions. This is particularly true in pavement management, where many of the rules represent assumptions, limitations, or rules of thumb of the experts. The complete set of rules must be complete, unique, and correct.

Context: The use of an expert system program begins with the user entering some known facts about the problem into the context. The context is the work space or short term memory of the system. It contains the information that describes the problem currently being solved.

Inference Engine: The inference engine is the knowledge processor. It searches through the knowledge base or the context in order to deduce new facts about the problem, which are then used for subsequent inferences.

Explanation Module: The explanation module provides the expert system with the capability of explaining its reasoning and problem solving strategy to the user.

Knowledge Acquisition Module: The information stored in the knowledge base must be entered in a rigid format. The knowledge acquisition module helps the expert input the required knowledge in the required format.

User Interface: The user accesses the system through an interface. Common interfaces include natural language queries, menu-driven selections, or pectoral icons.

Potential Applications of Expert Systems to Pavement Management

Selection of Appropriate Maintenance and Rehabilitation Alternatives

One potential use for an expert system within a PMS is for the selection of maintenance and rehabilitation activities. An expert system can take into account the various factors that affect the selection of a repair type, including different traffic levels, pavement types, pavement condition, geographical location, and so on. In this application, an expert system may help to offset any lack of experience of the pavement manager in pavement engineering.

Automated Image Processing and Pavement Deficiency Recognition

As described earlier in this chapter, machine vision and video image processing are being used to identify pavement distresses. Currently, image processing technology relies mainly on algorithmic techniques. Expert systems may have potential for interpreting the entire image.

Pavement Condition Evaluation

Expert systems may also be helpful in evaluating pavement condition and determining the cause of deterioration.

New Training Methods

One of the newest training techniques being used today involves the use of multimedia capabilities provided by compact disc-based (CD-based) technology. This training approach combines the use of photographs, graphics, video, and sound in an interactive format. Users have the ability to quickly review the information presented or investigate particular topics of the training in great detail. For example, a CD-based distress identification course would allow an individual the ability to quickly review familiar distress types, while investigating other distress types in more detail.

Through the use of hypertext hotwords and buttons, links are made between various items in the training program so the user can quickly move from one area to another. This feature may be used to compare the differences between distress types that may commonly be confused, such as alligator cracking and block cracking. The hypertext links also allow the user to select features such as audio descriptions of the distress or specific instructions for measuring the distress in the field.

There are a number of advantages to CD-based training. One of the greatest advantages is the flexibility in the use of one CD-based training package as a classroom tool, for self-instruction, or as a review mechanism, depending on the specific needs of the user. Additionally, these programs allow students to experiment with learning without enduring any negative feedback from an instructor or embarrassment in front of other class participants. Because of this, users are comfortable spending as much time as necessary on each aspect of the training. The participant is also much more attentive during a CD-based training program because of the interactivity with the program and the use of sound and graphics.

CD-based programs also provide opportunities to test a user's understanding of the concepts being taught by providing real-time feedback. Testing applications can easily be designed so that any areas not understood by the user can immediately be reviewed in more detail. Once the user understands the material, that portion of the test can be taken again. This process can be repeated until an acceptable level of understanding is reached.

Summary

New technology with possible applications to pavement management becomes available every day. It is the pavement manager's responsibility to keep abreast of new testing methods, equipment, or software that could improve the pavement management process. Reading technical publications, attending conferences and workshops, and self-study are excellent ways to monitor new technology.

Chapter 8 References

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11. Mesher, "Evaluation of New Ground Penetrating Radar Technology to Quantify Pavement Structures," Transportation Research Board 74th Annual Meeting, 1995.
12. Nazarian, et. al., "Use of Seismic Pavement Analyzer in Pavement Evaluation," Transportation Research Board 74th Annual Meeting, 1995.
13. Hendrickson, et. al., "*Expert Systems and Pavement Management*" and Ritchie, et. al., "*Application of Expert Systems for Managing Pavements,*" Proc., The Second International Conference on Managing Pavements, Toronto, Canada, October 1987.

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Additional Pavement Management Technical Information

Pavement Management

AASHTO Guidelines for Pavement Management Systems, American Association of State Highway and Transportation Officials, Washington, D.C., 1990.

This document describes the primary characteristics of a pavement management system, the various components of a pavement management systems, and how to use the products of a pavement management system as a strategic planning tool and for applications to pavement engineering.

A Guide for Local Agency Pavement Managers, Washington State Department of Transportation, TransAid Service Center, written by The Pavement Management System Guidebook Review Team and published by The Northwest Technology Transfer Center, December 1994.

This guide combines an explanation of the various pavement management system components and other supporting materials to help local agencies understand and implement a pavement management system.

R. Haas, W. R. Hudson, and J. Zaniewski, *Modern Pavement Management*, Publishing Co., Malablar, Florida, 1994.

This book provides information on the principles of evaluating, planning and programming, designing, constructing, maintaining, and carrying out research on pavements. It also discusses the implementation of pavement management systems.

Pavement and Road Surface Management for Local Agencies Course Notebook, prepared by Texas Transportation Institute Texas A&M University for the Pavement Division of the Federal Highway Administration, Washington, D.C., 1994.

This notebook provides detailed information on the implementation and use of a pavement management system at the local agency level. The course material provides a description of the basic components of pavement management. A suggested approach to implementation is provided. It provides information to help local agencies select software and data collection procedures appropriate for the agency.

Johnson, C., *Pavement (Maintenance) Management Systems*, American Public Works Association, Kansas City, Missouri, 1984.

This article provides an excellent overview of the pavement management process and the benefits a local agency can derive from implementing a pavement management system. It illustrates the benefits of a pavement management system through the application of pavement management principles to a sample road network.

Proceedings for the Third International Conference on Managing Pavements, Volumes I - III, Transportation Research Board, National Research Council, Washington, D.C., 1994.

The proceedings offer excellent insight into the current status of pavement management throughout the world. Of special interest are sections of the proceedings dedicated to local agency pavement management and institutional barriers.

Pavement Maintenance and Rehabilitation

D. Geoffroy, *NCHRP Synthesis of Practice 223: Cost-Effective Preventive Pavement Maintenance*, Transportation Research Board, National Research Council, Washington, D.C., 1996.

This synthesis includes a review of current preventive maintenance practices. It contains a literature review and summarizes the research being done in this area. It discusses the cost-effectiveness of preventive maintenance strategies and discusses treatment selection and timing.

Pavement Rehabilitation Research, WA-RD 214.1 Final Report, Washington State Department of Transportation, July 1990.

This document outlines the best methods and materials available to rehabilitate the asphalt pavements under the jurisdiction of the cities and counties in Washington State. A prioritization scheme is presented which can be used to select the most appropriate repair alternative to correct a specific problem.

Prioritization

K. Zimmerman, *NCHRP Synthesis of Practice 222: Pavement Management Methodologies to Select Projects and Recommend Preservation Treatments*, Transportation Research Board, National Research Council, Washington, D.C., 1995.

This synthesis includes a review of the predominant pavement management methodologies being used by U.S. state and Canadian provincial highway agencies. It provides a general description of each methodology and a summary of the requirements, benefits, hindrances, and constraints associated with each. Case studies are also included.

Pavement Evaluation

W. Gramling, *NCHRP Synthesis of Highway Practice 203: Current Practices in Determining Pavement Condition*, Transportation Research Board, National Research Council, Washington, D.C., 1994.

This synthesis summarizes current practices used in determining the condition of pavements, based on a survey of state highway agencies. The emphasis is on four measures of pavement condition that are used in pavement management systems: distress, roughness, structural capacity, and friction resistance.

Pavement Surface Condition Rating Manual, written by Northwest Pavement Management Systems Users Group and R. Keith Kay Washington State Department of Transportation, produced by Washington State Transportation Center University of Washington for Northwest Technology Transfer Center Washington State Department of Transportation Local Programs Division, March 1992.

This manual provides the name, description, severity levels, and quantification process for each distress type that an agency evaluates in its pavement management program. The distresses are categorized by pavement type. The definition of each distress type is followed by a description of its levels of severity, units of extent quantification, measurement procedure, and an example.

Design

1993 edition of the *AASHTO Guide for Design of Pavement Structures*, published by the American Association of State Highway and Transportation Officials, Washington, D.C.

This guide provides a comprehensive set of procedures which can be used for the design and rehabilitation of rigid and flexible pavements and aggregate surfaced roads.

WSDOT Pavement Guide, Volumes I - III, Washington State Department of Transportation, Olympia, Washington, February 1995.

This guide is organized in three volumes. Volume 1 is focused on WSDOT pavement policy. Volume 2 provides insight into the how and why of related pavement design, construction, performance, rehabilitation, and maintenance. Volume 3 provides documentation of pavement design software and case studies.

Statistics

Mahoney, J.P., *Statistical Methods for WSDOT Pavement and Material Applications*, WA-RD 315.1, Washington State Department of Transportation, Olympia, Washington, February 1994.

This report provides an overview of various statistical methods. The purpose of the report is to explain statistical methods (with an emphasis placed on regression analysis) in a straightforward manner to a broad group of users.

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Acronyms and Definitions

AASHTO — American Association of State Highway Transportation Officials.

ACP — Asphalt concrete pavement.

ADT — Average daily traffic.

APC — Asphalt over concrete.

Alternatives — Various choices of treatments available for providing a solution to a pavement problem.

Analysis Period — Period of time for which the economic analysis is to be made.

Attribute Database — Contains nongeographical data, such as segment names and pavement age, that describe a geographical feature.

Benefit-Cost Analysis — Relates the economic benefits of a solution to the costs incurred in providing that solution.

BST — Bituminous surface treatment.

CAD — Computer-aided drafting.

CAPP — County Arterial Pavement Preservation Program.

CD — Compact disc.

CI — Condition index.

CRAB — County Road Administration Board.

Deterministic Models — Predict the average value of a dependent variable (such as the remaining life of a pavement or its level of distress).

Digital Image — Mathematical representation of a normal pictorial image.

Distress — Physical deterioration of the pavement surface, such as potholes and cracking.

Empirical Models — Based on results of experiments or experience.

Expert System — Computer program that uses knowledge and inference procedures to solve problems.

FHWA — Federal Highway Administration.

FWD — Falling Weight Deflectometer.

GIS — Geographic Information System.

GPR — Ground Penetrating Radar.

GPS — Global Positioning System.

Geographical Database — Contains data that define the physical location of features.

Georelational Data Structure — Links locational and attribute data. Establishes the relationship between the location of features in the geographical database and their corresponding descriptions in the attribute database.

IBC — Incremental benefit cost.

IMS — Integrated Management System.

Inventory Data — Includes information pertaining to the physical characteristics of the pavement (geometrics, location reference identifiers, as-built materials and thickness, and so on) and traffic data.

Life-Cycle Costing — Economic assessment that considers all significant costs over the economic life, expressed in terms of equivalent dollars.

Markovian Theory — Based on assumption that the probability something will change from one condition state to another is only dependent on its current state.

Mechanistic Model — Based on fundamental principles of pavement behavior under load.

Mechanistic-Empirical Model — Combines elements of mechanistic and empirical models. The mechanistic component is the determination of pavement reactions such as stresses, strains, and deflections within the pavement layers through the use of mathematical models. The empirical portion relates these reactions to the performance of the pavement structure.

MIMS — Municipal Integrated Management System.

Models — Mathematical or conceptual presentation of a relationship.

Multi-Year Prioritization — Projects are considered in each analysis year and the optimal timing for rehabilitation is identified.

NDT — Nondestructive testing.

Network Level — The level at which key administrative decisions affecting programs for the road network are made.

Network Level Analysis — Evaluation of pavement to enable the selection of candidate projects, project scheduling, and budget estimates.

NWPMA — Northwest Pavement Managers Association.

Optimization — An analysis technique that evaluates repair strategies for the network as a whole before any specific projects or treatments are identified.

Overlay — A layer of paving material applied over the original road surface.

Quantization — Discrete scaling of the illumination levels in an image to gray scale values.

PCC — Portland cement concrete.

PCI — Pavement Condition Index.

PMS — Pavement Management System.

PSC — Pavement surface condition.

Patching — Area of pavement which has been replaced with new material.

Pavement Condition — Quantitative representation of distress in pavement.

Pavement Distress — The physical manifestations of defects in a pavement.

Pavement Maintenance — All routine actions, both responsive and preventive, which are taken to preserve the pavement structure.

Pavement Management System — A tool (usually computerized) that records and analyzes pavement condition and helps plan maintenance and rehabilitation requirements.

Pavement Structural Capacity — The maximum accumulated traffic loads that a pavement can withstand without incurring unacceptable distress.

Performance — Ability of a — pavement to fulfill its purpose over time.

Prediction Model — Mathematical description of the expected values that a pavement attribute will take during a specified analysis period.

Probabilistic Model — Predict a range (or distribution) of values for a dependent variable.

Project — Section of roadway that has similar age, geometry, and construction type.

Project Level — The level at which technical management decisions are made for specific projects or pavement segments.

Project Level Analysis — Evaluation of pavement to select the type and timing of rehabilitation or maintenance.

RWD — Rolling Weight Deflectometer.

Ranking — Prioritization that is performed in a sequential fashion.

Reconstruction — Construction of the equivalent of a new pavement structure which usually involves complete removal and replacement of the existing pavement structure.

Recycling — Re-use, usually after some reprocessing, of a material that has already served its first intended purpose.

Rehabilitation — Work undertaken to restore serviceability and extend the service life of an existing facility — This may include partial recycling of the existing pavement, placement of additional surface materials or other work necessary to return an existing pavement to a condition of structural or functional adequacy.

Regression Analysis — Statistical tool that is used to relate two or more variables in a mathematical equation.

Roughness — Irregularities in the pavement surface that affect ride comfort or quality.

Salvage Value — The relative value of the various alternatives at the end of the analysis period.

Seal Coat — A thin, liquefied asphalt surface treatment used to waterproof the pavement. Seal coats may or may not be covered with aggregate, depending on the intended purpose. Main types of seals are fog seals, sand seals, slurry seals, and aggregate seals (often referred to as "chip seals").

Segment — Subdivision of a project.

Single-Year Prioritization — Projects are considered independently in each of the analysis years.

Strategy — A plan or method for dealing with all aspects of a particular problem — For example, a rehabilitation strategy is a plan for maintaining a pavement in a serviceability condition for a specified time period.

Surface Friction — Skid resistance of the pavement.

Treatments — Materials and methods used to correct a deficiency in a pavement surface.

VCI — Visual Condition Index.

WAC — Washington Administrative Code.

WSDOT — Washington State Department of Transportation.

WSPMA — Washington State Pavement Management System.

13:P:DP/PMAG

Appendices

Appendix A
Case Studies Supplemental Information

Appendix B
Prioritized Repair Types Table
(WA-RD 214.1)

Appendix C
Cause of Distress Types

Appendix D
A Process to Demonstrate the Cost-Effectiveness of Preventive Maintenance
(NCHRP Synthesis 223)

Appendix E
Preventive Maintenance Primer
(NCHRP Synthesis 223)

Appendix F
Budget Options Report for Public Works Department

Appendix G
Budget Options Report for Board or Council Purposes

Appendix A Case Studies Supplemental Information

1. City of Bellevue Pavement Management Brief

Pavement Management

Overview

This report is a short history of the City of Bellevue's Pavement Management System. The idea behind a pavement management system is to inventory an agency's roadways, determine existing conditions and hence make educated decisions about how these roadways are going to be maintained.

Pavement inventory was one of the first accomplishments of the system. For the first time, it enabled Bellevue to determine the actual number of lane miles and road miles within the city. Before the initiation of the pavement management program, the amount of roadway the city maintained was an estimate. The system also helped identify and classify streets that might be candidates for overlays during the upcoming construction season. But most importantly, it brought to the attention of Public Works the condition of the roads and the rate at which they were deteriorating.

The rating of the city roads is based upon the successful system utilized by WSDOT. This system utilizes a default matrix with pavement distress as the predominate defect. This type of system enables the city to rate their pavement as it begins to deteriorate; fatigue, longitudinal and transverse cracking are the major defects that are used. Other defects are included in this system such as rutting, raveling, flushing and edge condition. These defects are given a point total based upon the severity and extent of the problem. This number is then subtracted from 100 (new pavement) to provide a rating on a pavement section. A system such as this allows the detection of early pavement failure, enabling the agency to estimate the anticipated life expectancy of a pavement section.

Predicting Pavement Life

By 1991, nearly all the city streets had at least three ratings over a period of six years. In conjunction with the original construction date, we now have four pavement condition points. With these rating points, the city can produce a pavement performance curve which enables a prediction as to how long a street might last form the year of original construction or the year of an overlay. This not only allows the city to select streets to be overlaid, but also lets us estimate pavement life and produce a five or six year overlay plan. Now the city can adjust the rehabilitation budget, adjust the overlay list, or make other changes to meet upcoming CIP projects or other needs.

The pavement curve tends to show the pavement will stay in good shape for a fairly long time before the curve starts to drop. Once the pavement starts to deteriorate, the curve falls fairly rapidly. Pavements with ratings in the 60 to 80 range would look fairly good if you were just driving on them. To see any defects, you would have to look very closely. Once the rating of the pavements reaches the 20 to 30 range, they are in pretty bad shape and defects are readily noticeable. Agencies would like to start thinking about repair or maintenance of a pavement before it gets below a rating of 50. The reason for this is that a pavement with a rating of 50 might only require an overlay at a cost of $10 per square yard. A pavement with a rating of 30 would probably require a rebuild at a cost of $40 to $100 per square yard.

Street Selection

The street selection process of the pavement management program is based on the function classification and rating value. The pavement management priority schedule places the emphasis of repairs to the arterial and collector streets.

Priority	*Function Classification*	*Rating*
1	1	Less than 50
2	2 & 3	Less than 40
3	4 & 5	Less than 30
4	6	Less than 20
5	1	70 to 50
6	2 & 3	70 to 40
7	4 & 5	60 to 30
8	6	60 to 20

The number of streets that need some rehabilitation action far exceeds the available funding for this type of program. Therefore, we look at streets with a rating of 40 or less as a possible candidate for our overlays.

A five-year overlay plan is produced from this selection process and the pavement life prediction. We then coordinate with the utility companies and city departments to determine the most effective use of the overlay budget.

The final street selection for each year is based on the vicinity of the city that predominately has that year’s indicated streets. We then add the following year’s streets in the same area. This reduces our construction costs and keeps us from paving a street adjacent to one paved the previous year.

2. How to Present a Case for Preserving the Roadway Surface to a Board of Commissioners (Clark County)

Overview

The purpose of the overview was to quickly communicate the seriousness of the problem being discussed. It was short (1½ pages of text) and straightforward. The overview served to capture the attention of the audience and set the stage for the rest of the presentation.

The overview began by making an immediate, strong case for the importance of the pavement infrastructure by pointing out that it is the service most used by all citizens and that the quality of the pavement system directly impacts all residential and industrial growth in the area. The overview then emphasized that "the rapid growth of Clark County during the past fifteen years has placed a tremendous burden upon its roadway system. The monies required to keep pace with this growth in improving and/or otherwise maintaining the roadways on even a very limited level have not been forthcoming, resulting in the system continuing to deteriorate at a rapid rate." The overview also drove home the point that if something was not done immediately to address the problem, "… the liability placed upon the county's roadway system will continue to accelerate at a rate that far exceeds the ability of present funding to control, through maintenance and/or restoration … if this is allowed to continue unchecked, the financial obligation to Clark County and its citizens will increase by 5 percent to 10 percent per year. When anticipated population and industrial growth is considered, the additional impact upon the system will increase at an even greater rate. These are factors that demand immediate action and resolution, if we are to save the system and escape a future unfundable financial crisis." The overview finished with a synopsis of the current road needs, broken out by urban needs and rural needs.

Pavement Management

The overview drove home the seriousness of the problem. The following section on pavement management described a way of objectively and scientifically determining the extent of the problem and evaluating alternative solutions to the problem. It also discussed why Clark County needed structural information on its pavements in order to make the best possible maintenance and repair decisions.

Exhibit A, shown below, was used to educate the audience about the importance of repairing a pavement before it has been allowed to deteriorate below a critical condition level. The report stated, "Exhibit A exemplifies the deterioration rate (curved line) in a typical roadway throughout its life-cycle. As the curve falls with respect to pavement condition, maintenance costs increase. The optimum benefit signifies a point where this rate begins to increase dramatically. It is at this point where an overlay will optimize benefits (structural adequacy is still present in the roadway) and minimize costs (existing structural integrity allows minimal overlay to extend roadway's life). If a roadway is allowed to drop below this point, costs increase significantly due to diminished structural stability requiring additional support from a more substantial overlay and yearly expenditures for increased maintenance activities. Once roadways have reached minimal benefit level, reduced structural adequacies require substantial overlays and/or reconstruction."

Pavement Deterioration / Rehabilitation Relationship

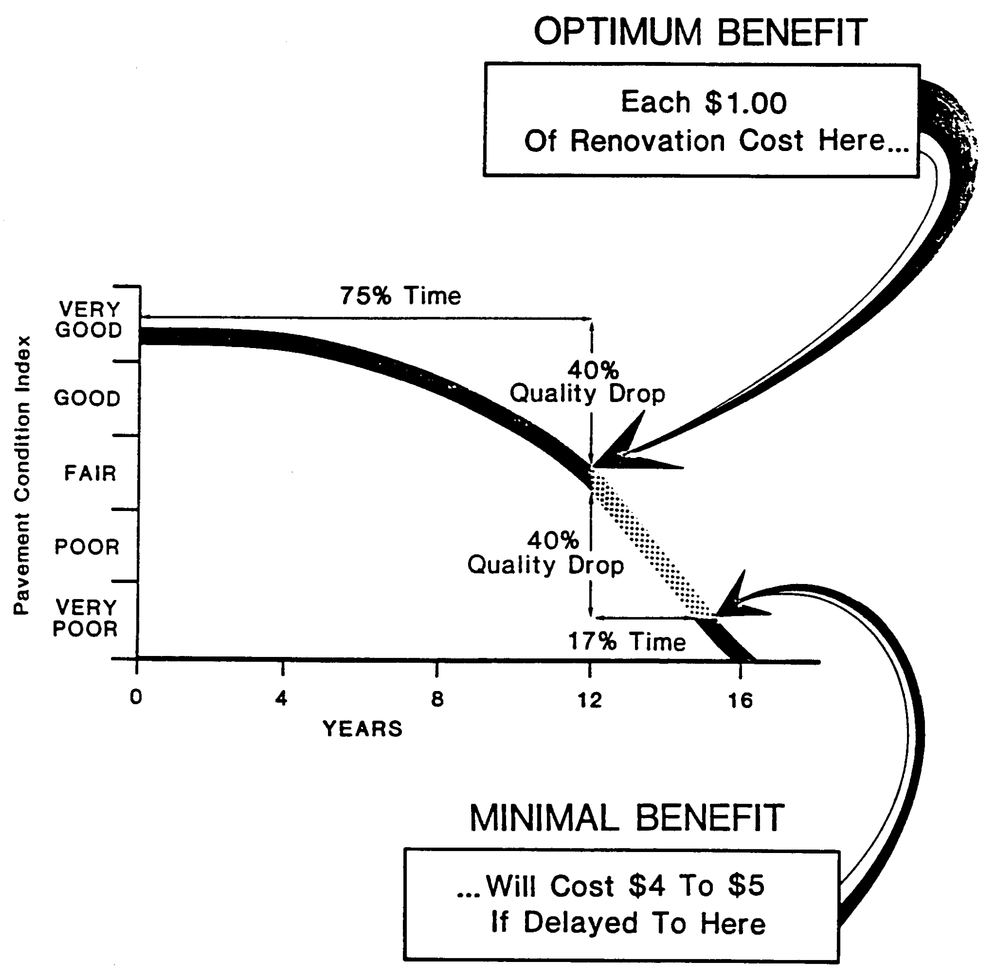


EXHIBIT A

The report then discussed the basic premise of pavement management, which is to repair pavements at the most cost-effective time in their life-cycle. It pointed out that after the present condition of each road has been determined, the repair work must be prioritized so that the pavements yielding the greatest return are fixed first. Clark County then presented the prioritization scheme, shown in Exhibit B, which it had adopted to maximize the benefits of the road system at cost-effective levels.

Exhibit B. Reverse Prioritization Scheme

Pavement Condition Index	*Rank*		
	Major and Secondary	*Collector*	*Tertiary and Parking*
Optimum: 56 - 60	1	3	
41 - 55	2	5	
26 - 40	4	7	10
Minimal: 11 - 25	6	9	12
0 - 10	8	11	13

The report then discussed why structural testing of the roadway system would play a critical role in the pavement management process. It was pointed out that the seal coat program within the county often obscured visible signs of distress, making a visual survey inadequate for assessing pavement condition. It also discussed the fact that a visual survey provides no measure of structural inadequacy and provides only limited input into the design of rehabilitation alternatives. On the other hand, the report stated that structural testing would provide the county with an excellent measure of structural capacity as well as essential design criteria. This portion of the report concluded with, “An effective PMS will save millions of dollars by correctly timing designed overlays onto deserving routes. Lack of direction will return us to the “windshield” game played every spring: which road looks the worst!”

Pavement Deflection Testing

The next portion of the report discussed in detail the use of pavement deflection testing in the pavement management process. It described how the road rater worked and how the collected data are used to estimate remaining life and to design overlays and other rehabilitation activities. It then showed how the deflection data were used to determine where each pavement segment lies within its life-cycle.

Exhibit C was used to show the audience how many lane miles of arterial roads were currently in each stage of the life-cycle. The report stated, “Optimum benefit sections (priorities #1 and #3) encompass structures normally requiring 2-inch overlays. These roadways reveal adequate bases, but also signify a point where deterioration rates are now beginning to increase. It is crucial we overlay during this phase, protecting what structural integrity we have left …. If roadways are allowed to fall into the reduced benefit section (priorities #2 and #5), the average required overlay depth becomes 2 ½ inches. Here the structural competency of each roadbed has fallen slightly, now requiring a (thicker) overlay … costs have also increased due to the deeper overlay section and continuing maintenance costs. Any road slipping further finds the partial benefit section (priorities #4, #7, and #10), where required average overlay depths are 3 inches. This phase has roadbeds with some structural capability, but seeks structural assistance through substantial overlay depths. Again, costs are due to inflate as overlay depths increase and maintenance costs climb. Any roadways found in the minimal benefit phase (priorities #6, #9, and #12) have little structural integrity remaining. The average overlay depth here is 4 inches … roadways in this condition are prime candidates for reconstruction."

Benefit Stages
REMAINING LIFE

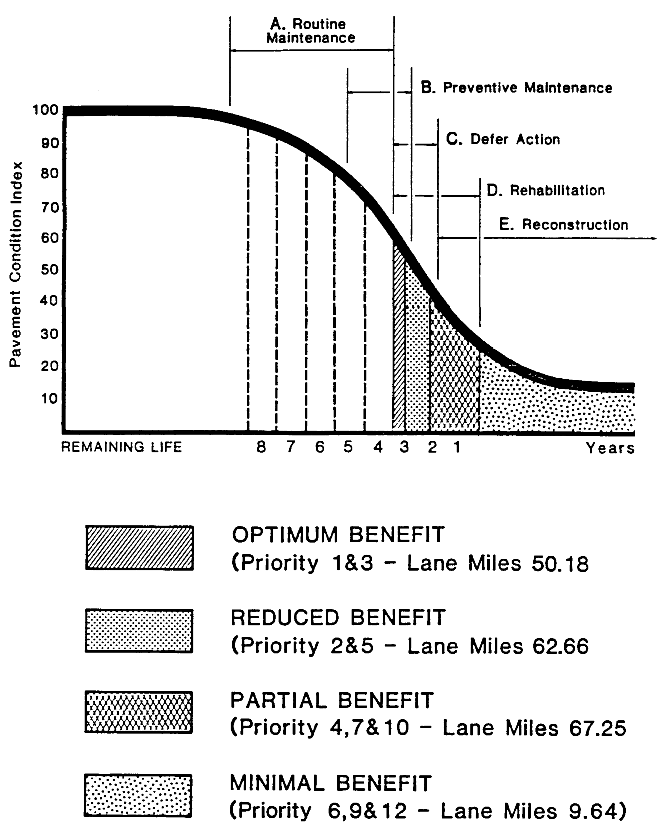


EXHIBIT C

This portion of the report concluded with the following statements, "… the road rater is currently providing valuable assistance in determining structural adequacy, isolating problem areas, identifying causes of deterioration, and designing for future overlays or other rehabilitation techniques."

Network Findings and Justifications

Now that the audience had been educated as to why and how the pavement system was being evaluated, the report moved on to summarize the findings of the pavement evaluation. It used Exhibit F to show the remaining life of the pavements within Clark County. Exhibit F also showed how many lane miles were in the different benefit categories (minimal, partial, reduced, and optimum).

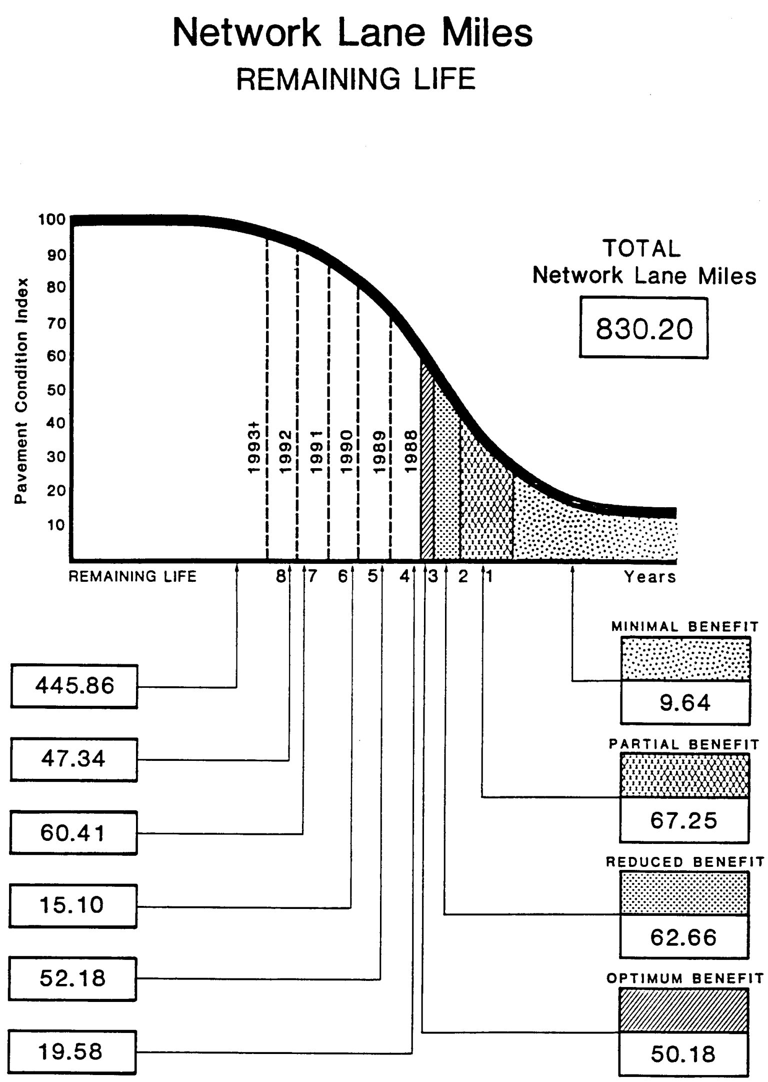


EXHIBIT F

Funding

The network findings portion of the report was followed by a section on funding. It discussed the amount of money needed for patching, sealing, and overlay projects. It compared this amount to the existing budget and stated, "… findings … would indicate that the present levels and methods of providing maintenance to the roadway system is falling far short of keeping pace with the advancing deterioration of the system. In order to reduce the county's liability as it now exists, the priority array and schedule of upgrading the roadway system over a period of years must be adopted." The report then provided the recommended 10-year road program, showing pavement location, repair type, miles, and cost.

Recommendations

The recommendations portion of the report was very brief, and drove home the conclusions developed during the previous portions of the report. It stated, "… it is very evident that a serious situation does exist. With a conservative estimated value of the road system in excess of $121 million, a present deficiency liability of over $20 million, and deterioration increase of 10 percent per year, this liability will exceed $50 million in ten years." Two recommendations it made were (1) "adopt the proposed recommendations that will provide the ongoing maintenance of roadway surfaces, upgrade the structural integrity of the system to a financial and manageable level in 10 years, and continue pavement management" and (2) "adopt the ten-year priority array of scheduled roadways."

Appendix

An appendix to the report provided a list of all roads that had been evaluated. It listed the road's priority level, remaining life, ADT, depth of overlay required, and lane miles.

3. City of Olympia Annual Pavement Condition Survey Report

City of
OLYMPIA
P.O. Box 1967, Olympia, WA 98507-1967

MEMORANDUM

TO: Art O'Neal, Director

FROM: David Riker, Transportation Division Manager
Public Works Department

DATE: September 22, 1994

SUBJECT: 1994 Pavement Condition Survey and Results

The annual pavement condition survey was conducted this spring. The pavement condition survey provides us with data from which a condition rating is calculated for each segment of the roadway network. These condition ratings reflect the amount and type of pavement cracking that has been observed. Please note the ratings do not reflect other deficiencies which might be present, such as humps or bumps in the pavement.

A rating of 100 indicates a pavement which has no cracking in the traveled portion of the roadway. Ratings under 40 are considered a "must" category with respect to needed roadway maintenance and generally indicate structural failure. These road surfaces usually require an asphalt overlay. Ratings between 40 and 60 are considered to be in a "should" category. This usually indicates cracking is just beginning and maintenance in the form of a seal coating may be appropriate.

The 1994 condition survey involved observations of over 2,000 segments of asphalt and bituminous pavement. A breakdown of the results of this survey is as follows:

Miles of Asphalt and Bituminous Roadway = 173.96

	Below 40		Between 40 and 60		Over 60		System Average Rating
1994 Miles	60.95	35.4%	34.30	19.72	77.08	44.31	52
1993 Miles	63.83	38.2%	30.69	18.4%	72.64	43.4%	51
1992 Miles	61.91	37.4%	30.50	18.4%	73.30	44.2%	52
1991 Miles	60.61	37.0%	32.15	19.6%	71.17	43.4%	52
1990 Miles	39.13	24.0%	34.99	21.5%	88.59	54.5%	61

ALL-AMERICA CITY 1986 1987

City Council	753-8450	Community Planning & Development	753-8314	Police	753-8300
City Manager	753-8447	Fire	753-8348	Public Works	753-8362
City Attorney	753-8449	Human Resources	753-8442	Area Code	(360)
Administrative Services	753-8325	Parks/Recreation/Cultural Services	753-8380		

Art O'Neal, Director
September 22, 1994
Page 2

Difference	Below 40	Between 40 and 60	Over 60
93-94	-2.8%	+3.6%	+.91%
92-93	+0.8%	0.00%	-00.66%
91-92	+0.4%	-1.65%	02.13%
90-91	+13.0%	-1.90%	-11.10%
89-90	+3.9%	-5.20%	+01.30%
88-89	+13.3%	+10.00%	-23.30%

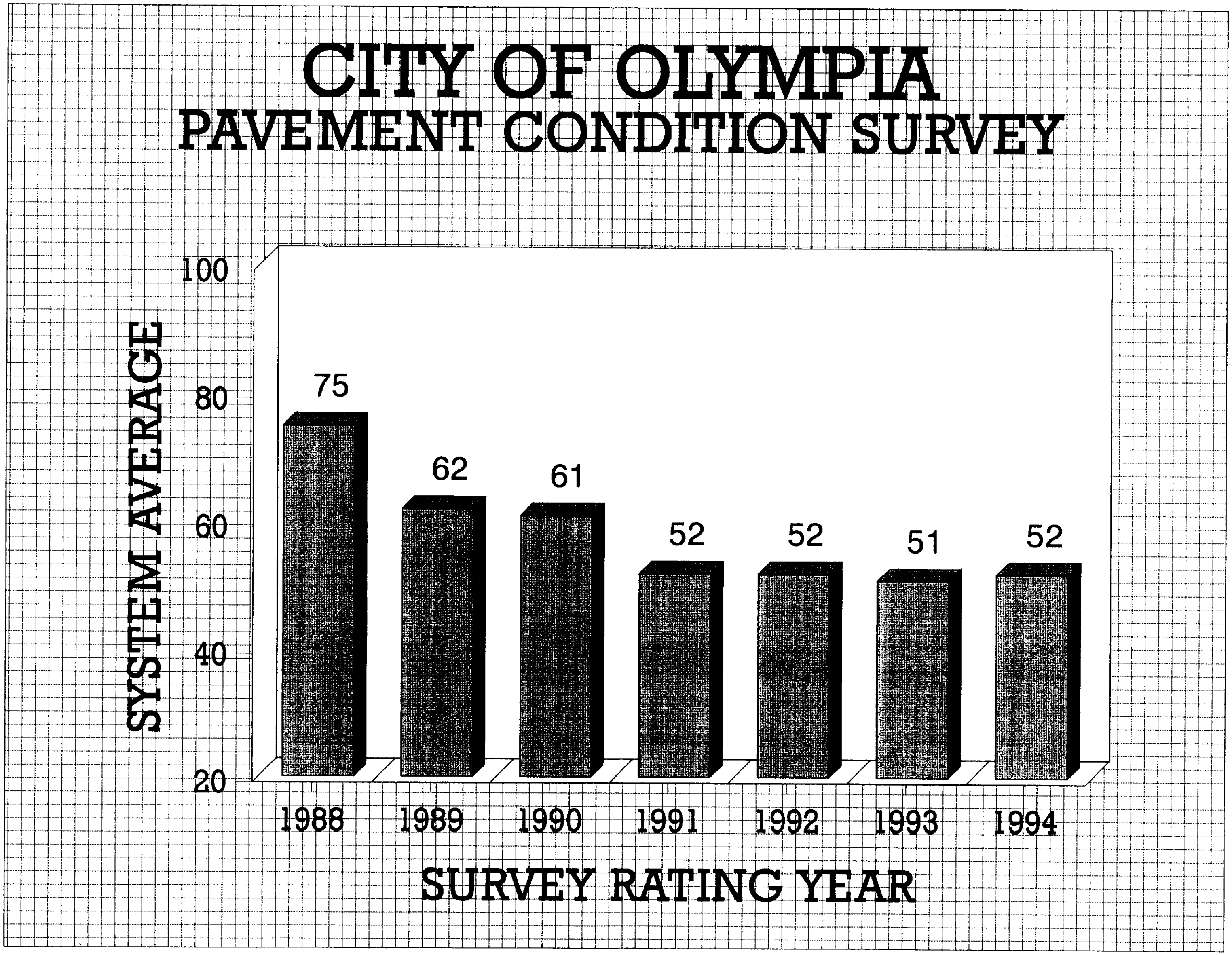
Stating the same results by Functional Class:

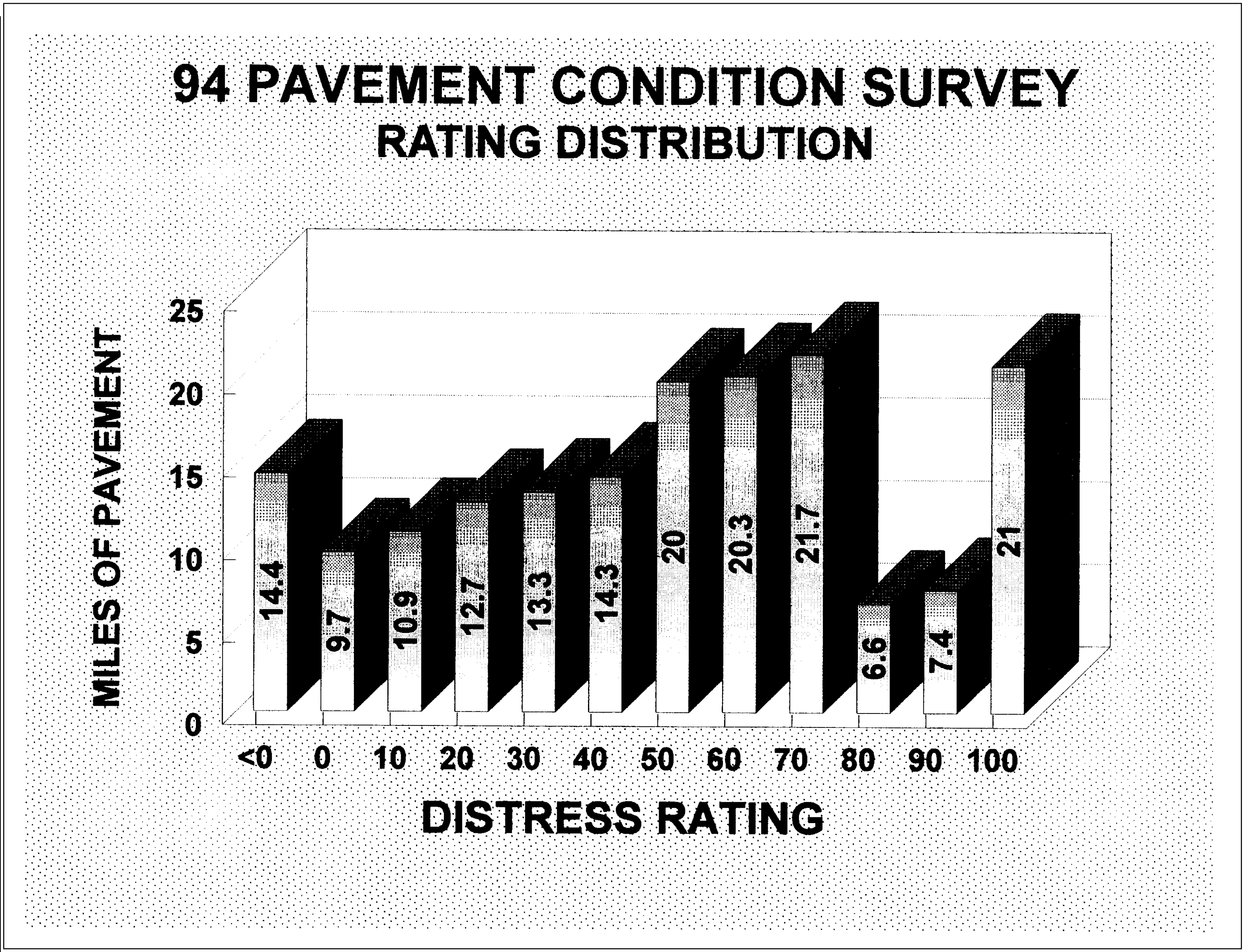
		1990	1991	1992	1993	1994
FC-1 Major Arterials						
Miles	Below 40	3.06	3.15	3.58	2.68	1.48
	Between 40 and 60	2.91	2.69	1.46	2.26	2.38
	Over 60	4.40	4.53	5.33	5.43	7.45
FC-2 Minor Arterials						
Miles	Below 40	6.01	13.49	9.86	7.88	5.46
	Between 40 and 60	7.55	4.07	4.42	2.37	7.03
	Over 60	8.40	4.01	7.96	12.37	11.45
FC-3 Collectors						
Miles	Below 40	4.46	7.89	6.50	6.21	6.89
	Between 40 and 60	4.37	2.48	2.57	3.30	8.05
	Over 60	6.07	4.57	6.62	6.24	8.08
FC-5 Local Access						
Miles	Below 40	25.60	36.24	41.97	47.06	47.27
	Between 40 and 60	20.16	23.31	22.05	22.76	22.36
	Over 60	69.72	57.50	54.26	49.26	44.58

Although the Street Section has increased their crack sealing and infrared patching programs, the result of the 1994 pavement condition survey indicate a continued increase in the need for maintenance, especially in the "must" category (below 40). The system average rating for 1994 is 52 compared with a system average of 74 in 1988. Due to the mild winter, the street network has remained virtually at the same condition since 1991. On the other hand, if the winter of 1994 becomes severe with freezing and thawing, the City could see large sections of the street work failing and needing costly repairs.

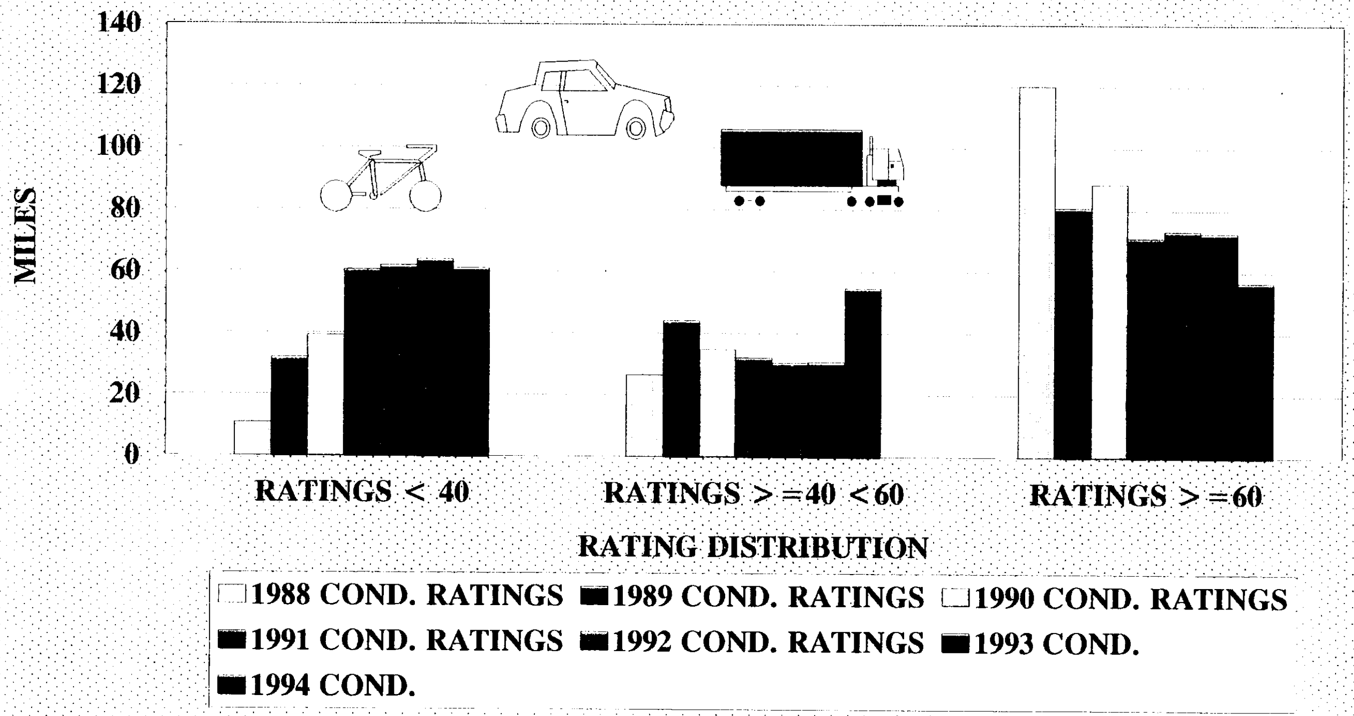
If you have any questions, please feel free to contact me at 8496.

DR:tmz(lc3)


CITY OF OLYMPIA
PAVEMENT CONDITION SURVEY
SYSTEM AVERAGE
100
80
60
40
20
75
62
61
52
52
51
52
1988
1989
1990
1991
1992
1993
1994
SURVEY RATING YEAR


94 PAVEMENT CONDITION SURVEY
RATING DISTRIBUTION
MILES OF PAVEMENT
0
5
10
15
20
25
14.4
9.7
10.9
12.7
13.3
14.3
20
20.3
21.7
6.6
7.4
21
<0
0
10
20
30
40
50
60
70
80
90
100
DISTRESS RATING

PAVEMENT CONDITION SURVEY
MAINTENANCE NEEDS IDENTIFICATION



RATINGS < 40 NEEDS OVERLAY
RATINGS > = 40 < 60 NEEDS MAINTENANCE
RATINGS > = 60 MINOR PAVE. DEFECTS

4. How to Introduce the Concepts of Pavement Management to a Board of Commissioners (Skagit County)

Overhead 1 — What is Pavement Management?

Pavement management includes a regular survey of roads to determine the most cost-effective maintenance or rehabilitation strategy for our pavements. Pavement management is a tool to manage our system using limited resources in the most cost-effective manner.

Overhead 2 — A Popular Way to Save Money Now is to Delay Needed Work Until Later

If a pavement is exhibiting pavement cracking or rutting, delaying pavement repair can expose the pavement to continued deterioration. If remedial action is taken in a timely fashion, a simple resurfacing may be all that is required to restore the road's serviceability. If, on the other hand, action is delayed, further deterioration can allow the surface pavement distress to extend into the road's base and subbase. This would result in major rehabilitation or reconstruction being required to repair the road at that point. A relatively small amount of deterioration occurs in the first 75 percent of a road's life. But after that, the decrease is dramatic. What would have cost $1,000 to rehabilitate to an almost new condition during that first 75 percent of life will cost between $4,000 and $5,000 during the last 25 percent of life.

Overhead 3 — When are Roads Rated?

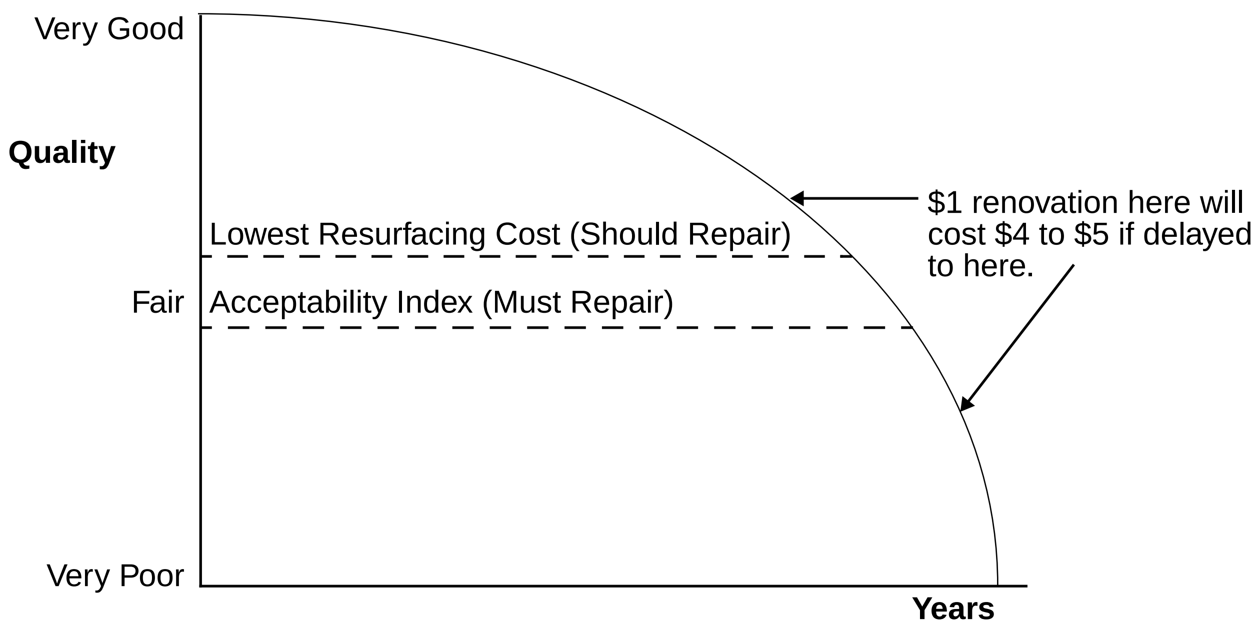
We rate roads to document the progressive deterioration of the pavement. Major collectors, minor collectors, minor arterials, and collectors are rated every two years. Local access roads are rated every three years. Concrete roads are rated every five years. The collectors and arterials are rated more frequently because of the higher volume of traffic they receive.

Overhead 4 — Road Distresses

During a pavement inspection, the roads are divided into half-mile increments or smaller. The roads are rated by identifying the type of distress present and measuring the amount of distress. This overhead shows the type of distress that is measured. This information provides the basis for identifying which roads need repair, determining the best way to fix the roads, for prioritizing road work, and preparing a long term plan.

Overhead 5 — Road Deterioration versus Time

The figure shown on this overhead shows road deterioration versus time. The two dashed lines represent when we should and when we must repair pavements to prevent higher repair costs. The area between these two dashed lines represents the optimum time for rehabilitation. Each pavement has its own curve, since each pavement deteriorates at its own rate. We use the visual distress data collected to develop these curves and identify the optimum time for rehabilitation.



Overhead 6 — Pavement Condition Rating Field Sheet

This is the rating sheet we use to record the distresses during our pavement rating.

Overhead 7 — Computer Screen Showing Visual Distress Data

This is how the information looks when we store it in our computerized PMS. The program automatically calculates a pavement condition rating based upon the distress information that was entered for each road.

Overhead 8 — Computer Screen Showing Results of Pavement Management Analysis

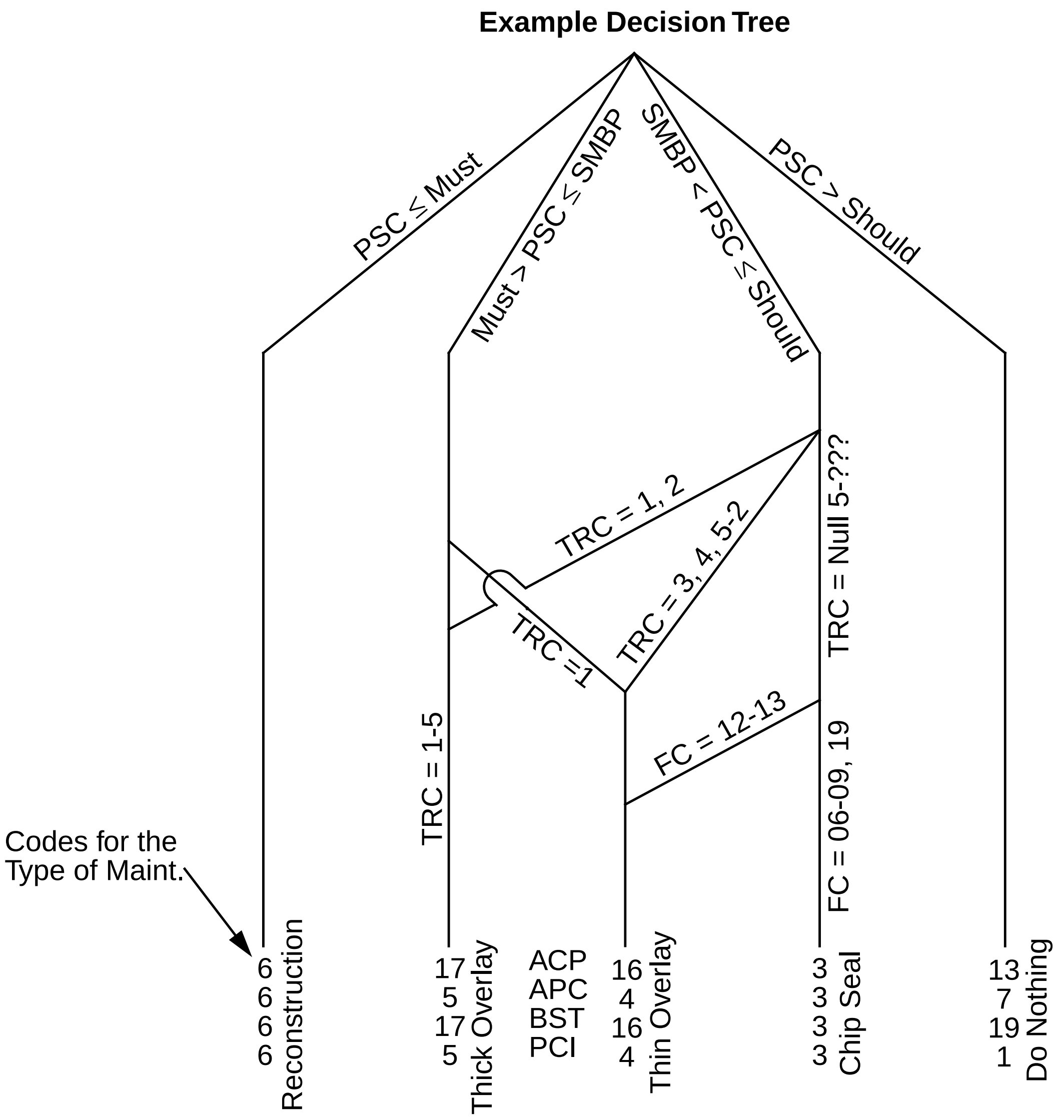
This screen from the PMS summarizes the pertinent information about a road. It identifies the road, shows when it was built and what its surface type is. It also shows traffic information and summarizes the condition of the road for each inspection date. Finally, it identifies the “should” and “must” years for pavement repair, what the recommended repair is, and how much the cost for the repair would be.

Overhead 9 — Pavement Condition Rating Scale

The PCR ranges from 0 to 100, with 0 being a failed pavement and 100 being a pavement without any visual signs of distress. CRAB has determined that once a road reaches a PCR of 60 it should be repaired, and once it drops to a PCR of 40 it must be repaired or the cost for repair will dramatically increase.

Overhead 10 — Rehabilitation Options

This overhead shows the rehabilitation repair types and associated costs that are used by Skagit County. The PMS uses this information to select a recommended repair for each road.



Note: SMBP = Should/Must Breakpoint
TRC = Truck Route
FC = Functional Class

Overhead 11 — Decision Tree

This decision tree, developed by CRAB, was created for Skagit County using our pavement types. Based on existing pavement type, PSC number, functional class, and traffic. The decision tree is used in the PMS to identify the type of repair is recommended based upon these conditions.

Overhead 12 — Analysis Options

The PMS can run an analysis to determine what budget is needed or you can enter a budget. After the analysis is complete, the PMS generates a list of roads identifying the type of rehabilitation recommended and the associated cost. This information is then used as a guide to the design and maintenance staff at Skagit County.

5. Skagit County PMS Update Forms

ROAD OVERLAY'S & RECONSTRUCTION

ROAD NUMBER/CRP ______________________________

ROAD NAME ______________________________

FROM MP/LOCATION ______________________________

____

TO MP/LOCATION ______________________________

____

PAVEMENT TYPE ______________________________

PAVEMENT THICKNESS ______________________________

RIGHT SHOULDER WIDTH & TREATMENT ______________________________

LEFT SHOULDER WIDTH & TREATMENT ______________________________

BASE MATERIAL: MP/LOCATION, THICKNESS

______ CSTC ______________________________

______ ATB ______________________________

______ GRAVEL BASE ______________________________

______ OTHER ______________________________

PLEASE ATTACH A TYPICAL CROSS-SECTION

Please return to Vicki Griffiths, Pavement Management

ROAD LOG/CRIS INFORMATION CHECKLIST

ROAD NAME:______________________ ROAD NUMBER:______________
BEGINNING MILEPOST:________ FROM INTERSECTION WITH:______________
ENDING MILEPOST:__________ TO:______________________
SECTION:________ TOWNSHIP:________ RANGE:_________ Right of Way__________

PAVEMENT TYPE:

- ☐ Unimproved
- ☐ Gravel and Ditched
- ☐ Gravel with no Ditches
- ☐ Low Type Bituminous
- ☐ Bituminous Concrete
- ☐ Portland Cement
- ☐ Asphalt
- ☐ Year Paved (approx)________
- ☐ Number of Lanes__________
- ☐ Pavement Width__________

SHOULDER TYPE:

- ☐ Paved
- ☐ Gravel
- ☐ Dirt
- ☐ Curbed
- ☐ None
- ☐ Other______________
- ☐ Width:
  - Left__________
  - Right__________

LANES MEDIAN:

- ☐ None
- ☐ Turn Lane
- ☐ Barrier(N.J/Concrete, etc.)
- ☐ Unprotected Barrier (grass, dirt)
- ☐ Other__________
- ☐ Width__________

CURBS:

- ☐ None
- ☐ Both Sides
- ☐ Right Side Only
- ☐ Left Side Only
- ☐ Rolled Edge
- ☐ Other__________

SIDEWALK:

- ☐ None
- ☐ Right Side Only
- ☐ Left Side Only
- ☐ Both Sides

BIKEWAY:

- ☐ None
- ☐ Within R/W
- ☐ Outside R/W
- ☐ Paint Stripe

COMMENTS:

____
____
____
____

FORM COMPLETED BY:____________________ **DATE:**____________________
Please return to Vicki Griffiths, Pavement Management

6. Spokane County "State of Pavement" Report

SPOKANE COUNTY
1994 PAVEMENT CONDITION REPORT

The Engineers Department of Spokane County Public Works has been actively pursuing any and all avenues to improve the way that we build and maintain County Roads. A major part of this effort has been the establishment of a Pavement Management System. The purpose of Pavement Management is to recommend the most cost effective treatments for our pavements and schedule their application at the most beneficial time. In other words, get the most bang for our pavement maintenance and rehabilitation buck.

The first step in the Pavement Management process is the determination of the existing pavement condition. From that basis we can establish what needs to be done now and project future conditions. We have now completed a full arterial system analysis of current condition. Current pavement condition is the subject of this first annual Pavement Condition Report. The report is organized into four parts. Part I gives basic network statistics and investment. Part II details the network surface condition survey. Part III details the network structural condition survey. Part IV analyzes the results of these surveys and their ramifications to the network.

Part I Network Statistics

The arterial system is defined as those roads having Federal Function Class (FFC) 7, 8, 14, 16 or 17. These classifications are identified by the function of the road:

FFC 7	Rural Major Collector
FFC 8	Rural Minor Collector
FFC 14	Urban Principal Arterial
FFC 16	Urban Minor Arterial
FFC 17	Urban Collector

Spokane County has a total of 810 center line mile of arterials. These combine into 11,748,727 square yards of pavement (approximately 3.793 square miles). This is roughly the equivalent of 1500 paved football fields. The distribution by function class is:

FFC	Miles	Area (sq. Yd.) Of Pavement
7	353	4,673,522
8	314	2,761,769
14	78	1,892,810
16	93	1,316,539
17	79	1,104,089

Figure 1 shows the various function classes and their percentage of the total arterial network in both centerline miles and square yards of pavement. Between 64 and 69 percent of the arterial network is outside the urban boundary.

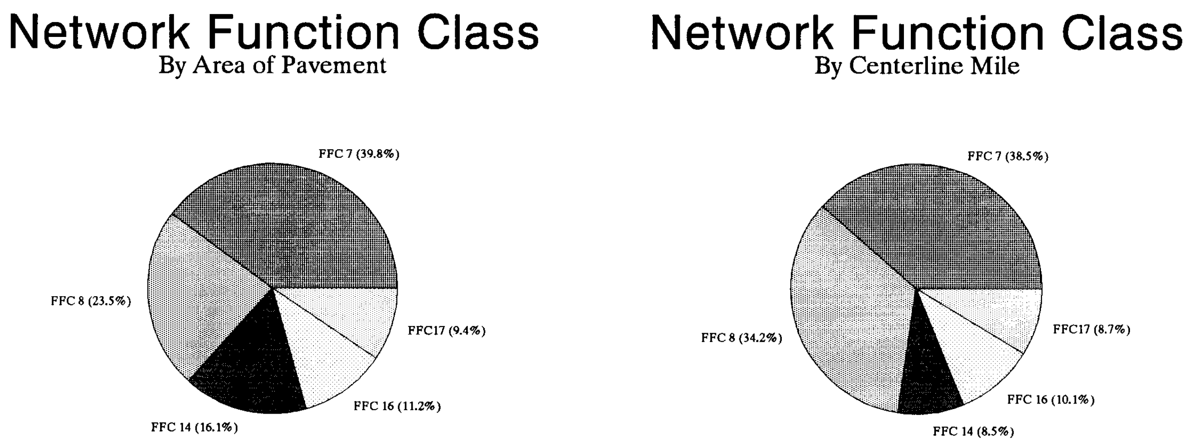


Figure 1

There are three pavement types existing in the network. The largest area of pavement is Asphalt Concrete Pavement or ACP (also known as "hot mix", "plant mix", etc.). The next most common type is Light Bituminous Surface Treatment or BST. And finally, the County owns a few miles of Portland Cement Concrete Pavement or PCCP. The network distribution by pavement type is as follows:

Pavement Type	Miles	Area (sq. yd.)
Graded	0.2 (0%)	
Gravel	108 (12%)	
BST	399 (44%)	5,207,993 (44%)
ACP	405 (44%)	6,416,221 (55%)
PCCP	5 (1%)	124,514 (1%)

Figure 2 shows how these pavement types are distributed in the Urban (FFC 14, 16 and 17) and Rural (FFC 7 and 8) arterials.

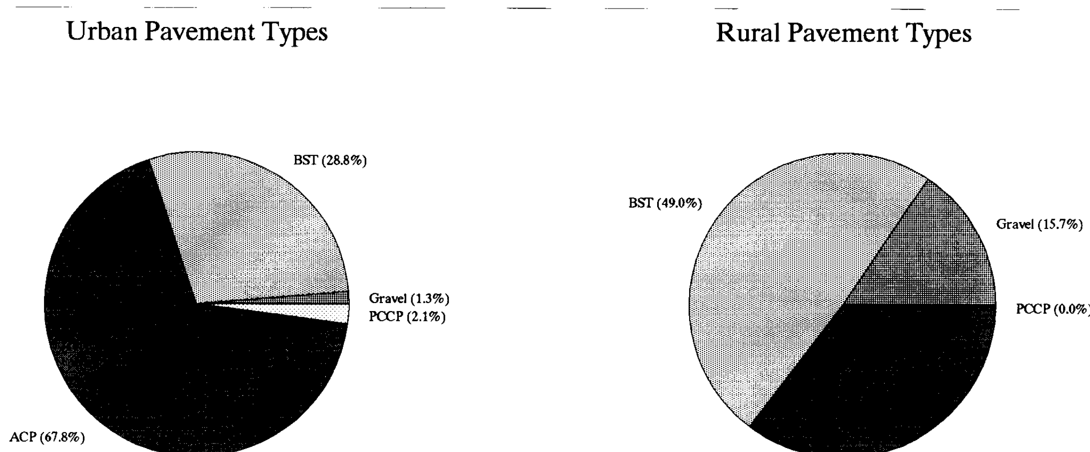


Figure 2

To get a feel for the magnitude of the public investment in our paved arterial network the replacement cost of the pavements was estimated. Using the average in place material costs for each pavement type (ACP = $11.38 per sq. Yd., BST = $9.18 per sq. Yd., and PCCP = $20.00 per sq. Yd.). The total investment in pavement material is $123,316,000. If the local access roads are considered we will add another $83,466,000. This totals $206,782,000 in materials alone. If replacement costs, traffic delays, and increased maintenance costs are considered it becomes apparent that the tax payers have a considerable financial stake in the County road network.

Part II Network Visual Condition

For the past three years the surface condition of the arterial network has been measured by the Pavement Management Section. Several methods of data collection have been tested. Last year a full scale evaluation of collection methods was performed and a method was selected that produces the required level of accuracy at a reasonable cost. In urban areas a team of pavement raters walks the roads and collects extensive data on all pavement defects. In the rural area a team of pavement raters drives the roads at 5 miles per hour and collects the same detail of data on pavement defects. With this information the type, severity and extent of the defects in each segment of road is determined. These defects are then given a value, calculated using the Washington State Department of Transportation continuous equations. This value is subtracted from 100 to give each segment a score called the Pavement Surface Condition (PSC). The following table gives defines the PSC in terms of recommended pavement treatments.

PSC Range	Indicated Treatment
100-80	None
79-60	Minor Repair (e.g. crack seal, seal coat)
59-40	Major Repair (e.g. overlay, patch & seal)
39-0	Structural Repair/Reconstruction

The average PSC for the arterial network is 84. This number includes all pavement types and function classes. The average is not very useful except as an indicator over time. Very little can be determined from the average in terms of what segments need to be repaired and how but, if it is tracked from year to year it can give us an idea of how the well the network is performing. The following table gives PSC averages for different groupings of roads.

Function	**Average Pavement Surface Condition**		
Class	**BST**	**ACP**	**PCCP**
14	85	79	81
16	87	81	87
17	87	81	-
7	80	88	70
8	89	79	-

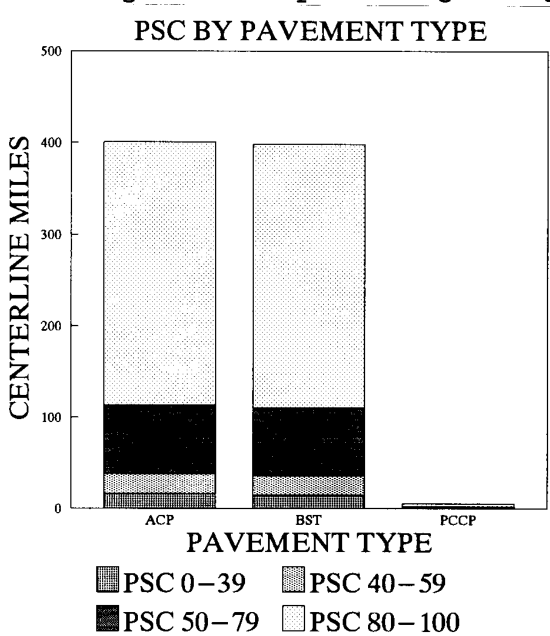
There are no apparent differences between these groups that can be seen from this data. The surface condition is slightly better for BST roads than ACP with the exception of the rural major collectors (FFC 7). Also, the urban network is more consistent across function classes than the rural system. The PSC for each segment is listed in the Appendix. The centerline miles in each category is shown below by pavement type.

	PSC Range			
Pavement Type	**0-39**	**40-59**	**60-79**	**80-100**
ACP	16.19	22.00	74.78	287.60
BST	13.94	21.96	74.35	287.84
PCCP	-	-	2.14	3.06

And by function class

	PSC Range			
Function Class	**0-39**	**40-59**	**60-79**	**80-100**
14	4.01	5.02	21.67	46.81
16	1.76	5.79	19.33	63.45
17	2.47	4.50	14.31	53.63
7	15.65	19.27	59.50	253.29
8	6.24	9.38	36.46	161.31

These tables are shown graphically in Figure 3. Figure 3 shows two things very clearly. The first is that the surface condition of ACP and BST are nearly identical. The second is that the rural network is in better condition than the urban network on a percentage basis (percentage of good to poor).



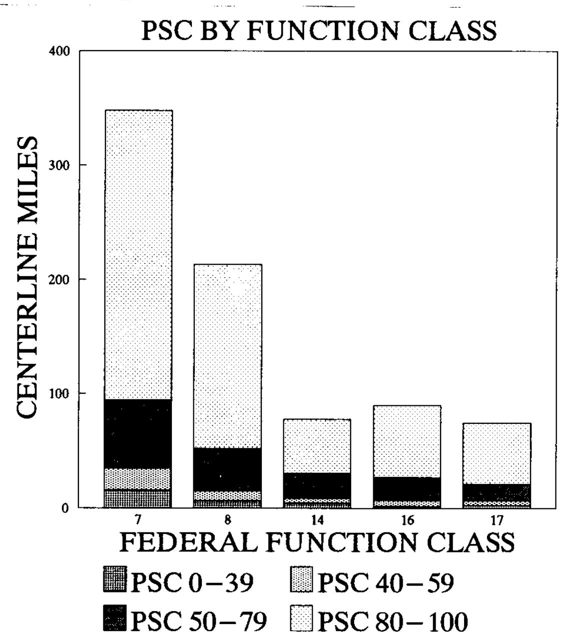


Figure 3

Finally, the total mileage of roads in need of treatment based on surface condition is:

Treatment	Centerline Miles
Reconstruction	30.13
Major Repair	43.96
Minor Repair	151.27

This means that 28% of the arterial network is in need of some sort of repair.

Part III Network Structural Condition

For the past eight years the structural condition of the network has been measured using a model 400B Road Rater. The Road Rater applies a 1,200 pound steady state dynamic load to the pavement and measures the surface deflection directly under the load and at one foot intervals out four feet. For network evaluation these tests are performed every 528 feet (0.10 mile) in the outside wheel path of all lanes. The resulting deflections are then adjusted for temperature and season. The adjusted deflections are converted to load carrying capacity using an Asphalt Institute procedure described in MS-17. Then using the current average daily traffic and an estimate of the percentage of truck loading, the yearly pavement loading are calculated. Finally, the load carrying capacity is divided by the yearly loads giving an estimated years to failure.

The following table gives the significance of the years to failure or as we report it the remaining life.

Remaining Life	Treatment Indicated
16-9	None
8-6	Structural Repair (e.g. thin overlay)
5-0	Structural Repair/Reconstruction

The average Remaining Life for the network is 9.98 years. This includes all pavement types and function classes. As with surface condition this number is not very useful by itself. And again, as with surface condition, followed over time it can give a good indication of how the network is performing. The following table gives Remaining Life averages for different groupings of roads.

	Average Remaining Life		
Function Class	**BST**	**ACP**	**PCCP**
14	13.4	10.9	15.6
16	12.6	13.4	16.0
17	12.5	13.4	-
7	8.6	10.5	-
8	9.4	11.4	-

Again, there are no outstanding trends in the data. It does appear that the urban roads in general (and in BST roads particularly) are stronger than the rural roads. Also, in the rural network ACP roads are fairing better than BST roads. The Remaining Life for each road segment is listed in the Appendix. The centerline miles in each category is shown below by pavement type.

	Remaining Life Range		
Pavement Type	**0-5**	**6-8**	**9-16**
ACP	60.81	34.64	276.09
BST	96.10	59.19	211.40
PCCP	-	-	3.90

And by function class

	Remaining Life Range		
Function Class	**0-5**	**6-8**	**9-16**
14	9.38	8.01	57.24
16	7.50	4.71	68.40
17	4.84	1.84	44.72
7	90.27	48.39	197.20
8	44.91	30.89	123.83

These tables are shown graphically in Figure 4. Figure 4 clearly shows that the urban network (FFC 14, 16, and 17) is in much better structural condition than the rural network. Also, the ACP roads are in significantly better structural condition than the BST roads.

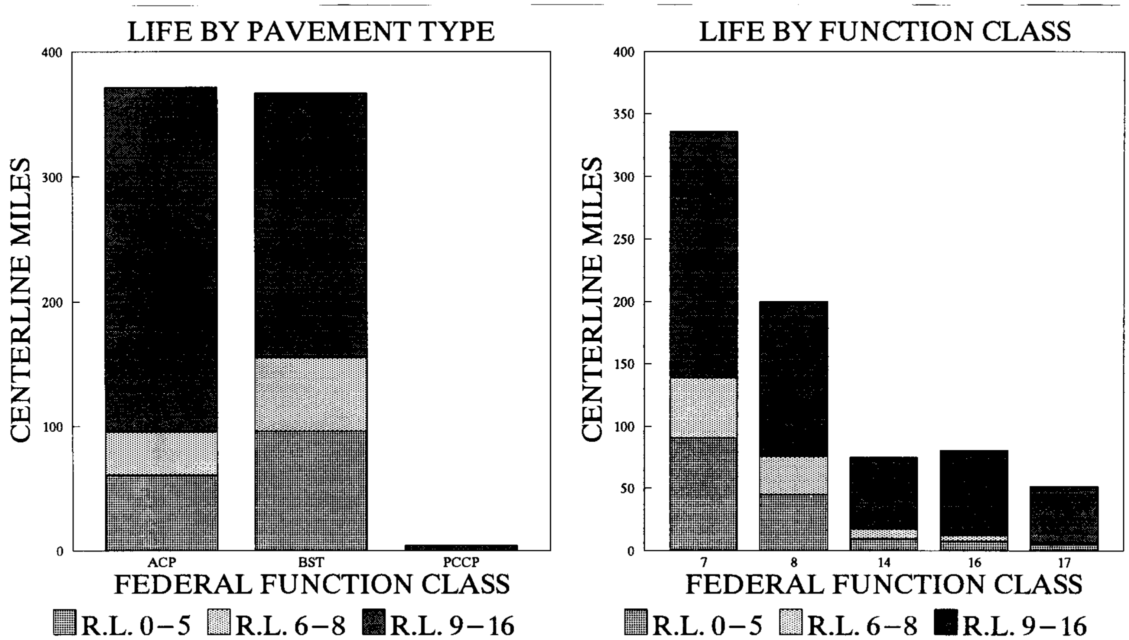


Figure 4

Finally, The total mileage of roads in need of treatment based on structural condition is

Treatment	Centerline Miles
Reconstruction/Major Repair	156.91
Structural Repair	93.83

Using this indicator 34% of the arterial network is in need of substantial repair.

Part IV Analysis and Conclusions

The first step in analyzing this information is to combine the structural and visual condition ratings. Figure 5 shows the break down of each PSC range within each Remaining Life range. While Remaining Life trends the same as PSC (that is the better the PSC the higher the percentage of the longer Remaining Life ranges) it is obvious that these indicators are measuring different aspects of pavement performance.

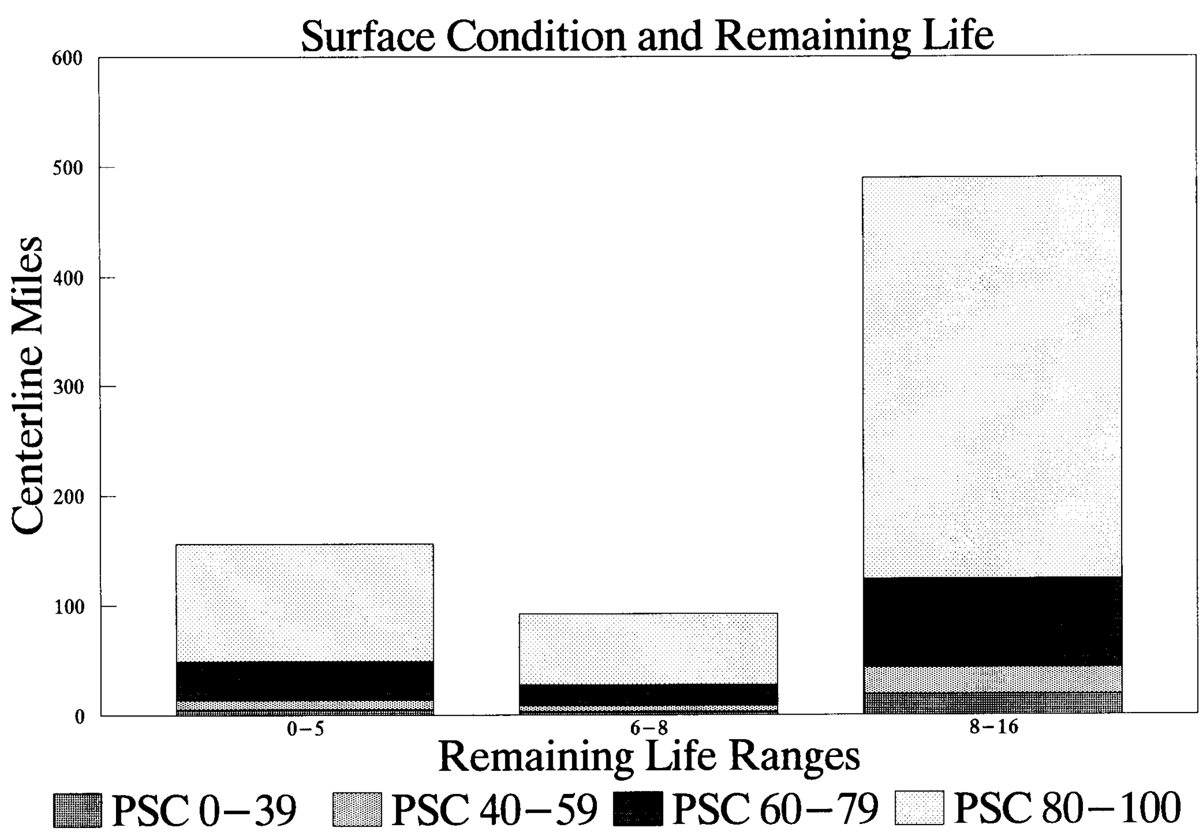


Figure 5

By measuring both structural condition and surface condition we are getting a more well rounded view of the roads by looking at both. It gives us a better idea of the rehabilitation that is (and will be) required for each segment of road. For example a segment that has a relatively low surface condition combined with a long remaining life does not need structural help but does require that the surface be sealed to keep water out of the substructure therefore a seal coat would be the best treatment. Conversely, a segment with high surface condition and low remaining life indicates a road that was not built adequately to carry the traffic load that it is carrying. This segment of road is in need of an overlay to add to its structural capacity.

Figure 6 shows Remaining Life ranges inside PSC ranges separated by pavement type for BST and ACP roads. Notice that these pavement types have almost identical surface condition as was shown in figure 3. It can also be seen that the remaining life for the BST pavements is significantly lower, particularly in the higher PSC ranges. This means that the BST roads are more fragile and potentially more expensive to maintain. This difference can be exacerbated by a maintenance strategy driven by reaction to surface defect. Using this strategy weak pavements are allowed to fail because little or no surface indication appears before serious structural failure occurs. If this happens then rehabilitation is much more expensive and, because there is no warning, the costs could not be predicted and a large backlog of work could result.

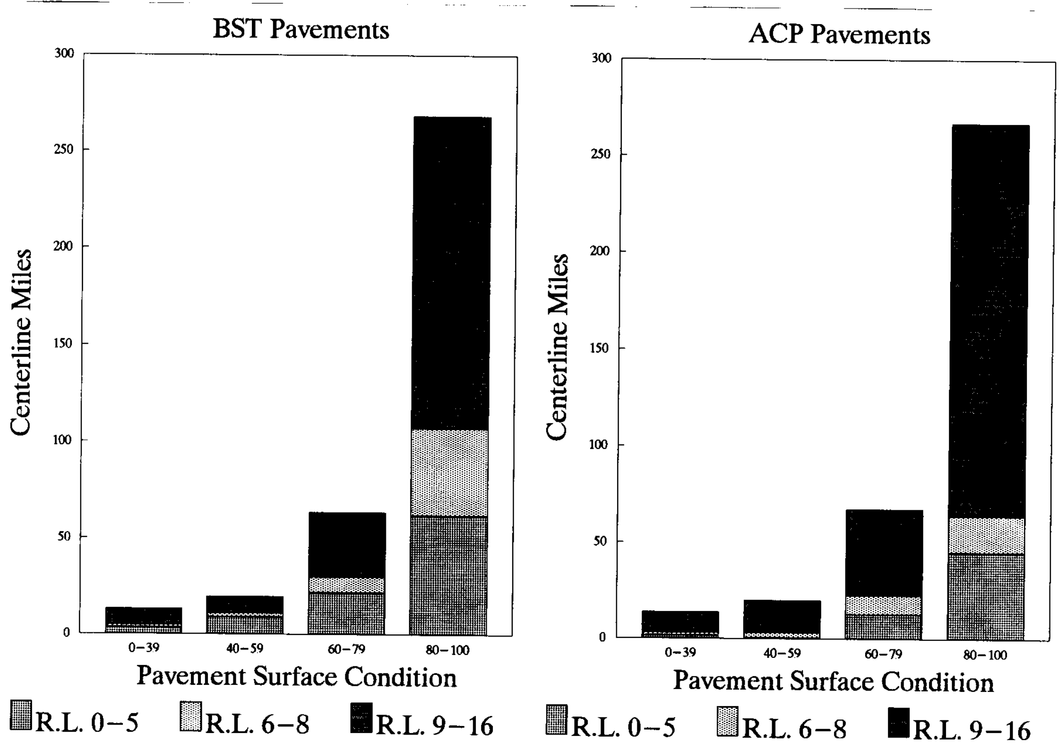


Figure 6

Conclusions

Through both surface condition and structural condition indicators the following miles of road need maintenance or rehabilitation treatments

Minor Repair	73.4 miles
Major Repair	49.7 miles
Structural Repair/Reconstruction	184.0 miles

This translates to 38% of the arterial network in need of some sort of repair and 23 % in need of structural strengthening. Figure 7 shows this graphically.

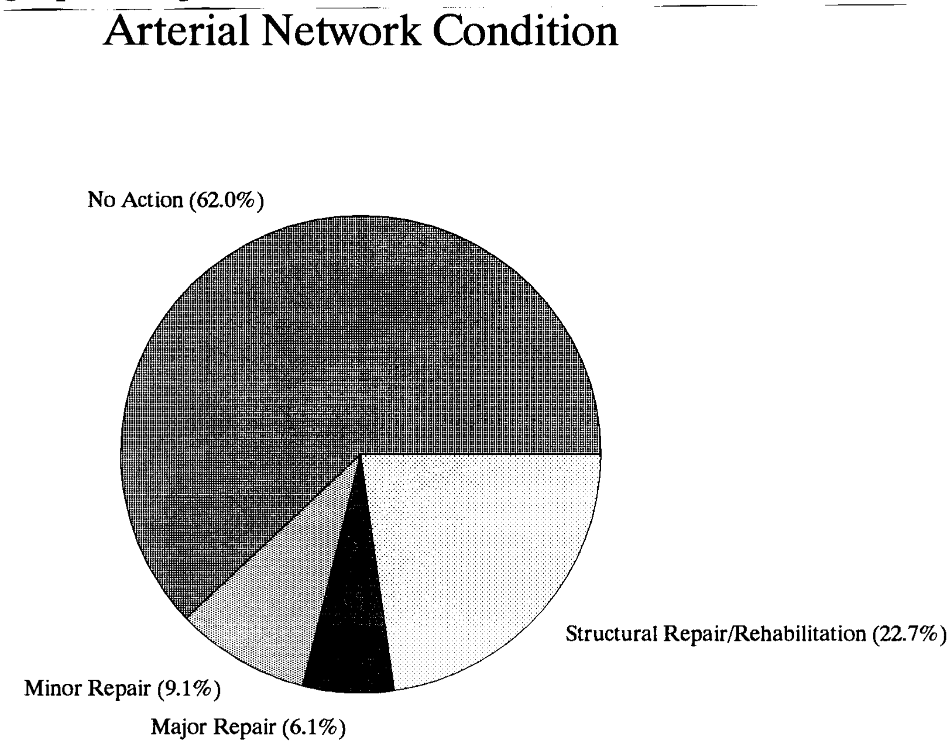


Figure 7

Surface type seems to play an important role in the arterial networks predicted remaining life. Network wide analysis shows the BST roads to have significantly shorter life expectancy than the ACP roads. The reasons for this are many, the most obvious being that most of our BST roads are built-up, more or less evolving into their present state while our ACP roads have a constructed structural section. Combine this with rapidly increasing loads on the semi-rural and rural roads and we get limited structural life. The danger is if we ignore these indications and do not add strength to these segment they will fail rapidly requiring more expensive repair, increased maintenance and reduced utility to the public.

7. Spokane County Checklist for Road Rater

In order to ensure consistent and reliable collection of structural testing information using a Road Rater, Spokane County developed the following checklist for equipment operators.

Daily Calibration

1. Perform a walk-around inspection of the Road Rater.
   - ❒ Check trailer connections.
   - ❒ Check all lights on the Road Rater and towing vehicle.
   - ❒ Check the Road Rater's sensors, sensor wires, and micro switches; check for leaks from the hydraulics; check the tires; etc.
2. Start towing vehicle and Road Rater.
   - ❒ Warm up the Road Rater.
   - ❒ Position locking safety pins in the out position.
   - ❒ Hook up sensor boom
   - ❒ Fill air springs to 40 - 45 PSI.
   - ❒ Get computer from office and hook it up in the towing vehicle.
   - ❒ Turn on power converter.
3. Go to calibration area.
   - ❒ Set up files in the computer (single force and multi force programs).
     - Single force (4 tests at 1.2 kips)
     - Multi force (4 tests each at 0.6, 1.2, 2.0, and 3.0 kips)

Caution: Before Taking Any Tests Make Sure That Pins Are Out

4. Perform daily calibration testing.
   - ❒ 4 tests at each load level.
   - ❒ Watch and listen to performance of the Road Rater; pay close attention to the computer screen; watch how the tests are performing.
   - ❒ Pay attention to both the bar graph and the numbers.
5. Move out of the calibration site.
   - ❒ Turn off motor to the Road Rater.
   - ❒ Reduce Road Rater data into Lotus 123 spreadsheets and check calibration of sensors. If sensors are out by 0.03 Mils or greater between tests, testing can't proceed. Fix the problem and repeat daily calibration procedure.
   - ❒ Start the Road Rater.

- ❒ Lower mast and remove sensor boom, then mount the boom on the trailer area of the Road Rater.

Caution: Make Sure That Boom Is Securely Mounted

- ❒ Elevate the boom back to the up position and turn off the motor.
- ❒ Set pins in and close doors to the Road Rater.

Field Testing

6. Drive to test site.
    - ❒ Turn on power convertor and computer.
    - ❒ Set up computer for road to be rated (Spokane County tests at 1/10 mile segments at 1.2 kips)
    - ❒ Start the Road Rater.

    Caution: **Remove Pins**

    - ❒ Install the sensor boom.
7. ***Caution:*** While testing always be aware of when the sensor bar has contact with the surface. It is advisable to wait until the alarm has quit sounding and you hear the mast seat to the up position before proceeding. It is recommended that you also take your foot off the brake before accelerating to insure that the Road Rater feet are clear of the surface. Remember, if your feet are still in contact with the surface and the alarm has quit, this could indicate that the up micro switch is faulty.
8. Perform load cell calibration.
    - ❒ Start the Road Rater motor.
    - ❒ Open control box on the Road Rater.
    - ❒ Short out mass by grounding TO #3 in the control box on the Road Rater.
    - ❒ Connect leads from an accurate volt meter to the pin locations on the circuit board.
    - ❒ Read volt meter with shunt off and with shunt on and record readings.
    - ❒ Take off the leads from the volt meter and remove short.
    - ❒ Make sure that you return the shunt to the off position.
    - ❒ Check readings to insure that they are in accordance with the manufacturer’s specifications. If they are not, refer to the manual or contact the manufacturer for further assistance.

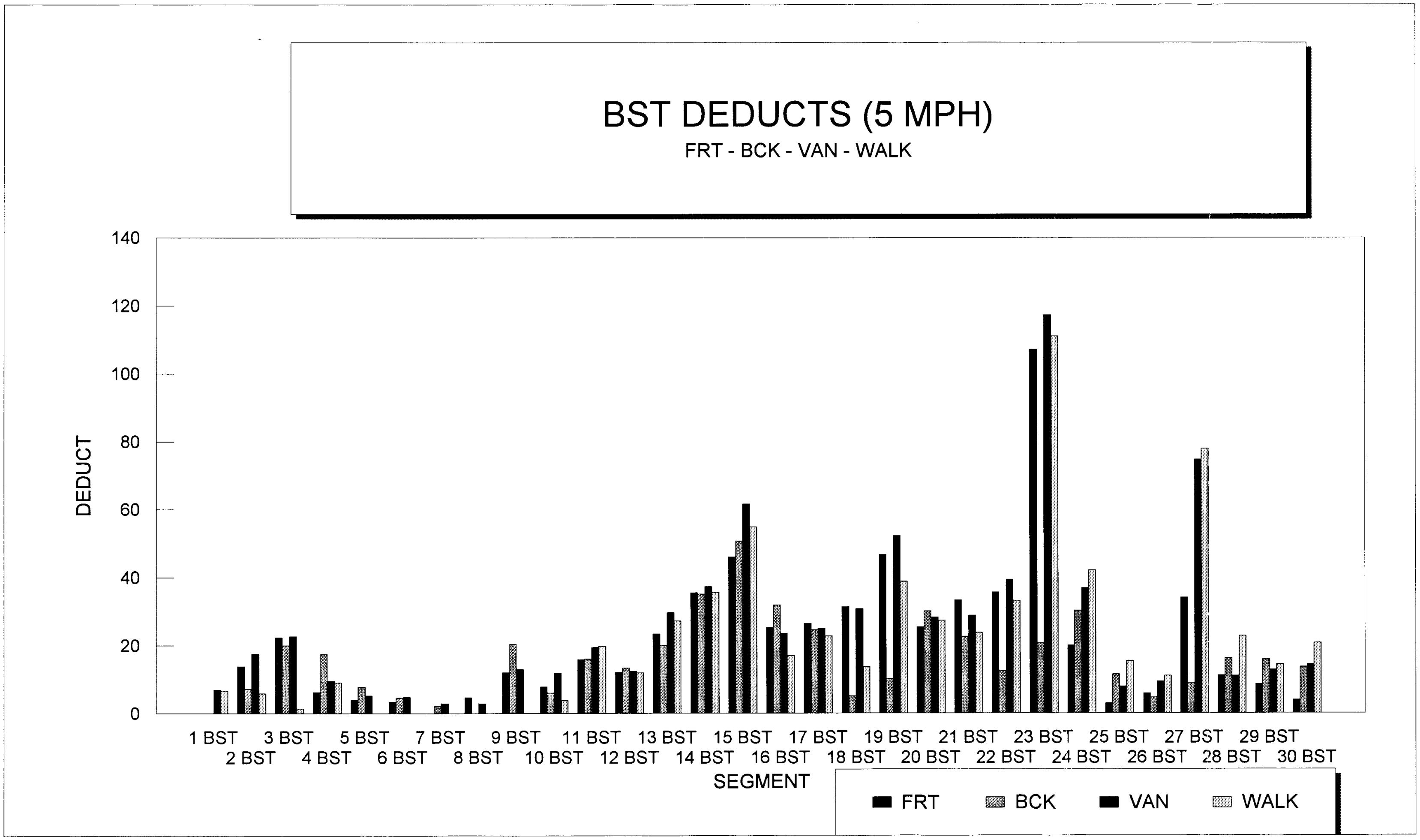
9. Perform sensor calibration.
   - ❒ Remove all sensors from the sensor bar.
   - ❒ Put in one sensor at a time into the calibration jib, using the #1 output for the control and the #2 output for the calibrated sensor.
   - ❒ Test each sensor 10 times at 3 force levels. (1.2, 2.0, 3.0)
   - ❒ After testing all sensors, reinstall all sensors back onto the boom in their correct order (make sure you put back all sensor cables back into their appropriate output on the control box and reset each sensor's appropriate Sensmult values into the computer).

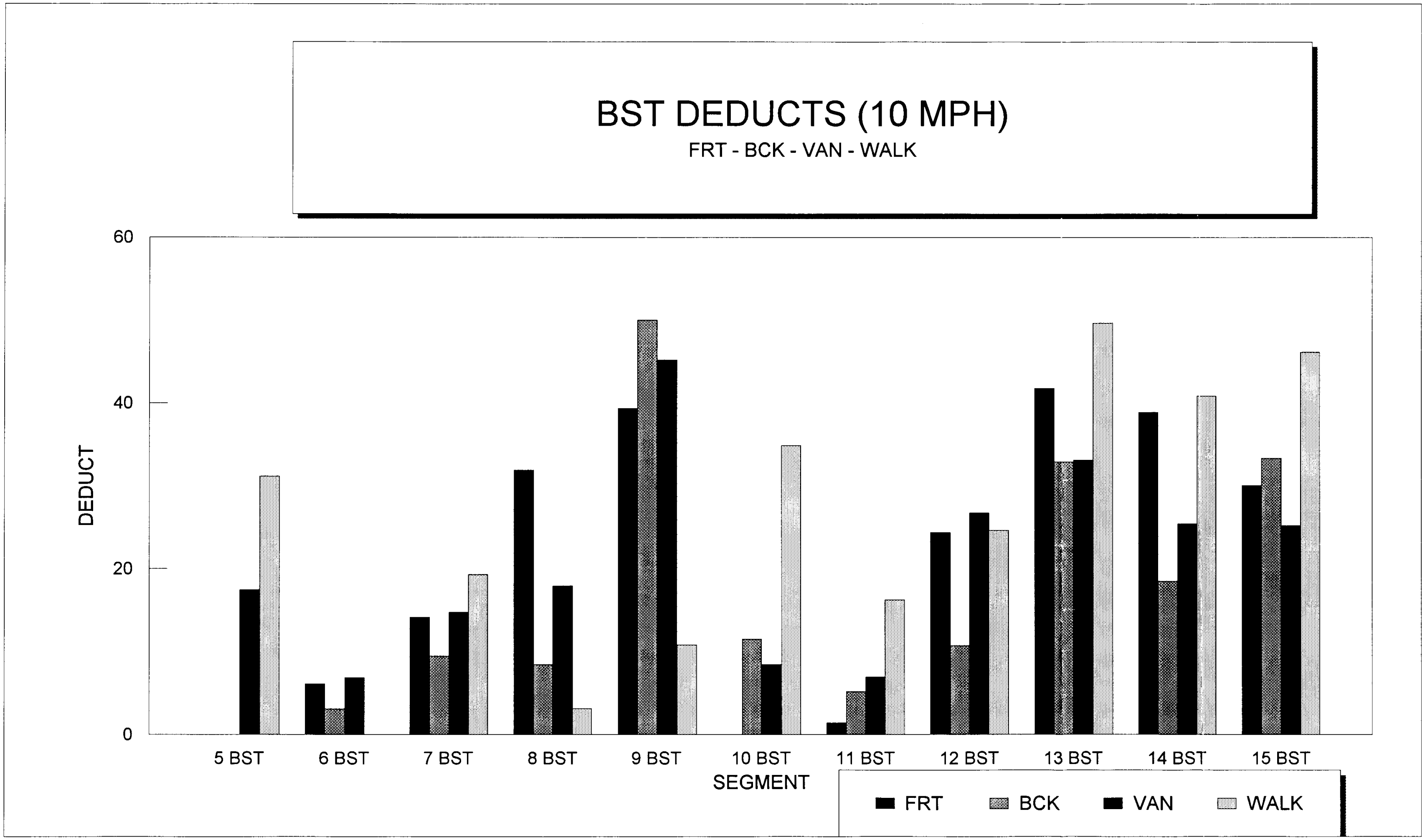
   Note: When you resume regular testing, you may want to delete your config files; they will automatically be created when testing is performed.

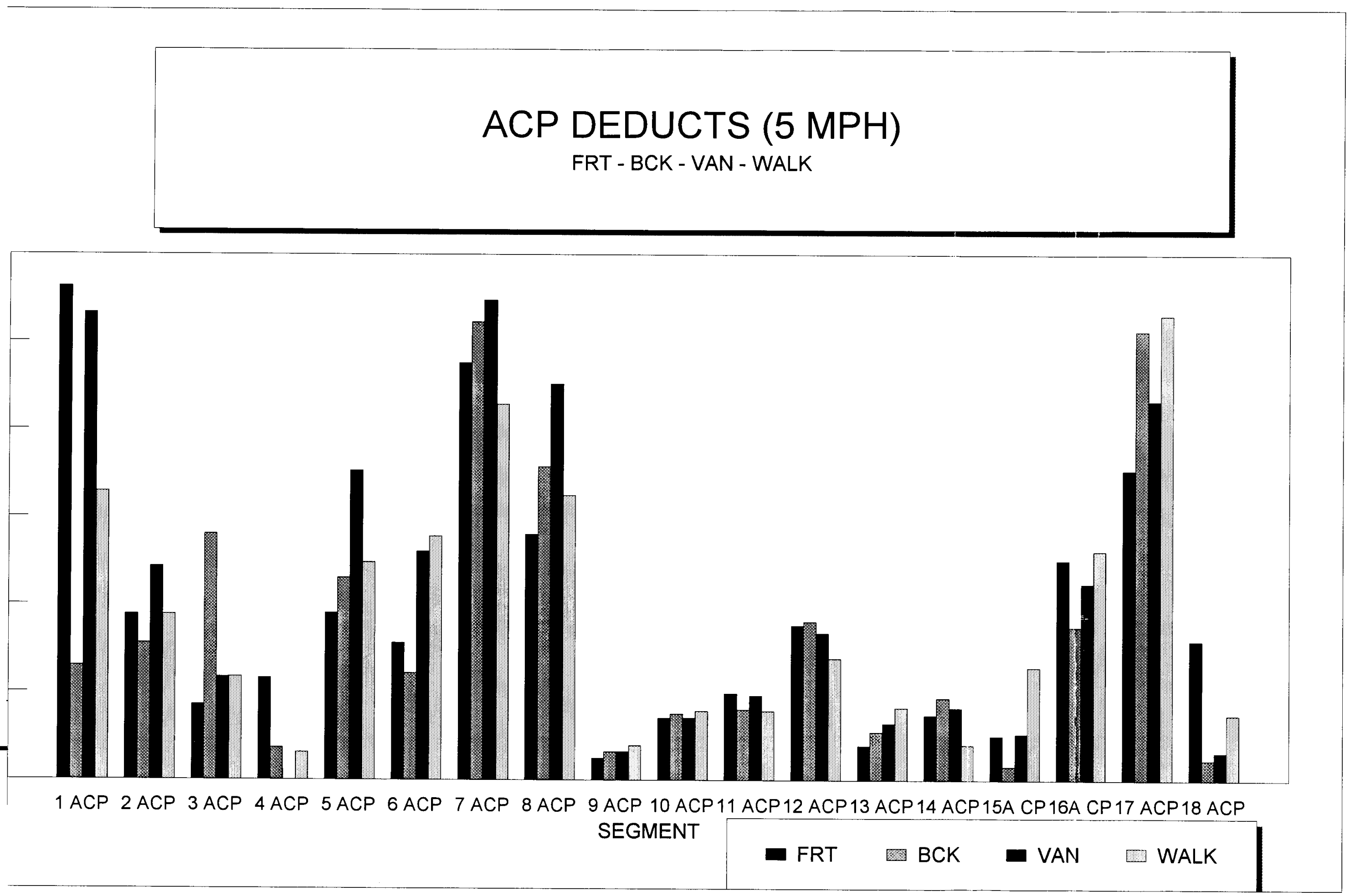
Data Reduction

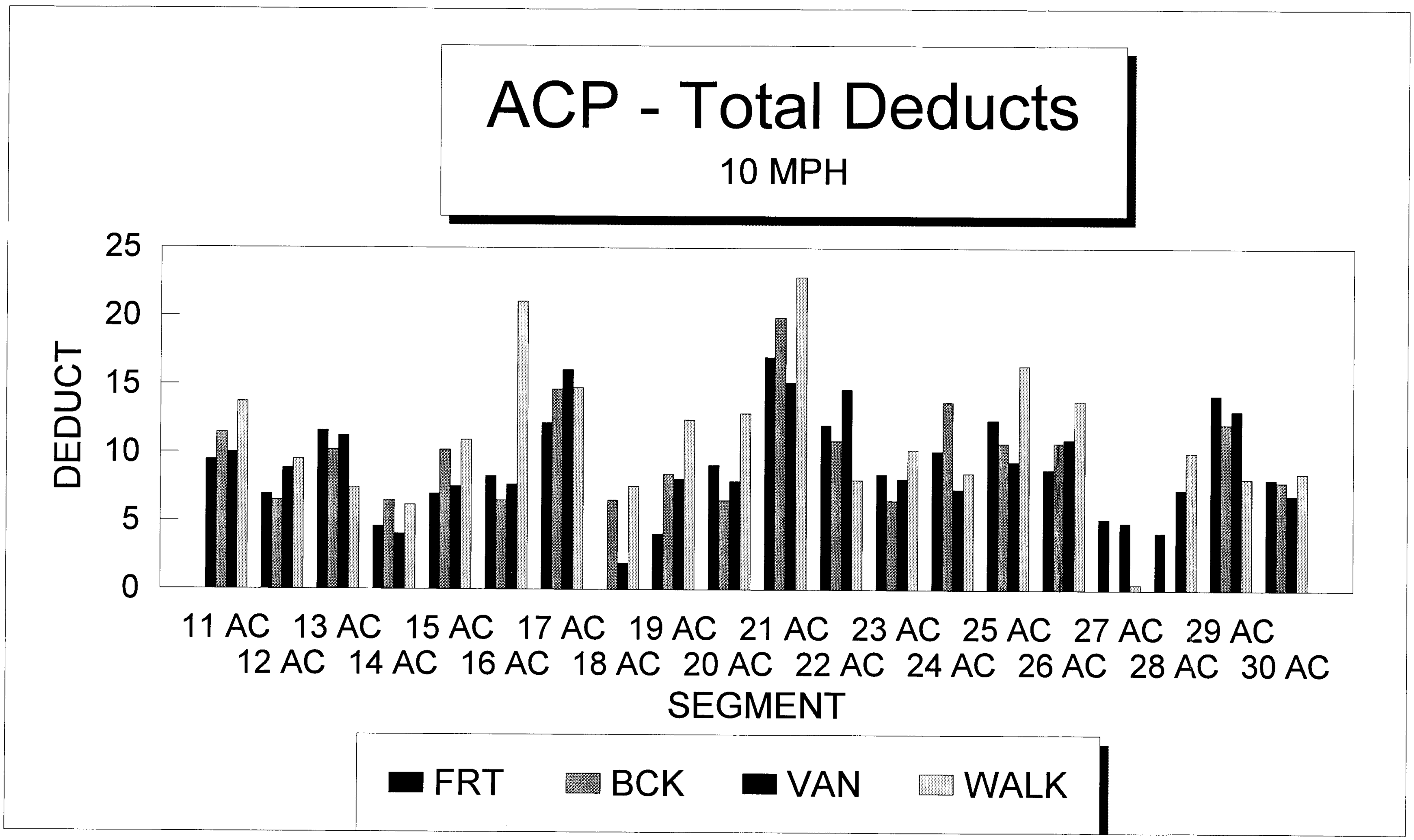
Date is reduced in a Lotus 123 spreadsheet, which is used to analyze the data to insure machine and sensor calibration.

8. Spokane County Visual Rating Comparison Graphs



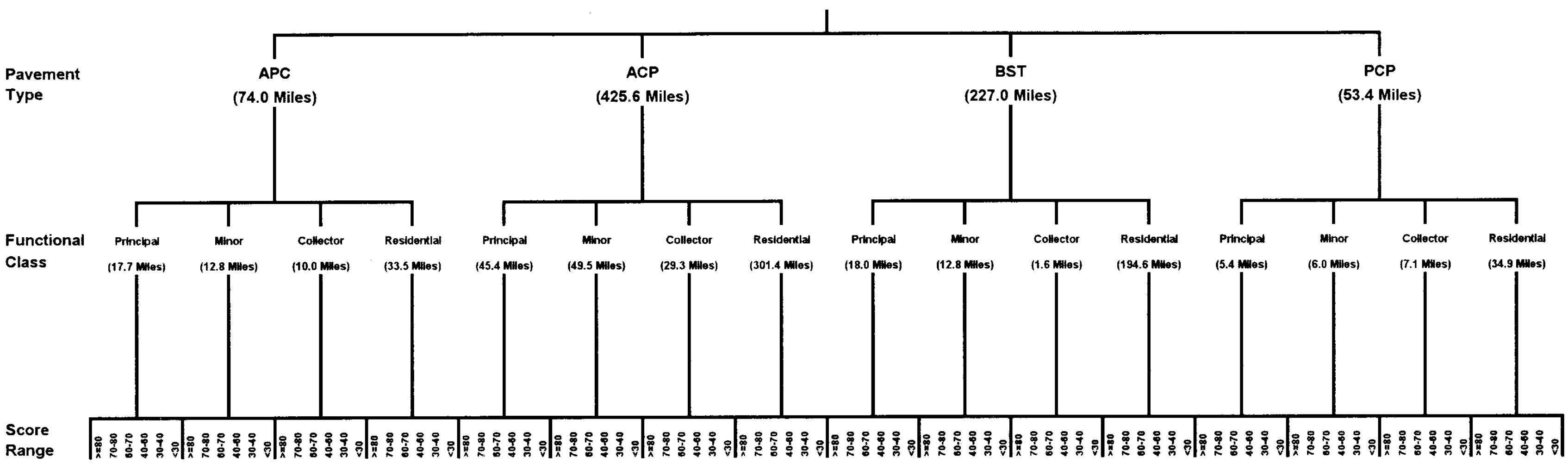

BST DEDUCTS (10 MPH)
FRT - BCK - VAN - WALK
DEDUCT
0
20
40
60
5 BST
6 BST
7 BST
8 BST
9 BST
10 BST
11 BST
12 BST
13 BST
14 BST
15 BST
SEGMENT
FRT
BCK
VAN
WALK


ACP DEDUCTS (5 MPH)
FRT - BCK - VAN - WALK
1 ACP
2 ACP
3 ACP
4 ACP
5 ACP
6 ACP
7 ACP
8 ACP
9 ACP
10 ACP
11 ACP
12 ACP
13 ACP
14 ACP
15A CP
16A CP
17 ACP
18 ACP
SEGMENT
FRT
BCK
VAN
WALK


ACP - Total Deducts
10 MPH
DEDUCT
25
20
15
10
5
0
11 AC
12 AC
13 AC
14 AC
15 AC
16 AC
17 AC
18 AC
19 AC
20 AC
21 AC
22 AC
23 AC
24 AC
25 AC
26 AC
27 AC
28 AC
29 AC
30 AC
SEGMENT
FRT
BCK
VAN
WALK

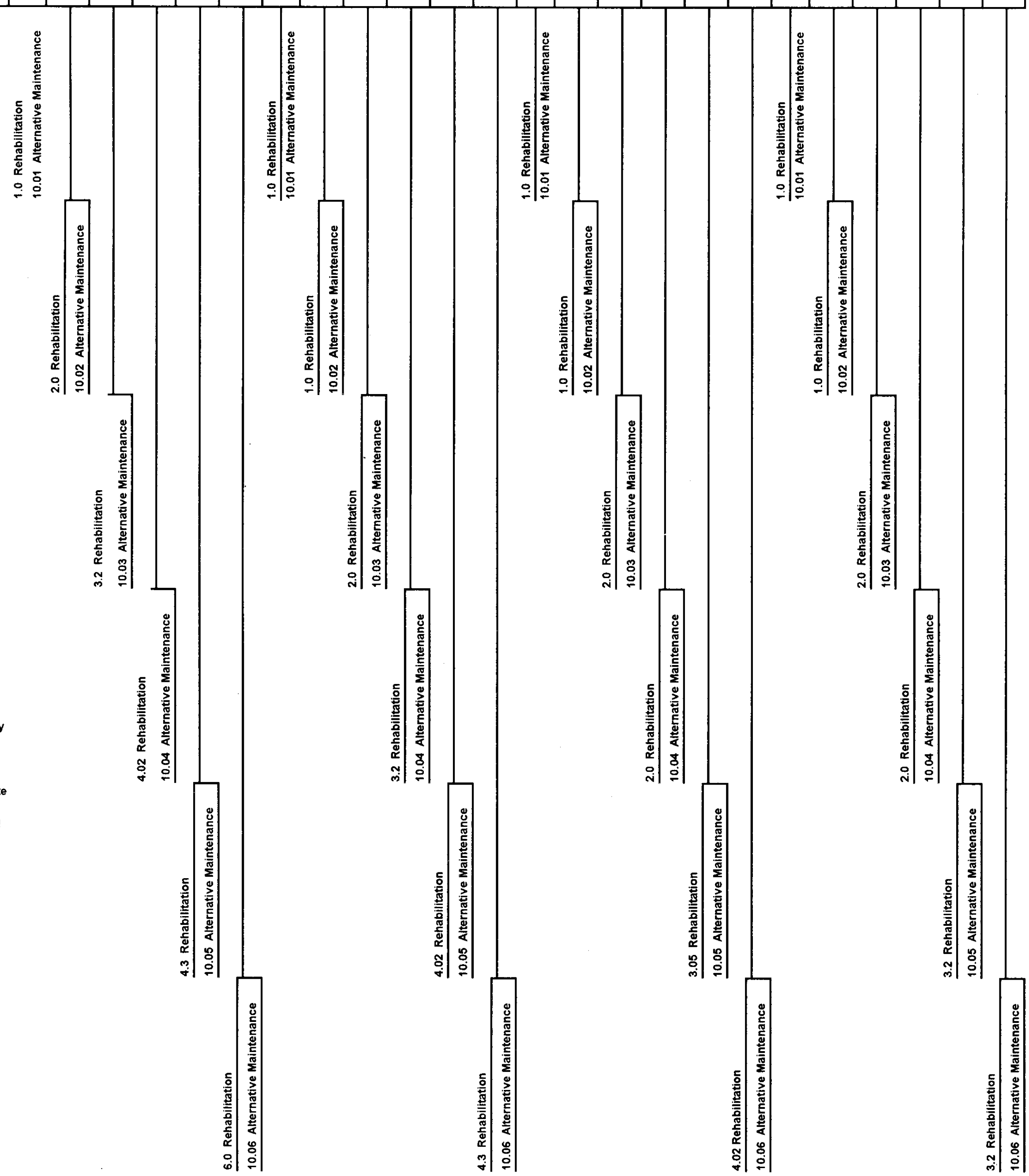
9. City of Tacoma PMS Score Driven Decision Tree

City of Tacoma
PMS Score Driven Decision Tree



ACP
Asphalt Concrete
(425.6 Miles)

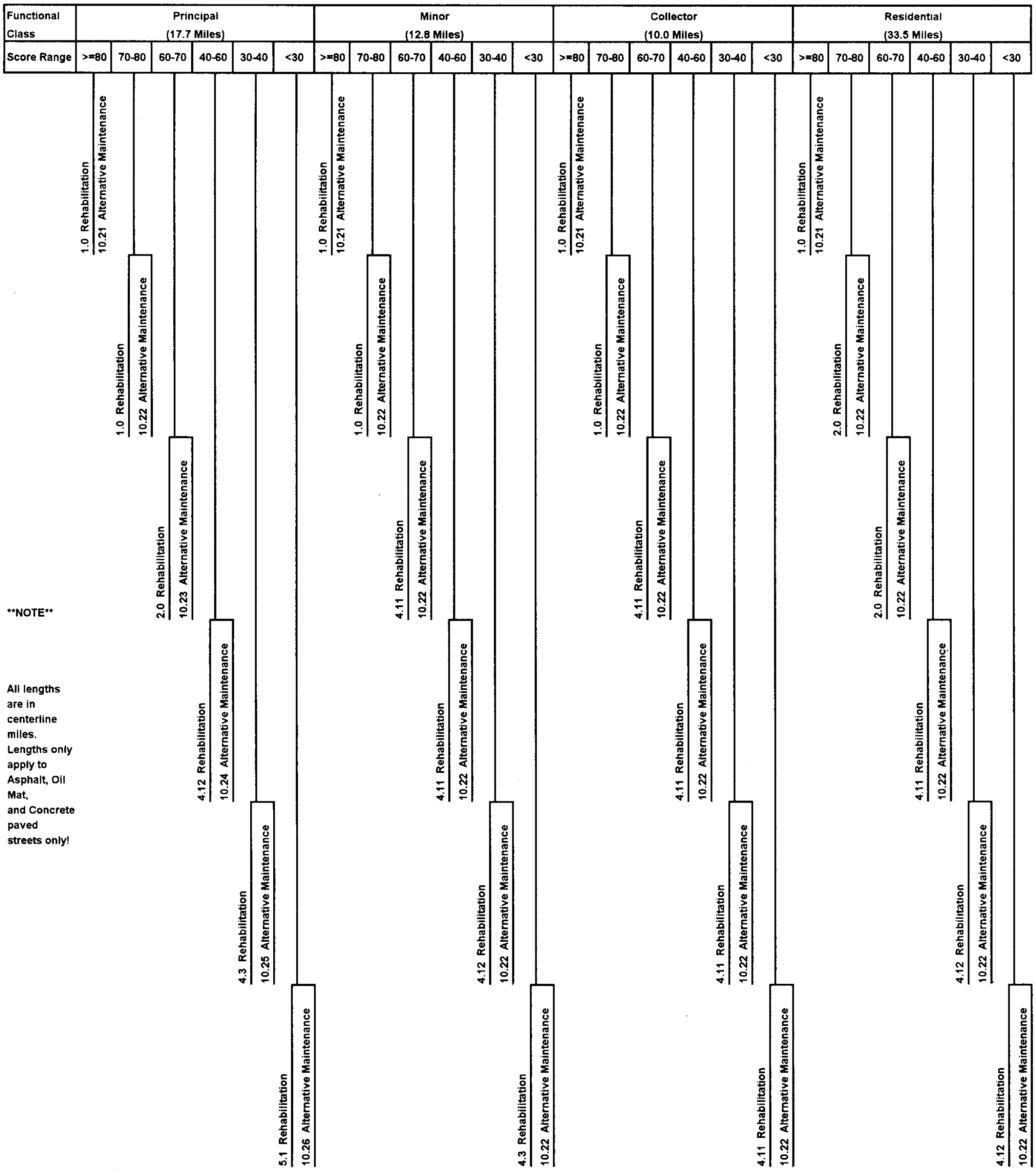
Functional Class	Principal (45.4 Miles)						Minor (49.5 Miles)						Collector (29.3 Miles)						Residential (301.4 Miles)					
Score Range	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30



NOTE

All lengths are in centerline miles. Lengths only apply to Asphalt, Oil Mat, and Concrete paved streets only!

APC
Asphalt over Concrete
(74.0 Miles)

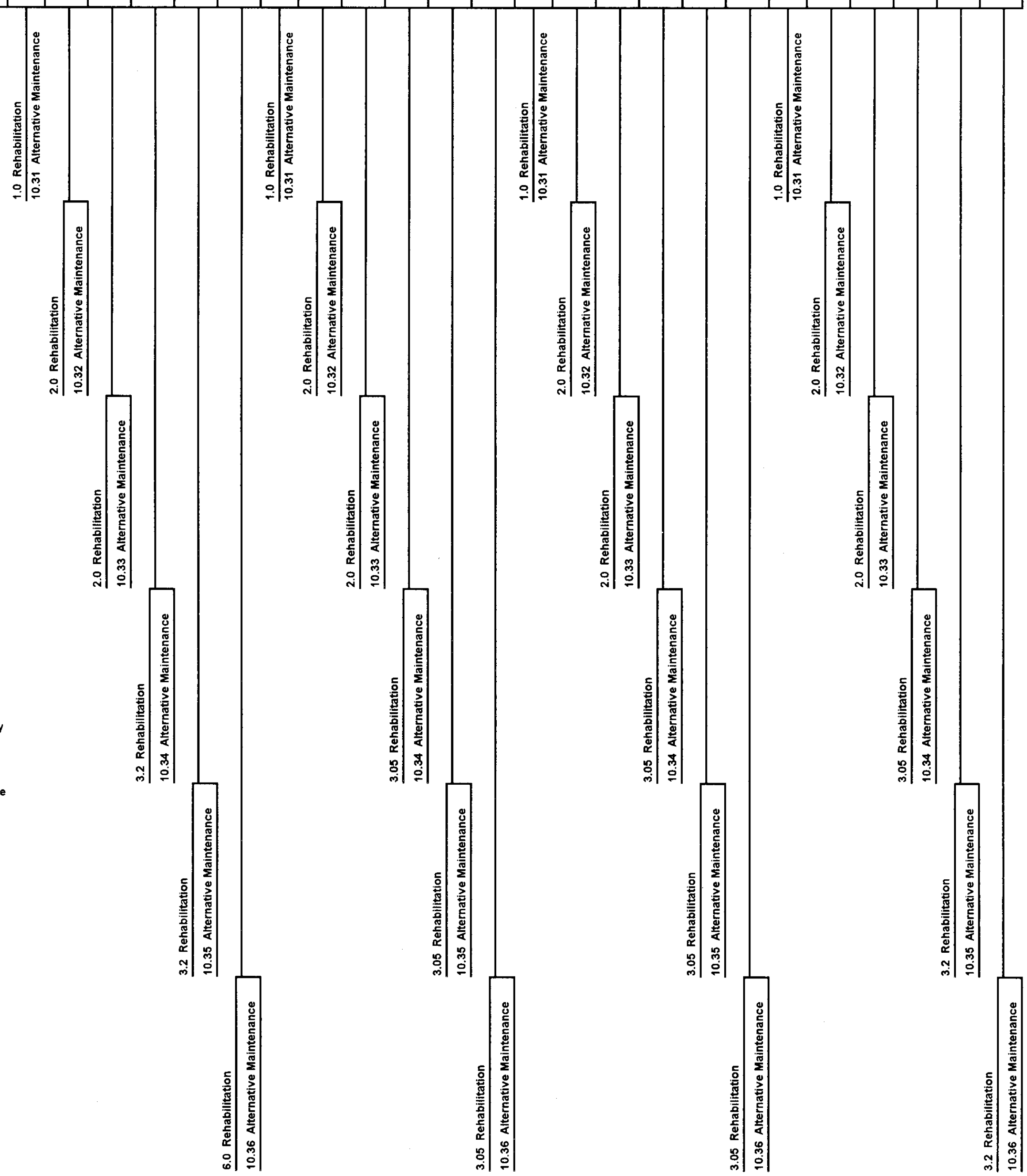


NOTE

All lengths are in centerline miles. Lengths only apply to Asphalt, Oil Mat, and Concrete paved streets only!

BST
Bituminous Surface Treatment
(227.0 Miles)

Functional Class	Principal (18.0 Miles)						Minor (12.8 Miles)						Collector (1.6 Miles)						Residential (194.6 Miles)					
Score Range	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30

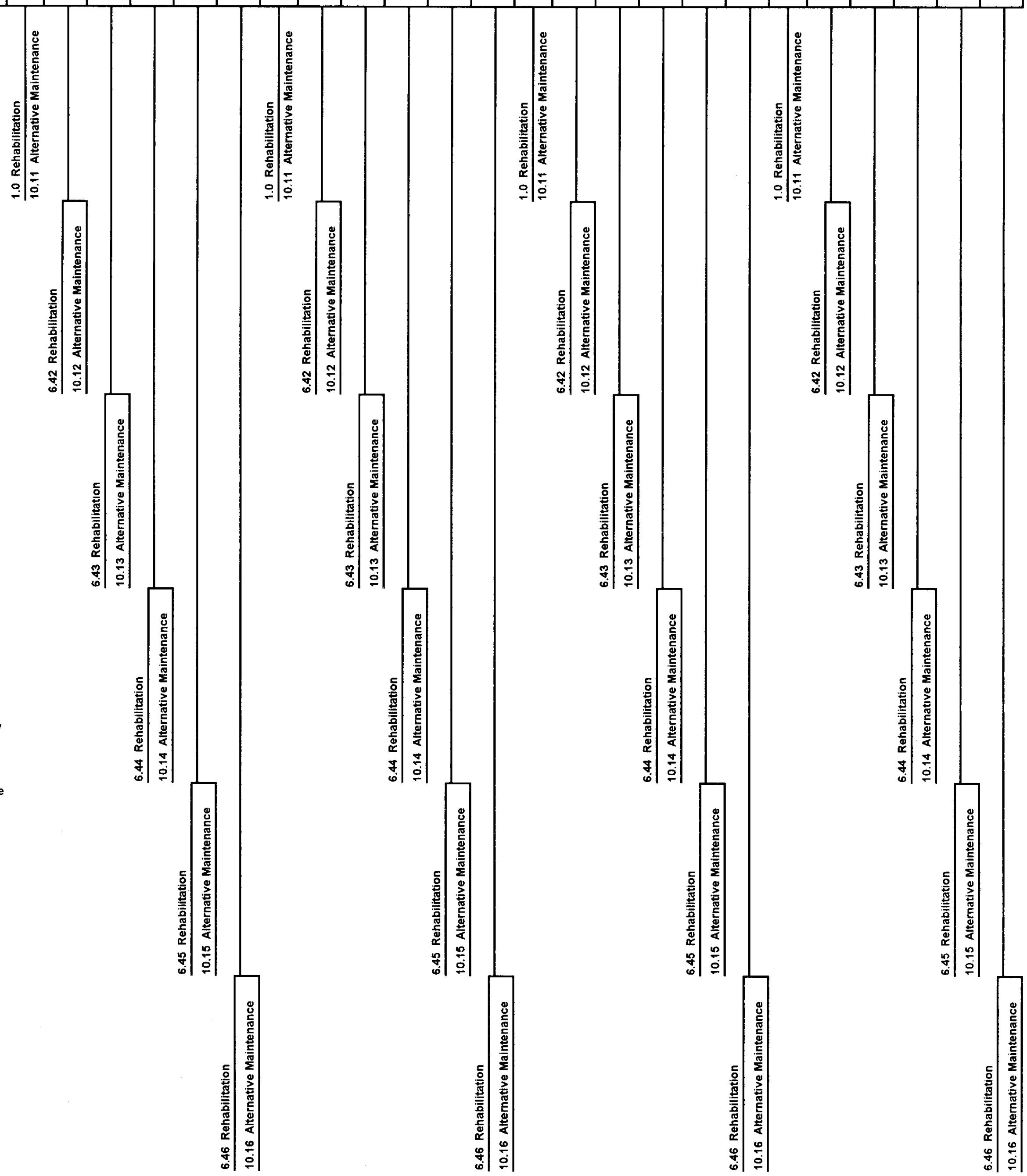


****NOTE****

All lengths are in centerline miles. Lengths only apply to Asphalt, Oil Mat, and Concrete paved streets only!

PCP
Portland Cement Concrete
(53.4 Miles)

Functional Class	Principal (5.4 Miles)						Minor (6.0 Miles)						Collector (7.1 Miles)						Residential (34.9 Miles)					
Score Range	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30	>=80	70-80	60-70	40-60	30-40	<30



NOTE

All lengths are in centerline miles. Lengths only apply to Asphalt, Oil Mat. and Concrete paved streets only!

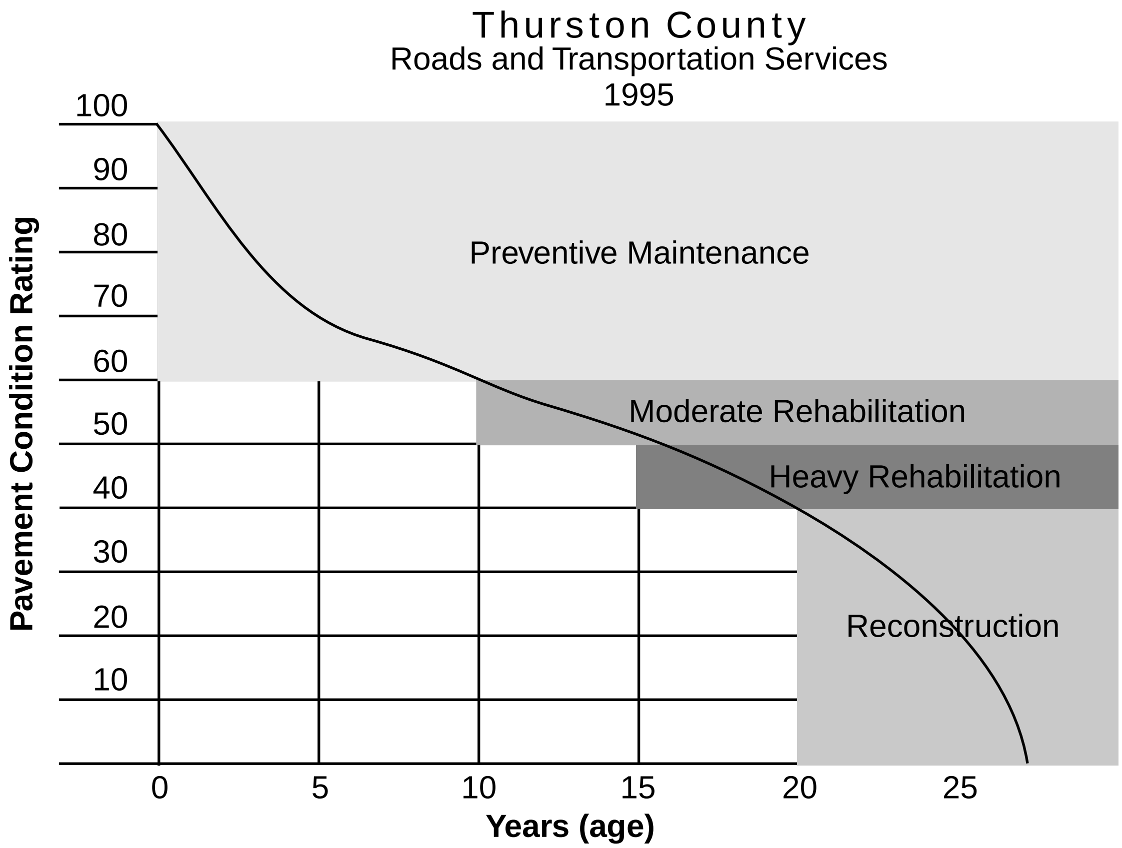
Definition of Numbers on Decision Tree

ID	Description	Unit Cost	Unit Meas	Must Life	Max. Score	Thick-ness	Grade Change	MR Fg
1.0	ROUTINE MAINTENANCE PCR 100	0.10	SY	6	100	0.0	0	Y
1.1	CRACK SEALING	0.30	LF	3	100	0.0	0	Y
1.11	CRACK SEAL + ROUTING	1.00	LF	5	100	0	0	Y
1.2	PATCHING — TEMPORARY	5.00	SY	1	100	0.0	0	Y
1.3	PATCHING — SKIN	8.00	SY	4	100	1.0	0	Y
1.4	PATCHING — DIGOUT	13.00	SY	8	100	4.0	0	Y
1.5	BLADE PATCHING	6.00	SY	4	100	1.0	1.0	Y
1.6	EDGE PATCHING	4.00	LF	4	100	0	0	Y
1.7	GRADE SHOULDERS	.10	LF	1	100	0	0	Y
2.0	SINGLE CHIP SEAL	.75	SY	7	100	.5	.50	Y
2.1	DOUBLE CHIP SEAL	1.90	SY	9	100	.75	.5	Y
2.15	OIL MAT/NATIVE — RES	3.00	SY	9	100	.75	.75	Y
2.2	SLURRY SEAL	1.00	SY	9	100	0.25	0.25	Y
2.3	FOG SEAL	0.35	SY	2	100	0.0	0	Y
2.4	CAPE SEAL	1.90	SY	10	100	0.3	.3	Y
2.6	SAND SEAL	0.50	SY	3	100	0	0	Y
3.0	THIN OVERLAY	5.50	SY	15	100	2.0	2	N
3.05	BASE STAB & DOUBLE CHIP SEAL	3.25	SY	18	100	1.0	1	N
3.1	THIN OVERLAY W/FABRIC + MILL	6.80	SY	16	100	2.0	0	N
3.2	BASE STAB & THIN OVERLAY	5.25	SY	20	100	2.0	2	N
3.3	THIN OVERLAY W/FABRIC + MILL	6.80	SY	16	100	2.0	2	N
3.4	THIN OVERLAY W/HEATER SCARIFY	5.00	SY	16	100	2.0	2	N
4.0	STRUCTURAL OVERLAY	7.50	SY	17	100	3.0	3	N
4.01	STR. OVERLAY — RES	5.00	SY	20	100	3.0	3	N
4.02	STR. OVERLAY — ART	6.00	SY	20	100	3.0	3	N
4.1	STR. OVERLAY W/MILL OR CRK RP	9.50	SY	18	100	3.0	0	N
4.11	STR. OVERLAY — RES. W/GRIND	8.00	SY	22	100	3.0	0	N
4.12	STR. OVERLAY — ART. W/GRIND	9.00	SY	22	100	3.0	0	N
4.2	STR. OVERLAY W/FABRIC	8.00	SY	18	100	3.0	3	N
4.3	STR. OVERLAY W/FABRIC + MILL	10.00	SY	18	100	3.0	0	N
5.0	THICK OVERLAY	10.00	SY	17	100	4.0	4	N
5.1	THICK OVERLAY W/MILL OR CRK R	13.00	SY	20	100	4.0	0	N
5.2	THICK OVERLAY W/FABRIC	12.00	SY	20	100	4.0	4	N
5.3	THICK OVERLAY W/FABRIC + MILL	18.30	SY	20	100	4.0	0	N
6.0	RECONSTRUCT WITH NEW BASE	30.00	SY	20	100	4.0	0	Y
6.1	IN-PLACE RECYCLE & OVERLAY	12.00	SY	20	100	4.0	0	N
6.2	INPLACE RECYCLING	20.00	SY	5	100	2	0	N
6.4	PCC — PANEL REPLACEMENT	2.0	SY	50	100	8	0	N
6.42	PCC — PANEL REPL. 85-70	4.00	SY	50	100	8	0	N
6.43	PCC — PANEL REPL. 70-55	6.00	SY	50	100	8	0	N
6.44	PCC — PANEL REPL. 55-40	8.00	SY	50	100	8	0	N
6.45	PCC — PANEL REPL. 40-25	10.00	SY	50	100	8	0	N

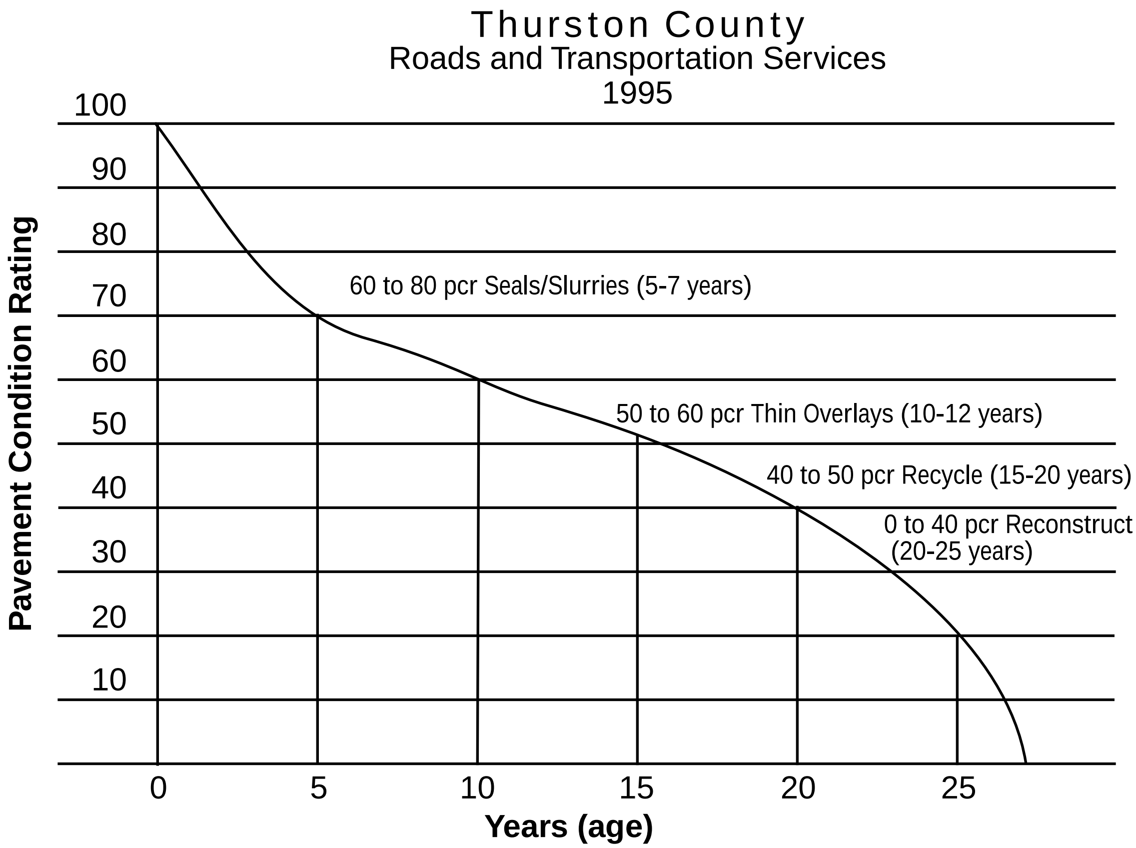
ID	Description	Unit Cost	Unit Meas	Must Life	Max. Score	Thick-ness	Grade Change	MR Fg
6.46	PCC PANEL REPL. 25-0	12.00	SY	50	100	8	0	N
6.5	PCC — RECONSTRUCT – 8 ≤	35.00	SY	50	100	8.0	0	N
6.6	PCC — RECONSTRUCT – 12<	45.00	SY	60	100	12	0	N
6.8	BST — REPLACEMENT COST	10.00	SY	10	100	12	0	N
6.9	GRV — REPLACEMENT COST	5.00	SY	1	100	6	0	N
9.0	CL A CALCULATED OVERLAY — COS	1.00	0.5≤	12	100		N	
9.1	CL B CALCULATED OVERLAY — COS	1.00	0.5≤	12	100		N	
9.2	CL C CALCULATED OVERLAY — COS	1.00	0.5≤	12	100		N	
9.3	CL D CALCULATED OVERLAY — COS	1.00	0.5≤	12	100		N	
10.01	ALT. MAINT. ACP PCR 100-85	0.01	SY	6	100	0	0	Y
10.02	ALT. MAINT. ACP PCR 85-70	0.09	SY	5	100	0	0	Y
10.03	ALT. MAINT. ACP PCR 70-55	0.29	SY	4	80	0	0	Y
10.04	ALT. MAINT. ACP PCR 55-40	0.49	SY	6	100	0	0	Y
10.05	ALT. MAINT. ACP PCR 40-25	2.41	SY	2	60	0	0	Y
10.06	ALT. MAINT. ACP PCR 25-0	1.69	SY	2	50	0	0	Y
10.11	ALT. MAINT. PCC PCR 100-85	0.00	SY	6	100	0	0	Y
10.12	ALT. MAINT. PCC PCR 85-70	0.00	SY	5	90	0	0	Y
10.13	ALT. MAINT. PCC PCR 70-55	0.30	SY	4	80	0	0	Y
10.14	ALT. MAINT. PCC PCR 55-40	0.50	SY	3	70	0	0	Y
10.15	ALT. MAINT. PCC PCR 40-25	1.00	SY	2	60	0	0	Y
10.16	ALT. MAINT. PCC PCR 25-0	1.50	SY	2	50	0	0	Y
10.21	ALT. MAINT. APC PCR 100-85	0.00	SY	6	100	0	0	Y
10.22	ALT. MAINT. APC PCR 85-70	0.00	SY	5	90	0	0	Y
10.23	ALT. MAINT. APC PCR 70-55	0.30	SY	4	80	0	0	Y
10.24	ALT. MAINT. APC PCR 55-40	0.50	SY	3	70	0	0	Y
10.25	ALT. MAINT. APC PCR 40-25	1.00	SY	2	60	0	0	Y
10.26	ALT. MAINT. APCC PCR 25-0	1.50	SY	2	50	0	0	Y
10.31	ALT. MAINT. BST PCR 100 — 85	0.00	SY	6	100	0	0	Y
10.32	ALT. MAINT. BST PCR 85-70	0.00	SY	5	90	0	0	Y
10.33	ALT. MAINT. BST PCR 70-55	0.10	SY	4	80	0	0	Y
10.34	ALT. MAINT. BST PCR 55-40	0.25	SY	3	70	0	0	Y
10.35	ALT. MAINT. BST PCR 40-25	0.50	SY	2	60	0	0	Y
10.36	ALT. MAINT. BST PCR 25-0	0.75	SY	2	50	0	0	Y

10. Thurston County Graphs on PMS Cost Effectiveness

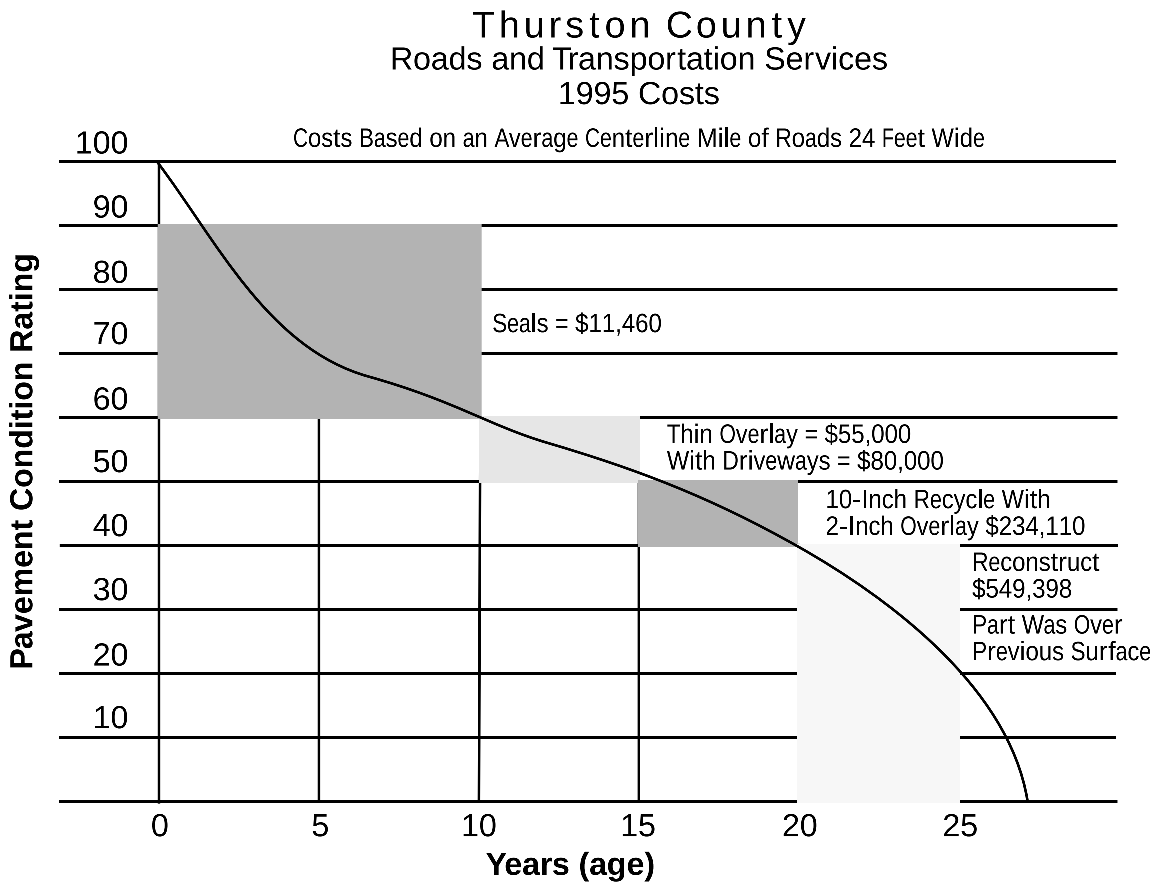
The graphs illustrate the basic premise of pavement management: if a pavement is allowed to deteriorate past a certain point in its life-cycle, it will cost much more to repair than if it had been corrected earlier. During the presentation, the following graph is shown first. It shows the type of repair that is appropriate for different pavement condition ratings.



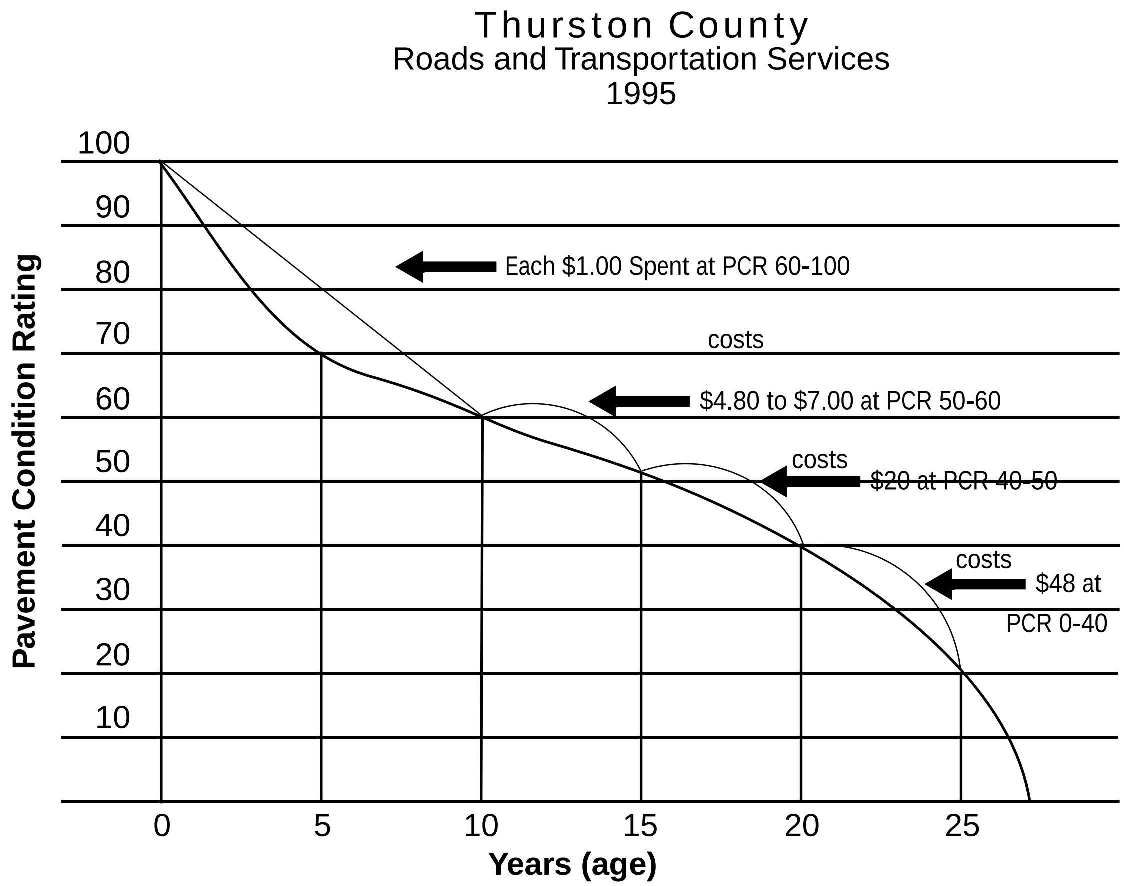
The following graph provides specific examples of the types of repair that are appropriate in each of the condition ranges. For example, for pavements with a rating between 60 and 100, preventive maintenance activities such as seals and slurries are appropriate. This graph could be accompanied with photographs of pavements in different condition levels to help the audience understand what the different ratings really mean.



The county now puts some actual numbers on the graph to bring the presentation from the theoretical down to reality. It shows the costs (average centerline mile, 24-foot wide road) of the different repair types. This graph, which follows, uses actual construction cost data compiled by Thurston County.



The final graph, shown on the next page, distills all the information previously presented into a straightforward format. It shows the relative amount spent for repair at the different condition levels. For example, $1 spent early in the pavement's life-cycle is compared with the $48 needed at the end of the pavement's life-cycle.



Note that Thurston County used a generic performance curve to develop its presentation materials. Performance curves based upon actual condition data over time would provide an even stronger case for pavement management and its benefits.

14:P:DP/PMAG

Table 5.1. — Prioritized Repair Alternatives

Low and Moderate Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Alligator Cracking	Localized	Low	1 Crack Seal 2. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. Crack Seal 2. Chip Seal 3. Patch
		Medium	1. Surface Recycle[1] 2. ATB[2] + Seal 3. Patch
		High	1. Surface Recycle[1] 2. ATB[2] + Seal 3. Full Depth Recycle 4. Thick Overlay 5. Reconstruct
Bleeding	Localized	Low	No Action
		Medium	1. Patch 2. Heat & Roll Sand 3. Burn
		High	1. Patch 2. Heat & Roll Sand 3. Burn
	Extensive	Low	No Action
		Medium	1. Burn + Sand Seal 2. Burn + Chip Seal 3. Burn + Slurry Seal
		High	1. Burn + Sand Seal 2. Burn + Chip Seal 3. Burn + Slurry Seal 4. Surface Recycling 5. Burn + Thin Overlay 6. Reconstruct

[1]Appropriate if problem in surface course, and not in the base or subgrade.
[2]Asphalt Treated Base

Low and Moderate Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Block Cracking	Localized	Low	1 Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Slurry Seal 2. Rejuvenator 3. Crack Seal 4. Chip Seal
		Medium	1. Chip Seal 2. ATB[1] + Seal 3. Crack Seal
		High	1. Surface Recycle 2. ATB[1] + Seal Coat 3. Thin Overlay 4. Full Depth Recycle 5. Reconstruct
Corrugation	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane + Think Overlay/ Chip Seal 2. Grind, Mill, or Plane 3. ATB[1] + Seal Coat 4. Surface Recycle
		High	1. Surface Recycle 2. ATB[1] + Seal Coat 3. Prelevel Course + Think Overlay 4. Grind, Mill, or Plane + Thin Overlay 5. Grind, Mill, or Plane 6. Reconstruct

[1]Asphalt Treated Base

Low and Moderate Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Depression	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. ATB[1] + Seal Coat 2. Patch
		High	1. ATB[1] + Seal Coat 2. ATB[1] + Thin Overlay 3. Full Depth Recycle 4. Reconstruct
Edge Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Shoulder Seal 2. Crack Seal
		Medium	1. ATB[1] + Seal Coat 2. Crack Seal
		High	1. ATB[1] + Seal Coat 2. Thin Overlay 3. Surface Recycle
Lane/Shoulder Drop-Off	Localized	Low	No Action
		Medium	No Action
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Add Aggregate + Grade 2. Level Shoulder + Chip Seal
		High	1. Level Shoulder + Chip 2. Add Aggregate + Grade

[1]Asphalt Treated Base

Low and Moderate Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Longitudinal & Transverse Cracking	Localized	Low	1 Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Crack Seal 2. Chip Seal 3. Slurry Seal 4. Rejuvenator
		Medium	1. Chip Seal 2. Crack Seal 3. Surface Recycle[1] 4. ATB[2] + Seal Coat[1]
		High	1. Surface Recycle[1] 2. ATB[2] + Seal Coat 3. Thin Overlay 4. Thick Overlay 5. Full Depth Recycle 6. Reconstruct
Patching	Localized	Low	No Action
		Medium	1. Crack Seal 2. Patch
		High	1. Patch 2. Crack Seal
	Extensive	Low	No Action
		Medium	1. ATB[1] + Seal Coat 2. Crack Seal
		High	1. ATB[1] + Seal Coat 2. Overlay 3. Full Depth Recycle 4. Reconstruct

[1]Appropriate if problem is nonload associated.
[2]Asphalt Treated Base

Low and Moderate Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Polished Aggregate	Localized	N/A	No Action
	Extensive	N/A	1. Sand Seal 2. Chip Seal 3. Slurry Seal 4. Open Graded Course 5. Grind, Mill, or Plane 6. Surface Recycle 7. Thin Overlay
Potholes	Localized	Low	1. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. ATB[1] + Seal Coat 2. Full Depth Recycle 3. Thick Overlay 4. Reconstruct
		Medium	1. ATB[1] + Seal Coat 2. Full Depth Recycle 3. Thick Overlay 4. Reconstruct
		High	1. Full Depth Recycle 2. Reconstruct 3. Thick Overlay 4. ATB[1] + Seal Coat

[1]Asphalt Treated Base

Low and Moderate Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Rutting	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch 2. ATB[1] + Seal Coat 3. ATB[1] + Thin Overlay 4. Grind, Mill, or Plane 5. Grind, Mill, or Plane + Thin Overlay 6. Surface Recycle
		High	1. ATB[1] + Seal Coat 2. ATB[1] + Thin Overlay 3. Grind, Mill, or Plane 4. Grind, Mill, or Plane + Thin Overlay/Chip 5. Surface Recycle 6. Thick Overlay 7. Full Depth Recycle 8. Reconstruct
Shoving	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch
		High	1. Surface Recycle 2. Reconstruct
Slippage Cracking	Localized	Low	1 Crack Seal
		Medium	1. Patch 2. Crack Seal
		High	1. Patch
	Extensive	Low	1. Crack Seal
		Medium	1. Patch
		High	1. Full Depth Recycle 2. Reconstruct 3. Patch

[1]Asphalt Treated Base

Low and Moderate Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Swell	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane 2. ATB[1] + Seal Coat
		High	1. Grind, Mill, or Plane 2. Full Depth Recycle 3. Reconstruct
Weathering & Raveling	Localized	Low	No Action
		Medium	No Action
		High	1. Patch
	Extensive	Low	1. Sand Seal 2. Fog Seal 3. Rejuvenator 4. Slurry Seal 5. ATB[1] + Seal Coat
		Medium	1. Sand Seal 2. Chip Seal 3. Slurry Seal 4. Open Graded Course 5. ATB[1] + Seal Coat
		High	1. Chip Seal 2. Thin Overlay 3. Open Graded Course 4. Surface Recycle 5. Reconstruct

[1]Asphalt Treated Base

Prioritized Repair Alternatives

High Traffic Volumes

Distress Type	Distress Density	Distress Severity	Repair Action
Alligator Cracking	Localized	Low	1 Crack Seal 2. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. Crack Seal 2. Patch
		Medium	1. Surface Recycle1 2. Patch
		High	1. Surface Recycle[1] 2. Full Depth Recycle 3. Thick Overlay 4. Reconstruct
Bleeding	Localized	Low	No Action
		Medium	1. Patch 2. Heat & Roll Sand 3. Burn
		High	1. Patch 2. Heat & Roll Sand 3. Burn
	Extensive	Low	No Action
		Medium	1. Burn + Sand Seal[2]
		High	1. Burn + Chip Seal[2] 2. Surface Recycling 3. Burn + Thin Overlay 4. Reconstruct

[1]Appropriate if problem in surface course, and not in the base or subgrade.
[2]Asphalt Treated Base

High Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Block Cracking	Localized	Low	1 Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Slurry Seal 2. Chip Seal[1]
		Medium	1. Chip Seal[1] 2. Crack Seal
		High	1. Surface Recycle 2. Thin Overlay 3. Full Depth Recycle 4. Reconstruct
Corrugation	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane + Think Overlay/ Chip Seal 2. Surface Recycle
		High	1. Surface Recycle 2. Prelevel Course + Think Overlay 3. Grind, Mill, or Plane + Thin Overlay 4. Reconstruct
Depression	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch
		High	1. Full Depth Recycle 2. Reconstruct

[1]Modified binder required for high traffic volumes.

High Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Edge Cracking	Localized	Low	1. Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Shoulder Seal 2. Crack Seal
		Medium	1. Crack Seal
		High	1. Thin Overlay 2. Surface Recycle
Lane/Shoulder Drop-Off	Localized	Low	No Action
		Medium	No Action
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Add Aggregate + Grade 2. Level Shoulder + Chip Seal
		High	1. Level Shoulder + Chip 2. Add Aggregate + Grade
Longitudinal & Transverse Cracking	Localized	Low	1 Crack Seal
		Medium	1. Crack Seal
		High	1. Patch 2. Crack Seal
	Extensive	Low	1. Crack Seal 2. Chip Seal[1] 3. Rejuvenator
		Medium	1. Chip Seal[1] 2. Crack Seal 3. Surface Recycle[2]
		High	1. Surface Recycle[2] 2. Thin Overlay 3. Thick Overlay 4. Full Depth Recycle 5. Reconstruct

[1]Modified binder required for high traffic volumes.
2Appropriate if problem in surface course, and not in the base or subgrade.

High Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Patching	Localized	Low	No Action
		Medium	1. Crack Seal 2. Patch
		High	1. Patch 2. Crack Seal
	Extensive	Low	No Action
		Medium	1. Overlay 2. Crack Seal
		High	1. Overlay 2. Full Depth Recycle 3. Reconstruct
Polished Aggregate	Localized	N/A	No Action
	Extensive	N/A	1. Chip Seal[1] 2. Surface Recycle 3. Thin Overlay
Potholes	Localized	Low	1. Patch
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	1. Full Depth Recycle 2. Thick Overlay 3. Reconstruct
		Medium	1. Full Depth Recycle 2. Thick Overlay 3. Reconstruct
		High	1. Full Depth Recycle 2. Reconstruct 3. Thick Overlay

High Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Rutting	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch 2. Grind, Mill, or Plane + Thin Overlay 3. Surface Recycle
		High	1. Grind, Mill, or Plane + Thin Overlay 2. Surface Recycle 3. Thick Overlay 4. Full Depth Recycle 5. Reconstruct
Shoving	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Patch
		High	1. Surface Recycle 2. Reconstruct
Slippage Cracking	Localized	Low	1 Crack Seal
		Medium	1. Patch 2. Crack Seal
		High	1. Patch
	Extensive	Low	1. Crack Seal
		Medium	1. Patch
		High	1. Full Depth Recycle 2. Reconstruct 3. Patch

High Traffic Volumes (Continued)

Distress Type	Distress Density	Distress Severity	Repair Action
Swell	Localized	Low	No Action
		Medium	1. Patch
		High	1. Patch
	Extensive	Low	No Action
		Medium	1. Grind, Mill, or Plane + Thin Overlay
		High	1. Full Depth Recycle 2. Reconstruct
Weathering & Raveling	Localized	Low	No Action
		Medium	No Action
		High	1. Patch
	Extensive	Low	1. Sand Seal 2. Fog Seal 3. Rejuvenator
		Medium	1. Sand Seal 2. Chip Seal[1]
		High	1. Chip Seal[1] 2. Thin Overlay 3. Surface Recycle 4. Reconstruct

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PORTLAND CEMENT CONCRETE PAVEMENT DISTRESSES

Distress Type	Description of Distress	Cause of Distress
Cracking	Cracking defects are irregular breaks that may form transversely, longitudinally, or diagonally within a slab. Construction joints, which are straight and obviously formed or cut, are not considered cracks.	Cracks are usually caused by a combination of load repetition, curling stresses, and shrinkage stresses. Narrow cracks (less than 1/8 inch in unreinforced PCC and less than 1/2 inch in reinforced PCC) are usually warping - or friction-related and are not considered major structural distresses. Wider cracks are usually working cracks and are considered major structural distresses.
Joint and Crack Spalling	Spalling occurs when fragments break off or chip off along the edges of the pavement joints or cracks.	Spalling results from excessive stresses at the joint or crack caused by infiltration of incompressible materials or traffic loads. Weak concrete at the joint (caused by overworking) combined with traffic loads is another cause of spalling.
Pumping and Blowing	Pumping and blowing refer to the ejection of water from underneath he pavement.	Pumping and blowing is caused by the deflection of the slab under passing loads. As the water is ejected, it carries particles of gravel, sand, clay, or silt, resulting in a progressive loss of pavement support.
Faulting and Settlement	Faulting and/or settlement occurs when abutting pavements separate vertically at joints or cracks. The results is a "step" difference between the adjoining pavement surfaces.	Settlement or faulting is caused by upheaval or consolidation.
Patching	Patching is the temporary or semi-permanent replacement of all, or part, of a slab.	N/A
Raveling or Scaling	Pavement scaling is the progressive disintegration of the pavement from the surface downward, or from the edges inward, by the dislodgment of aggregate particles.	Scaling may be caused by overfinishing of the concrete, deicing salts, improper construction, freeze-thaw cycles, poor aggregate, or alkali-silica reactivity.
Blowups	Blowups are the shattering or upward buckling of pavement slabs at transverse cracks or joints.	Blowups occur in hot weather, usually at a transverse crack or joint that is not wide enough to permit expansion of the concrete slabs. The insufficient width is usually caused by infiltration of incompressible materials into the joint space. When expansion cannot relieve enough pressure, a localized upward movement of the slab edges or shattering will occur in the vicinity of the joint.
Wear	Wear is a surface depression in the wheel path.	Wear results from tire abrasion (usually studded tires).

FLEXIBLE PAVEMENT DISTRESSES

Distress Type	Description of Distress	Cause of Distress
Rutting and Wear	Rutting and wear are surface depressions in the wheel paths. Pavement uplift may occur along the sides of the depression.	Rutting is caused by permanent deformation in any of the pavement layers or the subgrade, usually caused by consolidation or lateral movement of the materials due to traffic loads. Wear results from tire abrasion.
Alligator Cracking	Alligator cracking usually begins as a single longitudinal, discontinuous crack within the wheel path that progresses to a more branched pattern that beings to interconnect into a pattern resembling chicken wire or the skin of an alligator.	Alligator cracking is associated with loads and is usually limited to areas of repeated traffic loading. It is caused by fatigue failure of the asphalt concrete surface. The cracking initiates at the bottom of the asphalt surface (or stabilized base), where tensile stress and strain are the highest under a wheel load. The cracks propagate to the surface.
Longitudinal Cracking	Longitudinal cracks run roughly parallel to the roadway center line.	Longitudinal cracks may be caused by a poorly constructed paving lane joints or cracks or joints in the underlying pavement layers.
Transverse Cracking	Transverse cracks run roughly perpendicular to the roadway center line. They may extend partially or fully across the roadway.	Transverse cracks may be due to surface shrinkage caused by low temperatures, hardening of the asphalt, or cracks or joints in the underlying pavement layers.
Raveling and Weathering	Raveling and weathering are pavement surface deterioration that causes ACP to lose its smooth surface and begin to appear very open and rough like very coarse sand paper.	Raveling occurs when aggregate particles are dislodged. Weathering is caused by a loss of the asphalt binder. Raveling and weathering may indicate that the asphalt binder has hardened significantly.
Flushing (Bleeding)	Flushing is indicated by an excess of bituminous material on the pavement surface, which presents a shiny, glass-like reflective surface that may become sticky in hot temperatures.	Bleeding is caused by excessive amounts of asphalt cement or tars in the mix and/or low air void content. It occurs when asphalt fills the voids of the mix during hot weather and then expands out onto the surface of the pavement.
Patching	Patching is a localized area where the original pavement has been replaced.	N/A
Corrugation and Waves	Corrugations and waves are regularly occurring transverse undulations in the pavement surface. Corrugations occur as closely spaced ripples, while waves are undulations whose distance from peak to valley is more than 3 feet.	Corrugation is usually caused by traffic action combined with an unstable pavement surface or base.
Sags and Humps	Sags and humps are localized depressions or elevated areas of the pavement.	Sags and humps may result from settlement, pavement shoving, displacement due to subgrade swelling, frost action, or displacement due to tree roots.

FLEXIBLE PAVEMENT DISTRESSES

Distress Type	Description of Distress	Cause of Distress
Block Cracking	Block cracks divide the pavement surface into nearly rectangular pieces with cracks that intersect at about 90 degrees.	Block cracking is caused principally by shrinkage of the asphalt concrete and daily temperature cycling (which results in daily stress/strain cycling). It is not load-associated, although load can increase the severity of individual cracks. The occurrence of block cracking usually indicates that the asphalt has hardened significantly through aging.
Pavement Edge Condition	Pavement edge condition refers to the deterioration of the pavement near the edge of the pavement.	This distress may be caused by weakened base or subgrade near the edge of the pavement and can be accelerated by traffic loading.
Crack Seal Condition	Crack seal condition refers to the condition of any existing crack sealant.	Typical causes of crack seal deterioration include the stripping of crack sealant, extrusion of crack sealant, weed growth, hardening of the filler, and loss of bond to the crack edges.

APPENDIX G OF NCHRP SYNTHESIS 223

A Process to Demonstrate the Cost-Effectiveness of Preventive Maintenance

The following describes a process to assess the impact of alternative pavement management strategies on a highway network that does not require detailed knowledge of each segment of the network. The description was adapted from a presentation made by Ray Gerke at the Seventh AASHTO/TRB Maintenance Management Conference held in Orlando, Florida from July 18 to 21, 1994 (*1*). The process uses the condition transition matrix presented in the paper and adds a methodology that can be used to estimate the condition transition matrices for the initial network condition with and without preventive maintenance.

The cost-effectiveness of preventive maintenance is demonstrated by comparing the end condition of the highway network after 5 years using a preventive maintenance strategy and a worst-first strategy. The example is typical of the conditions experienced in a state or local transportation agency.

The following assumptions and limitations were made in this example:

- The present pavement condition of the network can be characterized by a network pavement performance curve and a simple matrix.
- The performance of the network with no work being done can be approximated as the average of the performance of the individual segments.
- The effect of the preventive maintenance strategy on the network can be approximated by the effect of the strategy on an individual segment.
- The distribution of the Very Good, Good, Fair, Mediocre, and Poor pavements in the hypothetical network reflects the distribution in the nation's urban and rural arterials network in 1990 as reported by FHWA on page 12 of "Our Nations Highways: Selected Facts and Figures," Publication No. FHWA-PL-92-004.
- The preventive maintenance strategy selected will increase the time before an asphalt pavement needs to be rehabilitated from 10 to 14 years, reflecting an increase in pavement life of 4 years. These values are typical of those reported by the agencies responding to the questionnaire.
- A preventive maintenance treatment, by definition, does not increase the pavement condition rating. Therefore, there is no increase in the Present Serviceability Index (PSI) when a preventive maintenance treatment is applied.
- The cost of the preventive maintenance treatments and the cost to rehabilitate a pavement are typical of those reported by the agencies responding to the questionnaire.

Step 1 Classify the System By Pavement Performance and Condition

The purpose of the analysis is to compare the cost-effectiveness of alternative pavement maintenance strategies on the *network*. Ideally, transportation agencies would have a performance model for their entire network. In many agencies, that doesn't exist. Therefore, it is necessary to identify groups or families of pavements with similar performance characteristics and use that information to estimate the performance of the network. Factors that an agency should consider in grouping the highway segments into categories with similar pavement performance characteristics are: pavement type, volume of trucks, physiographic provinces, and geographic regions, (i.e., an urban region with PCC pavement network with a large volume of heavy trucks). The performance of the pavements should be similar but need not be identical. The objective is to categorize the agency's network into a manageable number of categories with similar performance characteristics for analysis purposes. The pavement sections in each category are then sorted by condition. For the purposes of this analysis, four or five levels of pavement condition are sufficient. The following analysis is performed for each category of pavements and results are combined to present the impact of a preventive maintenance strategy on the agency's network.

Table G-1 illustrates this analysis for a small hypothetical agency with a highway system of 1,000 lane miles of asphalt concrete pavement. The entire system has similar performance characteristics and only one category is needed to demonstrate the cost-effectiveness of a network preventive maintenance strategy. The pavement sections were grouped into the five levels of pavement condition shown in Table G-1. For this analysis, the five levels of pavement condition used by the FHWA on page 12 of "Our Nation's Highways: Selected Facts and Figures," were selected because they may be more meaningful to executive management and other decision makers not familiar with technical pavement condition terminology, such as PSI.

Step 2 Establish Network Pavement Performance Characteristics With No Maintenance or Rehabilitation (Do Nothing)

Analyze the performance history of the highway segments in each pavement condition rating level that have not been worked on recently and determine the average number of years that the sections remain in each pavement condition rating level, (i.e., for the segments in the network, how many years were they rated Very Good, rated Good, rated Fair, etc). If the network is very large, it is not necessary to use every section. Determine the averages using a representative random sample. The purpose of the analysis is to determine the performance characteristics of the network when no work is done and not the performance of an individual section of pavement. Table G-2 illustrates the results of this analysis for the hypothetical agency.

The network pavement performance curve resulting from these averages is shown as the lower curve in Figure G-1. Based on the averages determined in Table G-2, the network

TABLE G-1

INITIAL NETWORK CONDITION

Condition Rating	PSI Range	Description	Number of Lane Miles
Very Good	>=4.0	New or almost new pavement; will not require improvement for some time.	200
Good	3.5-4.0	In decent condition; will not require improvement in the near future.	280
Fair	2.5-3.5	Will likely need improvement in the near future.	370
Mediocre	2.0-2.5	Needs near-term improvement to preserve usability.	100
Poor	<=2.0	Needs immediate improvement to restore serviceability.	50

TABLE G-2

NETWORK PERFORMANCE WITH NO MAINTENANCE OR REHABILITATION

Condition Rating	PSI Range	Average No. of Years with Condition Rating
Very Good	>=4.0	5
Good	3.5-4.0	2
Fair	2.5-3.5	2
Mediocre	2.0-2.5	1
Poor	<=2.0	

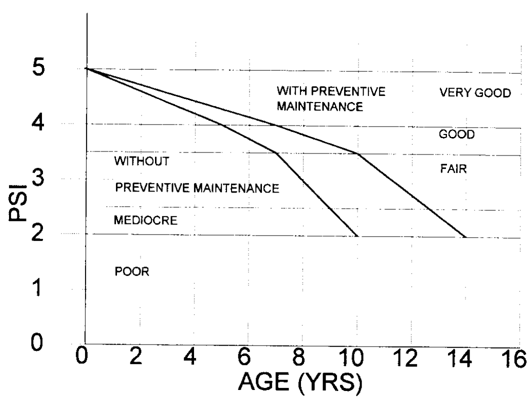

FIGURE G-1 Network pavement performance curves.

pavement performance factors in Table G-3 are developed. If the pavement sections remain in a Very Good condition for an average of 5 years, then 20 percent of the sections drop down to Good each year and 80 percent remain at the Very Good level. Likewise, 50 percent of the sections in a Good condition drop down to Fair and 50 percent remain at the Good level.

Step 3 Develop Proposed Network Preventive Maintenance Strategy

A preventive maintenance strategy is developed based on the observed improvements in pavement performance and increases in the time required for rehabilitation on selected sections of the network where different preventive maintenance treatments were used. An agency may also use the experience reported by neighboring agencies in arriving at its proposed strategy. For this example, the proposed network pavement preventive maintenance strategy is shown in Table G-4.

Step 4 Establish Network Pavement Performance Factors with Preventive Maintenance

Because there is no historical database that can be analyzed to determine the percentage of the highway network in each pavement condition rating level that remains the same and the percentage that drops from year to year with preventive maintenance, the network percentages have to be estimated based on the observed improvement in the performance of pavement sections. The pavement and maintenance engineers for the agency have observed that sealing cracks and a single application chip seal, on the average, add 2 years to the pavement at the Very Good condition rating level and if repeated when the pavement is rated Good, add about another 2 years before the pavement reaches a Poor condition rating level, at which time it needs to be rehabilitated. Overall, the proposed preventive

TABLE G-3
NETWORK PAVEMENT PERFORMANCE FACTORS WITH DO-NOTHING STRATEGY

From Condition Level	To Condition Level After One Year (Percent)				
	Very Good	Good	Fair	Mediocre	Poor
Very Good	80.0	20.0	-	-	-
Good	-	50.0	50.0	-	-
Fair	-	-	50.0	50.0	-
Mediocre	-	-	-	0.0	100.0
Poor	-	-	-	-	100.0

TABLE G-4
PROPOSED NETWORK PREVENTIVE MAINTENANCE STRATEGY

Pavement Condition	Preventive Maintenance Treatment	Year of Application	Cost of Treatment (per lane mile)
Very Good	Crack Filling	3	$2,500
Very Good	Single Application Chip Seal	5	$6,000
Good	Crack Filling	8	$2,500
Fair	Single Application Chip Seal	10	$6,000

maintenance strategy, on the average, extends the performance of the pavement network 4 years before rehabilitation is required. A simple method and, as reported in the literature, a reasonable assumption is that the pavement performance curve is a straight line. However, for this example, it is assumed that the network pavement performance is curvilinear. The length of time that a pavement is assumed to remain in each pavement condition level is shown in Table G-5. The network

TABLE G-5
NETWORK PERFORMANCE WITH PREVENTIVE MAINTENANCE

Condition Rating	PSI Range	Average No. of Years in Condition Rating
Very Good	>=4.0	7
Good	3.5-4.0	3
Fair	2.5-3.5	2.7
Mediocre	2.0-2.5	1.3
Poor	<=2.0	

pavement performance curve with preventive maintenance is shown as the upper curve in Figure G-1.

Using the same approach as described above for the do-nothing alternative, the network pavement performance factors (shown in Table G-6) with the preventive maintenance strategy are determined.

Step 5 Determine the Funding Required

The funding analysis can be done in one of two ways. One way is to determine how much money would be needed to achieve an agreed on network end condition after a specified number of years. The second approach, more common in state and local transportation agencies, is to do "what if" analyses. Given a certain funding level and funding strategy, what will the network end conditions be after a specified number of years. The second approach will be used in this example. The analysis will be done for an annual budget of $8 million and the analysis will compare the network end condition after 5 years with a do-nothing strategy, a worst-first funding strategy, and a preventive maintenance strategy. The analysis will also compare the funding required for the worst-first and the funding level for the preventive maintenance strategy to obtain approximately the same pavement network end condition after 5 years.

100

TABLE G-6

NETWORK PAVEMENT PERFORMANCE FACTORS WITH THE PREVENTIVE MAINTENANCE STRATEGY

From Condition Level	To Condition Level After One Year (Percent)				
	Very Good	Good	Fair	Mediocre	Poor
Very Good	85.7	14.3	-	-	-
Good	-	66.7	33.3	-	
Fair	-	-	63.0	37.0	-
Mediocre	-	-	-	23.1	76.9
Poor	-	-	-	-	100.0

TABLE G-7

PAVEMENT NETWORK END CONDITION WITH DO-NOTHING STRATEGY

Pavement Condition	Lane Miles					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Very Good	200	0.8(200)=160	128	102	82	66
Good	280	0.2(200)+0.5(280)= 180	122	87	64	48
Fair	370	0.5(280)+ 0.5(370)=325	253	187	137	100
Mediocre	100	0.5(370)=185	163	126	94	68
Poor	50	1.0(100)+1.0(50)=150	335	498	624	717

TABLE G-8

PAVEMENT NETWORK END CONDITION WITH WORST-FIRST FUNDING STRATEGY

Pavement Condition	Lane Miles						
		Year 1					
	Year 0	Before Rehab	After Rehab	Year 2	Year 3	Year 4	Year 5
Very Good	200	160	160+80=240	272	298	318	334
Good	280	180	180	138	123	121	124
Fair	370	325	325	253	195	159	140
Mediocre	100	185	185	163	126	98	80
Poor	50	150	150-80=70	175	258	304	321

TABLE G-9

EXPENDITURE OF FUNDS WITH PREVENTIVE MAINTENANCE STRATEGY FUNDED AT $8 MILLION ANNUALLY

Pave Age	Pave Cond.	Lane Miles Year 0	Prevent Maint. Treat	Unit Costs	Total Costs
3	Very Good	200	Crack Seal	$2,500	(200/7)(2500) =$ 71,400
5	Very Good	200	Chip Seal	$6,000	(200/7)(6000) =$ 171,400
8	Good	280	Crack Seal	$2,500	(280/3)(2500) =$ 233,300
10	Fair	370	Chip Seal	$6,000	(370/2.7)(6000) =$ 822,200
Cost of Prevent Maint in Year 0					$ 1,298,300
Available for Rehabilitation					$ 6,701,700
Number of Lane Miles Rehabilitated					67.0

TABLE G-10

PAVEMENT NETWORK END CONDITION WITH PREVENTIVE MAINTENANCE STRATEGY FUNDED AT $8 MILLION ANNUALLY

	Lane Miles						
		Year 1					
Pavement Condition	Year 0	Before Rehab	After Rehab	Year 2	Year 3	Year 4	Year 5
Very Good	200	0.857(200)= 171	238	272	303	329	352
Good	280	0.143(200)+ 0.667(280)= 215	215	178	157	148	146
Fair	370	0.333(280)+ 0.63(370)= 326	326	277	234	200	175
Mediocre	100	0.37(370)+ 0.231(100)= 160	160	158	139	119	101
Poor	50	0.769(100)+ 1.0(50)= 127	60	115	167	205	225

Step 6 Analysis

Do-Nothing Strategy

Table G-7 shows the results of the analysis for the do-nothing strategy. This analysis shows the pavement network end condition after 5 years. The analysis is performed by multiplying the mileage in Table G-1 by the factors in Table G-3. The computations are shown for the first year to illustrate the process.

Worst-First Funding Strategy

Table G-8 shows the results of the analysis for the worst-first funding strategy with an annual budget of $8 million. The first step in the analysis is identical to the computations for the do-nothing analysis in Table G-7 above. The mileage in Table G-1 is multiplied by the factors in Table G-3. Then, the number of lane miles of poor pavement to be rehabilitated is determined by dividing the annual budget ($8 million) by

TABLE G-11

PAVEMENT NETWORK END CONDITION WITH PREVENTIVE MAINTENANCE STRATEGY FUNDED AT $6.4 MILLION ANNUALLY

	Lane Miles					
Pavement Condition	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Very Good	200	222	243	262	279	294
Good	280	215	175	152	138	132
Fair	370	326	277	233	197	170
Mediocre	100	160	158	139	118	100
Poor	50	76	147	215	267	303

TABLE G-12

COMPARISON OF THE EFFECT OF ALTERNATIVE STRATEGIES ON NETWORK CONDITION AFTER 5 YEARS

	Lane Miles				
		Year 5 Network End Condition			
				Preventive Maintenance Annual Funding Level	
Pavement Condition	Year 0	Do Nothing	Worst-First $8 Million Annually	$8 Million	$6.4 Million
Very Good	200	66	334	352	294
Good	280	48	124	146	132
Fair	370	100	140	175	170
Mediocre	100	68	80	101	100
Poor	50	717	321	225	303

the cost to rehabilitate one lane mile ($100,000). The number of lane miles rehabilitated is 80. The number of lane miles rated Poor is then decreased by 80 and the number rated Very Good is increased by 80. When there are more lane miles rehabilitated than there are lane miles rated Poor, the number of lane miles of pavements rated Mediocre is decreased by the difference between the number rehabilitated and the number rated Poor. The computations are shown for the first year to illustrate the process.

Preventive Maintenance Strategies

Table G-10 shows the results of the analysis for the preventive maintenance strategy with an annual budget of $8 million. The first step, as shown in Table G-9 for the first year, is to spend that portion of the annual budget needed for the preventive maintenance treatments required by the strategy starting with the pavements rated Very Good, then Good, and Fair. The second single application chip seal, at year 10, is at the end of the Good condition level or the beginning of the Fair condition level. For the purposes of computing the cost of the preventive maintenance strategy in this example, the second chip seal was applied to the pavements in a Fair condition. In this instance, this resulted in a slightly higher cost for the preventive maintenance strategy. Any remaining funds are then available to rehabilitate pavements rated Poor and the number of lane miles rehabilitated is computed. The second step is to multiply the mileage in Table G-1 by the pavement network deterioration factors for the preventive maintenance strategy in Table G-6. The third step is to add the number of lane miles of pavements rated Poor and Mediocre that were rehabilitated to the lane miles of pavement rated Very Good and subtract the same number from the number rated Poor and Mediocre.

There is a significant improvement in the pavement network end condition with the preventive maintenance strategy over the worst-first strategy. Frequently, policy makers want to compare the funding required for each strategy to obtain approximately the same network end condition. Table G-11 shows the results of the analysis for the preventive maintenance strategy annually funded at $6.4 million.

A side-by-side comparison of the network end conditions for the worst-first and preventive maintenance strategies funded at $8 million annually as illustrated in Table G-12 shows the improvement in the condition of the pavement network obtained over 5 years using the preventive maintenance strategy. The number of lane miles of the pavement rated Very Good increased from 334 to 353 while the number of lane miles of pavement rated Poor decreased from 321 to 225. Furthermore, the network condition after 5 years is approximately the same (the total lane miles rated Poor and Mediocre is 401 vs 403) for the worst-first strategy funded at $8 million annually and the preventive maintenance strategy funded at $6.4 million annually for an annual savings of $1.6 million, or 20 percent.

REFERENCE

1. Sparks, G.A., R. Gerke, and D. Kaweski, "Integrating Maintenance Management and Pavement Management Systems," in *Preprints*, Seventh AASHTO/TRB Maintenance Management Conference, Transportation Research Board, National Research Council, Washington, DC (July 18–21, 1994), Preprint C.

APPENDIX A OF NCHRP SYNTHESIS 223

Primer on Preventive Maintenance for Pavements

This appendix describes terms commonly encountered when discussing preventive maintenance of pavements. This includes the different types of pavements, the causes of the most commonly occurring problems for each type of pavement, and the categories of pavement maintenance and preventive maintenance treatments generally used.

The objective of this appendix is to serve as a primer that can be used by DOT administrative, engineering, operations, and maintenance personnel in briefing administrative, budget, finance, and legislative personnel on the benefits of preventive maintenance for pavements. It is not intended to be a complete or authoritative discussion of pavement design, rehabilitation, reconstruction, construction, maintenance, or management. There are many excellent references that cover each of those areas in considerable depth (*1-14*, e.g.). Rather, it covers basic information and terminology that is part of the daily vernacular of practicing highway, pavement, and maintenance engineers. Furthermore, the scope of the primer is limited to a discussion of those pavement activities generally considered to be preventive and generally performed by either in-house or contract maintenance forces. Pavement activities or treatments that are corrective, (e.g., grinding PCC pavements to improve the rideability) or done as part of a rehabilitation project, (e.g., crack and seat of PCC pavements to reduce or eliminate reflective cracking) are not covered in this primer.

TYPES OF PAVEMENTS AND SHOULDERS

There are four types of roadway surfaces: (1) flexible, (2) rigid, (3) composite, and (4) gravel or unpaved. This report does not address the maintenance of gravel or unpaved roads. The subsequent discussion is limited to the three types of paved surfaces.

Flexible Pavement

A flexible pavement is a roadway structure consisting of subbase, base, and surface courses over a prepared roadbed. The surface course generally consists of one or more layers of asphalt cement concrete (AC). The materials used for the base and subbase depend on several factors, including the amount, mix, and weight of heavy trucks, the drainage conditions, the repetition of freeze-thaw cycles, the local availability of durable crushed stone, gravel, or other granular materials, and the native roadbed soils. Materials commonly used for the base and subbase include AC, for the higher type pavements (i.e., Interstates and expressways), crushed stone, crushed or natural gravel, and locally available materials treated with an asphalt emulsion, asphalt cement, lime, calcium chloride, or portland cement to give it strength and stability. Figure A-1 shows the cross section of a typical flexible pavement. The strength of a flexible pavement is obtained from the strength of the individual layers, with each layer stronger than the one below it. A flexible pavement distributes the wheel loads downward to the roadbed. Flexible pavements may be full-depth asphalt concrete, layered, as described above, or may simply consist of a surface treatment over a treated granular base. Flexible pavements are commonly known as asphalt pavements, asphalt concrete pavements (ACP), asphalt cement concrete pavements (ACCP) and bituminous concrete pavements (*13,14,15*).

Rigid Pavement

A rigid pavement consists of a portland cement concrete (PCC) slab and may have a base or subbase over a prepared roadbed. The base or subbase may be a crushed stone or gravel, locally available natural granular materials, may be

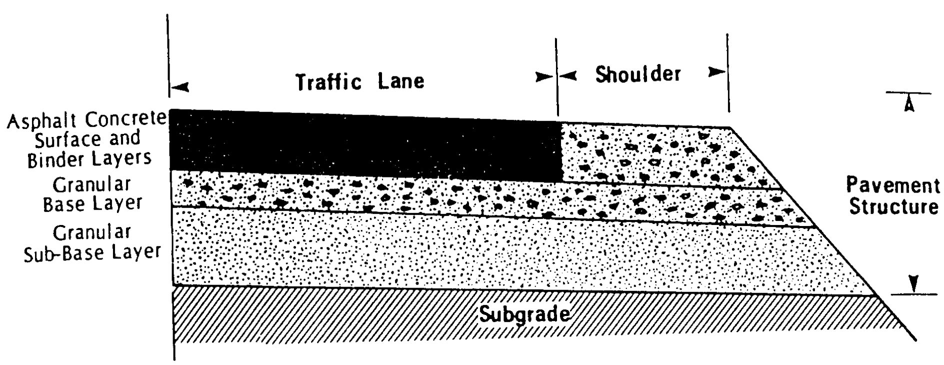

FIGURE A-1 Typical flexible pavement cross section (*8*).

treated as discussed in the section on flexible pavements, or the concrete slab may be placed directly on the native soil. Figure A-2 shows a cross section of a typical rigid pavement. A rigid pavement distributes the wheel loads over a wide area through the strength and bending action of the PCC slab.

There are two basic types of rigid pavements: (1) jointed concrete pavement (JCP), and (2) continuous reinforced concrete pavements (CRCP). The primary differences between the two are the joint spacing and the amount of reinforcing steel.

Jointed concrete pavements have expansion and contraction joints perpendicular to the direction of traffic to allow for the expansion and contraction of the slab with changes in temperature and moisture. A dowel bar or other type of load transfer device may be provided to carry the wheel load from one slab to the next. The opening for the joint is provided either by the form work before the slab is poured or saw cut after the PCC slab has cured. A flexible sealer is then placed in the joint opening. The sealer material can either be preformed neoprene of the proper width; an extruded material, such as silicone; or a poured material, such as hot liquid asphalt.

The slab contracts to its shortest length in the winter with the coldest temperatures and expands to its longest length with the hot summer temperatures. Generally, the joint spacing for JCP ranges from approximately 4 to 35 m (12 to 113 ft) however, hardly anyone uses the longer spacings anymore. The changes in length of the longer slabs caused by changes in temperature may be 250 mm (1 in.) or more. Joints are provided in CRCP only at bridges or to facilitate construction. Additional reinforcing steel is provided in CRCP to resist the stresses caused by changes in temperature and moisture (*13-15*). For those interested in a more in-depth discussion of rigid pavements, the two synthesis reports by McGhee provide detailed information on current practices (*12,16*).

Composite Pavement

A composite pavement usually is an asphalt concrete overlay of a portland cement concrete pavement. This includes both pavements where the initial design and construction provided for an AC overlay of a PCC pavement and where the AC overlay was subsequently added during the rehabilitation of an old PCC pavement.

Shoulders

Shoulders are defined by AASHTO as "the portion of the roadway contiguous with the travelled way for accommodation of stopped vehicles for emergency use, and for lateral support of base and subbase courses"(*13*). Shoulders can be paved or unpaved. Unpaved shoulders are normally constructed using gravel or sod. Most paved shoulders, with the exception of some Interstates and expressways, consist of asphalt concrete or an asphalt-treated granular material over a granular base and subbase. Furthermore, on many facilities constructed prior to the mid 1970s, the shoulder layers are not as thick as the adjacent pavement. Some, but not all, of the Interstates and expressways with rigid pavements have a PCC shoulder. Presently, AASHTO and FHWA suggest, for high-volume roadways, that paved shoulders be constructed of the same material as the adjacent pavement (*13,17*).

CATEGORIES OF MAINTENANCE ACTIVITIES

There is no nationally recognized glossary of maintenance terms and activities. Local and regional usages vary. An activity that one maintenance engineer may call routine maintenance may be referred to as corrective maintenance by another. The finance and budget laws of each state may affect the terminology. An activity that is considered a preventive treatment in one state because it is funded from the maintenance budget may be considered a corrective treatment in an other state because it is funded from the capital budget. There are also variations in terminology based on whether the work is done by in-house forces or contractor forces.

One way to categorize maintenance activities is by the urgency needed to accomplish the work. The two common

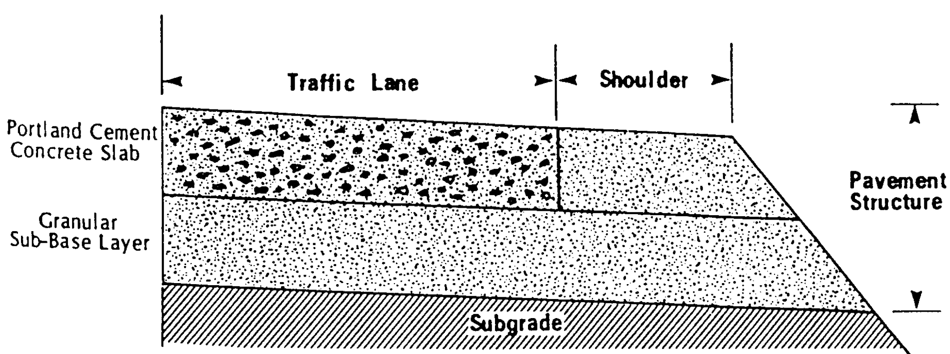

FIGURE A-2 Typical rigid pavement cross section (*8*).

TABLE A-1

PRINCIPAL DIFFERENCES IN TYPES OF MAINTENANCE ACTIVITIES

Type of Maintenance	Planned?	Performed Before Deterioration Has Occurred?	Extends The Useful Life Of The Facility?
Routine	YES	NOT NECESSARILY	SOMETIMES
Demand	NO	NO	NOT NECESSARILY
Preventive	YES	YES	YES
Corrective	GENERALLY	NO	YES

the pothole. Figure A-3 illustrates a deep pothole in an asphalt concrete pavement. Typically, water seeps into the subbase either through cracks in the surface or from standing water along the side of the pavement. If the water is not properly drained from the subbase, it softens the subbase materials and reduces its strength. The repetitious pounding of the wheel loads from traffic, especially those of heavy trucks, fatigues the asphalt concrete surface, thus increasing the size and number of cracks, which allows more water to enter the subbase and further weaken the surface layer. Eventually, the surface layer caves in and breaks into pieces. At that point, every pass of a wheel enlarges the hole by ejecting water, chunks of asphalt concrete, base, and subbase material. In northern climates, this process is accelerated in the spring by the daily cycle of freezing at night and thawing during the day. The expansion caused by freezing raises the surface layer while the thawing further softens the base and subbase (*21*). This process is illustrated in Figure A-4.

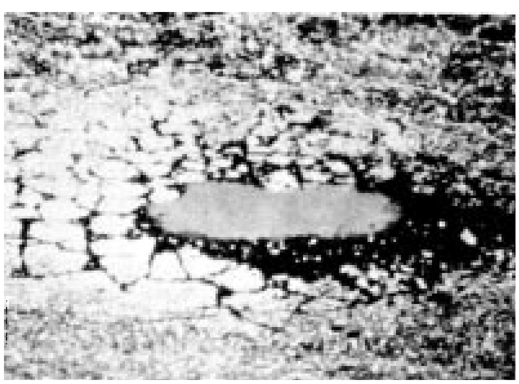

FIGURE A-3 Pothole *(20)*.

Edge Cracking

Edge cracking is longitudinal cracking along the edge of the pavement, as shown in Figure A-5. Edge cracking may be caused by a lack of support along the edge of the pavement from water softening the base and subbase. Water flowing off the pavement seeps into the base and subbase through the edge joint between the pavement and the shoulder.

Lane-to-Shoulder Dropoff

The lane-to-shoulder dropoff is the difference in elevation between the pavement and the shoulder. Figure A-6 illustrates lane-to-shoulder dropoff. It is caused by the differences in material characteristics and layer thicknesses between the pavement and the shoulder. Trucks encroaching on the shoulder are one of the major causes of lane-to-shoulder dropoff (*13*). Another contributing factor is the softening of the base and subbase beneath the shoulder from water entering at the edge joint between the pavement and the shoulder, through surface cracks in the shoulder, or seeping in from the outside edges of the shoulder. Research has shown that excessive lane-to-shoulder dropoff can affect vehicle dynamics and may contribute to accidents (*22*).

Pavement Oxidation

As an asphalt pavement ages, the asphalt cement that binds the aggregate together becomes brittle and the pavement begins to ravel. Initially the raveling consists of the loss of the asphalt binder and the fine aggregate, but in the more advanced stages, the coarse particles are also lost. Figure A-7 shows three examples of raveling, slight to severe.

Composite Pavement

All of the problems encountered in flexible pavements are possible also in composite pavements. In addition, the transverse joints in the underlying portland cement concrete pavement over time reflect up through the asphalt concrete overlay causing a transverse crack in the AC overlay. There are several techniques that may be used during construction to minimize reflective cracking. One technique however, which is to saw through the newly paved AC overlay directly over the old joint and to fill the saw cut with a joint sealing material, requires subsequent preventive maintenance (*24*).

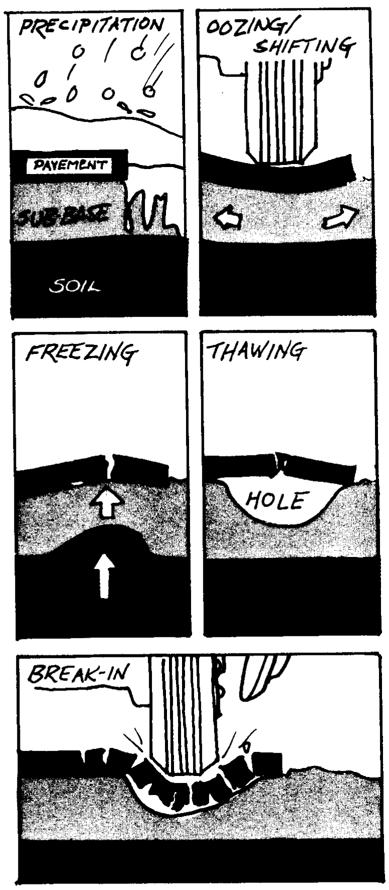

FIGURE A-4 Formation of a pothole *(21)*.

Rigid Pavement

Blow-up

The blow-up is the most disruptive and potentially dangerous rigid pavement problem. Figure A-8 illustrates the blow-up or buckling of a rigid pavement. Blow-ups are caused by the excessive expansion of the slab from heat or moisture, frequently resulting from insufficient joint space. The joint and crack spaces fill up with incompressible materials, such as sand, grit, and metal particles. This is compounded when the joint sealer comes out of the joint opening under the action of traffic (*12*). Sanding and salting operations in northern states during the winter, when joint and crack openings are at their widest, further add to this problem. Moisture infiltration is much more severe when joint seals have failed or are missing.

Pumping

Pumping is the ejection of mixtures of water and clay or silt along or through joints, cracks, or pavement edges (*15*).

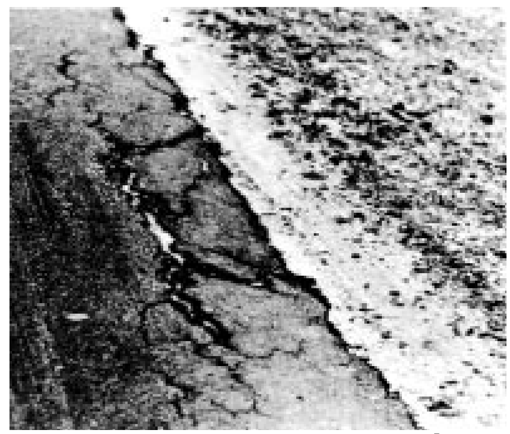

FIGURE A-5 Flexible pavement edge cracking *(15)*.

FIGURE A-6 Lane-shoulder dropoff *(20)*.

Figure A-9 illustrates pumping. The expulsion of water is caused by the repetitive action of wheel loads. As the water and suspended solids are ejected through the transverse and longitudinal pavement joints, a progressively larger void is formed under the pavement. With a loss of support, pavement slab edge and corner cracks develop (*12*).

Joint Faulting

Joint faulting is the differential vertical displacement of abutting slabs at joints or cracks, caused by repetitive axle loads, creating a "step" in the pavement surface (*12,15*). Figure A-10 illustrates faulting. The PCC slab prior to the transverse joint in the direction of traffic is known as the "approach" slab and the slab after the joint is known as the "leave" slab. Faulting is caused by the action of repetitive axle loads slowly forcing water and suspended solids, which are under the approach slab, beneath the leave slab as the wheel

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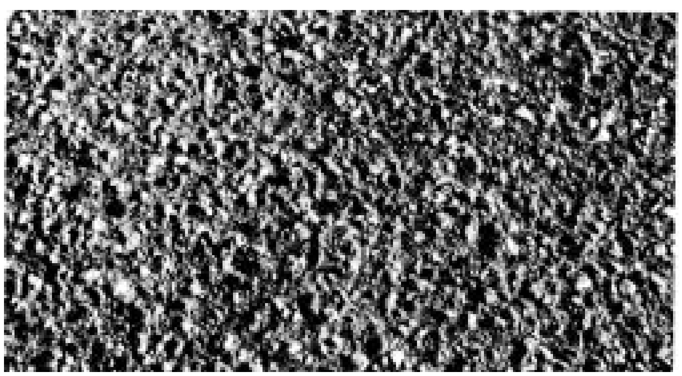
Slight

Smallest aggregate particles worn away exposing tops of large aggregate



Moderate to severe

Erosion further exposes large aggregate

Severe

Loss of large aggregate leaves very rough texture (foreground)

FIGURE A-7 Raveling *(23)*.

FIGURE A-8 Blowup of portland cement concrete pavement *(15)*.

FIGURE A-9 Pumping of portland cement concrete pavement *(20)*.

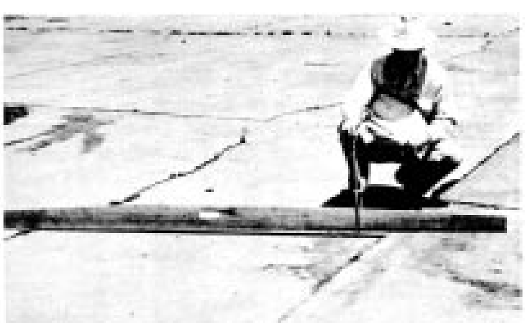


FIGURE A-10 Faulting of portland cement concrete pavement *(15)*.

approaches the joint. When the wheel crosses the joint onto the leave slab, the water and solids are forced back underneath the approach slab at a high velocity. This action causes a void under the leave slab and a buildup of material under the ap proach slab. Thus, what appears to be a depression of the leave slab, is rather the lifting of the approach slab (*12*).

Summary

All of the above pavement problems, with the possible exception of blow-ups of rigid pavement, have one thing in common: water. The presence of water in a pavement base or subbase accelerates the deterioration of flexible, composite, and rigid pavements.

CATEGORIES OF PREVENTIVE MAINTENANCE TREATMENTS FOR PAVEMENTS

The pavement and shoulder are the "roof" of the highway. One of their functions is to keep water from entering the pavement base and subbase from above. Therefore, the purpose of most preventive pavement maintenance techniques is to keep water away from the pavement base or subbase, either by sealing the surface of the pavement and shoulders or by facilitating drainage.

DRAINAGE

Periodically cleaning ditches and driveway culverts parallel to and cross culverts beneath the roadway facilitates the rapid flow of water away from pavement sections and avoids ponding in ditches and seepage into the pavement base and subbase. In addition, a DOT should cut back or blade the shoulders to remove the build up of material along the outer edge of the shoulder that blocks water from flowing off the paved surface. These preventive pavement maintenance drainage practices are applicable to all types of pavements.

Flexible Pavement

Water enters the flexible pavement section through cracks in the surface of the pavement and shoulder and through the longitudinal joints between the pavement and shoulder. The types of preventive maintenance treatments for flexible pavements are:

Crack Sealing and Crack Filling

Crack sealing and crack filling are both preventive maintenance treatments for flexible pavements. SHRP has provided the following definitions to delineate the differences between the two treatments (*9*).

- Crack sealing is "the placement of specialized materials either above or into *working* cracks using unique configurations to prevent the intrusion of water and *incompressibles* into the crack."

- Crack filling is "the placement of materials into *non-working* cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement."

All the surface cracks, the longitudinal joint between the pavement and the shoulders, and the longitudinal joint between lanes that may develop because of the cold edge during the paving process should be sealed or filled. There are several techniques for sealing and filling cracks. The simplest and quickest, which also has the shortest life, is to clean the debris out of the crack with compressed air and then spread a hot asphalt sealer over the crack with a squeegee. A better treatment is to rout or countersink the crack to form a reservoir for the sealer and to use a polymer-modified polyester fiberized asphalt as the sealing material. Some of the simplest and quickest treatments may last only 6 months, while the routing (countersinking) treatment has lasted up to 5 and 6 years in Ontario and New York respectively (*25* and personal communication with John Bugler, NYSDOT).

When the surface of the asphalt pavement has numerous cracks, or it has raveled and it is no longer feasible or practical to treat the individual cracks, a sealing technique that seals the entire surface is used. These are referred to as surface treatments and include slurry seals, micro-surfacing, chip seals, and thin overlays.

Slurry Seals: a mixture of well-graded fine sand, mineral filler, and dilute asphalt emulsion. The mixture is spread over the entire surface with either a squeegee or spreader box attached behind a truck. Slurry seals are considered to have a nominal life of 3 to 5 years (*26*).

Micro-Surfacing: a mixture of polymer-modified asphalt emulsion, crushed mineral aggregate, mineral filler, water, and additive to control the time to harden. The mixture is spread on the pavement with a spreader box attached behind a truck. Generally micro-surfacing is used to fill ruts and to improve surface texture. However, it has been used to seal surface cracks with mixed results (*27*).

Chip Seals: also known as surface treatment in some sections of the country, are constructed by spraying an asphalt emulsion with a liquid asphalt distributor on the pavement and then spreading on a layer of small crushed stone with a self-propelled spreader or a spreader box attached behind a truck. Some agencies use an additive in the asphalt cement or emulsion to increase stone retention and the performance of the chip seal. In addition to sealing the surface cracks, a chip seal can be used to increase the surface friction of a smooth pavement. Multiple applications of the asphalt emulsion and stone are also used by some agencies, depending on the condition of the pavement surface. In addition, some states use multiple chip seal courses to upgrade a gravel or stabilized road surface to a hard surface roadway for light weight traffic. In New York, chip seals with a plain asphalt emulsion have lasted 3 to 4 years, depending on traffic (*28*). In Washington State, chip seals using a polymer-modified sealer have lasted as long as 5 to 7 years on high-volume roadways (*26*).

Thin Hot-Mix Asphalt Overlays: The performance and the constructibility of the surface treatments discussed above are especially sensitive to traffic volumes. When the traffic volumes are high and it is no longer possible to obtain satisfactory performance or to construct the surface treatment, a thin overlay consisting of approximately 30 mm or less (1¼ in.) of a hot-mix asphalt (HMA) concrete is applied. The service life of a thin overlay ranges from about 8 years to 11 years (*26*).

Composite Pavement

Preventive maintenance treatments for flexible pavements are also applicable to a composite pavement. In addition, the sawed and sealed transverse joints need to be resealed periodically to keep water from entering the pavement structure. The same crack sealing techniques used for flexible pavements are also applicable to composite pavements.

Rigid Pavement

Joint and Crack Sealing

The importance of properly sealed joints and cracks in concrete pavements cannot be overstated. Sealing of longitudinal lane/shoulder joints is considered equally as important as sealing of transverse joints. As was the case with flexible pavements, cracks should be routed and sealed. Properly sealed joints and cracks increase the life of the pavement by preventing the infiltration of incompressibles into the joint and cracks and by reducing the amount of moisture entering the pavement structure (*17*). The life of a PCC joint seal ranges from 2 years to 8 years and depends greatly on the care taken to clean and prepare the crack or joint opening, the type of joint material used, and the care taken to place the material.

Retrofit Load Transfer

The failure of the dowel or the load transfer device across the transverse joint for any reason leads to accelerated pavement pumping and slab cracking. Retrofit load transfer is restoring load transfer across joints in PCC or placing load transfer devices across any cracks that may have developed since the pavement was constructed. While a variety of devices have been tried, the most promising devices are smooth, round dowels for joints or deformed reinforcing bars for non-working cracks where there is not vertical movement. These devices are placed in slots in the pavements that are backfilled with concrete patching material. This is a relatively recent practice and there is limited experience with the technique. However, based on work done in Puerto Rico, FHWA reports that it appears an additional 10-15 years service life may be obtained for PCC pavements using this technique (*29*).

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Sample Budget Options Report

I. Purpose

The purpose of the Network-Level Budget Options Report is to assist the agency in utilizing the results of the agency's Network-Level Pavement Management System (PMS). Specifically, we are trying to link the PMS recommended repair program costs to your budget and improve your overall maintenance and rehabilitation strategy. This report should help you to assess the adequacy of your revenues to meet the maintenance needs recommended by the PMS program. It should also help you in getting a maximum return for your expenditure by: (1) implementing a multi-year roadway rehabilitation and maintenance program, (2) developing a preventive maintenance program, and (3) selecting the most cost effective repairs.

II. Summary and Findings

- The estimate of the agency's total Department of Public Works (DPW) roadway related revenues projected over the next five years is $6.36 million. Of that amount, $1.97 million is estimated to be available for pavement repair.
- Based on the survey of the agency's roadway network and past spending practices, the overall Pavement Condition Index (PCI) of the system is 75[1] or a "Very Good" condition. Section III-C illustrates the current condition of the agency's roadways. **Figure A** shows the current condition of the agency's roadways — functional class by condition.
- **Using the most cost-effective strategies, the PMS Recommended Program will require an expenditure of $7.0 million over the next five years or roughly $1.4 million per year, if this expense is spread evenly.**
- **Comparison of the cost to fix the network with the projected estimated revenues indicates a deficit of $5.0 million over the five-year period, based on staff estimates.**

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[1]On a scale of 0-100:

	70-100	=	Excellent/Very Good
	50-69	=	Good/Fair
	25-49	=	Fair/Poor
	0-24	=	Very Poor/Failed

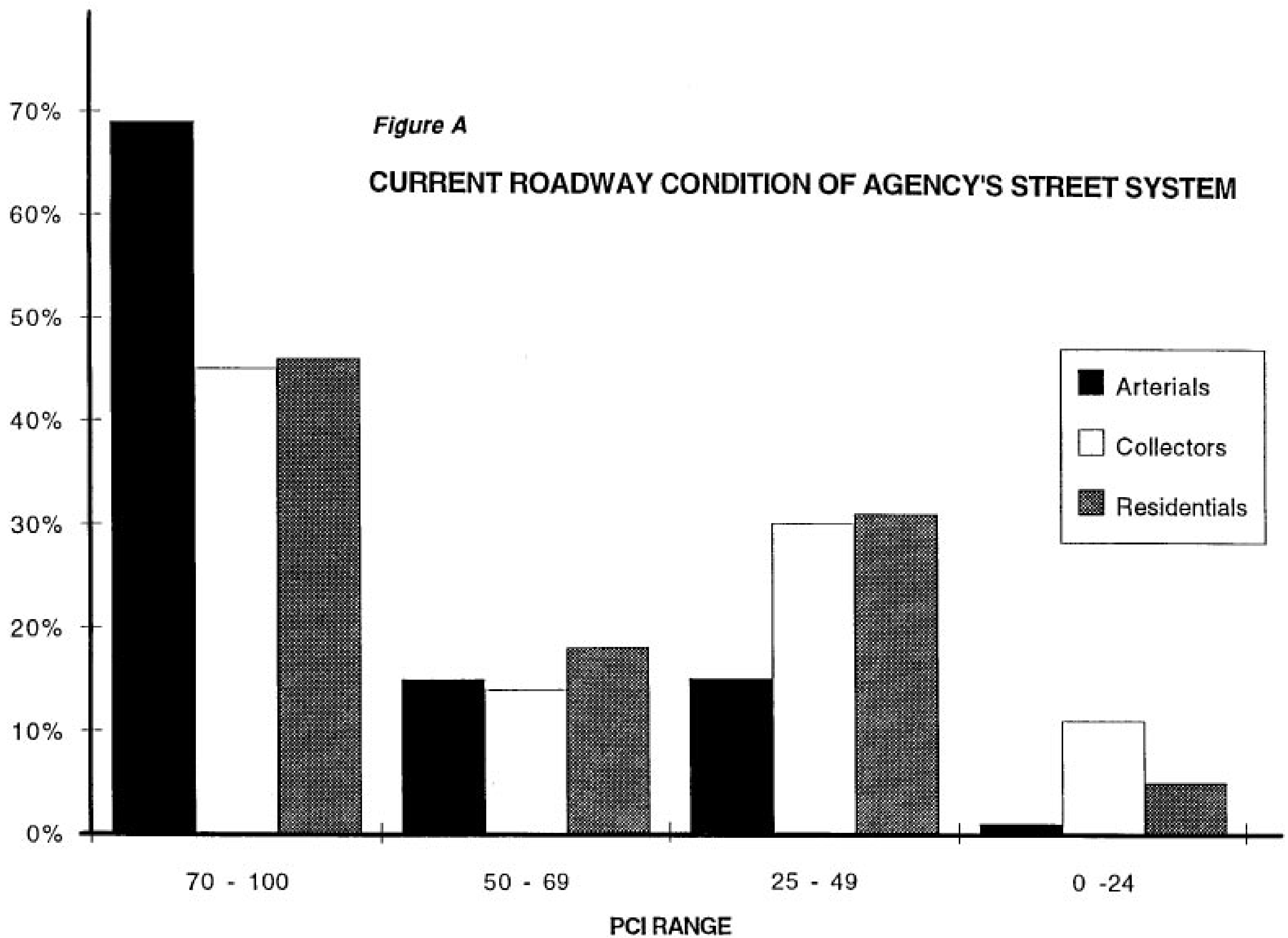


Figure A
CURRENT ROADWAY CONDITION OF AGENCY'S STREET SYSTEM
70%
60%
50%
40%
30%
20%
10%
0%
Arterials
Collectors
Residentials
70 - 100
50 - 69
25 - 49
0 -24
PCI RANGE

- Various budget levels and maintenance options have been tested to illustrate and evaluate various levels of pavement repair expenditures over a five-year analysis period. The four budget options programs tested are as follows:

  Option 1 — The PMS Recommendation (heavy needs in first year)

  Cost — $7.0 million over five years with $4.4 million in the first year.

  Rehabilitation/Preventive Maintenance Split — Varies by year from 0 percent to 26 percent for preventive maintenance.

  Result — PCI is raised from 75 to 84 in the first year and then maintained at 84. There is no deferred maintenance in any year.

  Option 2 — Modified PMS Recommendation (needs spread evenly over five years)

  Cost — $7.0 million over five years at $1.4 million per year.

  Rehabilitation/Preventive Maintenance Split — A constant 9 percent per year for preventive maintenance.

  Result — PCI gradually rises to 84 by fifth year, and a deferred maintenance cost of $3.0 million in the first year has dropped to $.5 million by the fifth year.

  Option 3 — Test Funding Level Between PMS Recommendation and Estimate of the Agency's Revenues

  Cost — $4.5 million over five years at $0.9 million per year.

  Rehabilitation/Preventive Maintenance Split — A constant 9 percent per year for preventive maintenance.

  Result — PCI rises to 82 by fifth year, and deferred maintenance is $3.5 million in year one increasing slightly to $3.7 million by year five.

  Option 4 — Constrained to Estimate of the Agency's Revenues

  Cost — $1.9 million over five years; $0.32 million in first year projected at a 10 percent growth rate per year.

  Rehabilitation/Preventive Maintenance Split — A constant 9 percent per year for preventive maintenance.

  Result — PCI slightly decreasing to low 70s, and deferred maintenance of $4.1 million rises to $7.0 million by year five.

- **Figure B** is a chart showing the impact of the maintenance and rehabilitation options on the roadway network PCI over a five-year period. **Figure C** is a chart showing the impact of deferred maintenance on the roadway network by option over a five-year period.
- The future condition of the roadway network under selected options over a five-year production period will be:

		Years				
		1	**2**	**3**	**4**	**5**
No Maintenance Option:	PCI =	69	67	65	63	61
Option 1:	PCI =	84	84	84	84	84
Option 2:	PCI =	76	78	82	83	84
Option 3:	PCI =	74	77	78	79	82
Option 4:	PCI =	71	71	71	72	72

- **Figure D** shows the above table graphally.

III. Overview

A. Organization of Report

The report is composed of six sections. Each section identifies and evaluates a technical or financial component linking the output of the program to the jurisdiction's budget process.

Section A estimates total Department of Public Works' (DPW) roadway revenues available over the next five years. Based on a 10 percent annual growth rate, the agency will generate roughly $6.36 million in total roadway revenues over the five-year projection period shown in Table 4. Based on seven-year historical trends (see Table 2), 31 percent of total roadway revenues is available for pavement repair work yielding a pavement repair budget of $1.97 million over the next five years.

Section B identifies the existing condition of the roadway network and recommended treatments utilizing outputs from the Budget Needs module. The objective of the model is to bring the roadway network up to a very good condition and maintain it there. Based on a PCI developed to measure the health of the existing pavement, the current overall condition of the agency's network is considered to be in very good condition (PCI 75). Based on the analysis and past spending practices, a portion of the current network is suffering from load-related distress and some deferred maintenance. If not corrected, the

Figure B

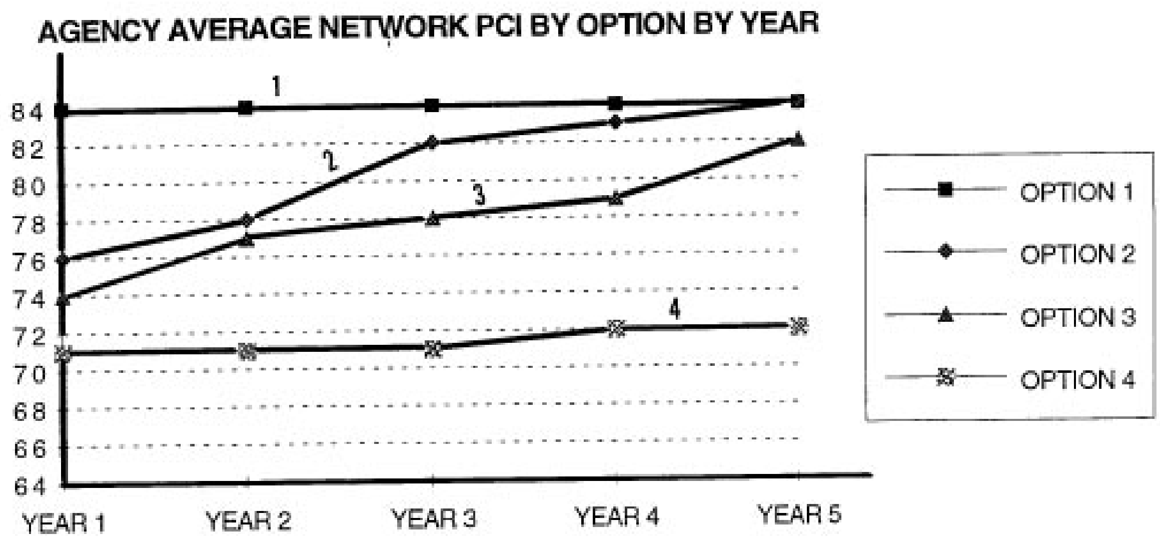


Figure C

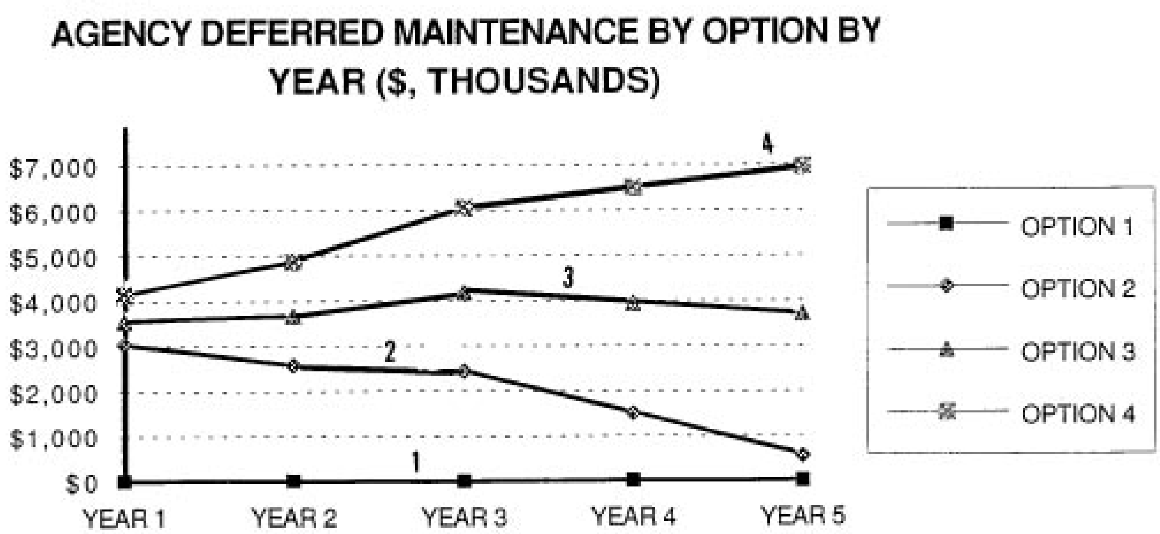
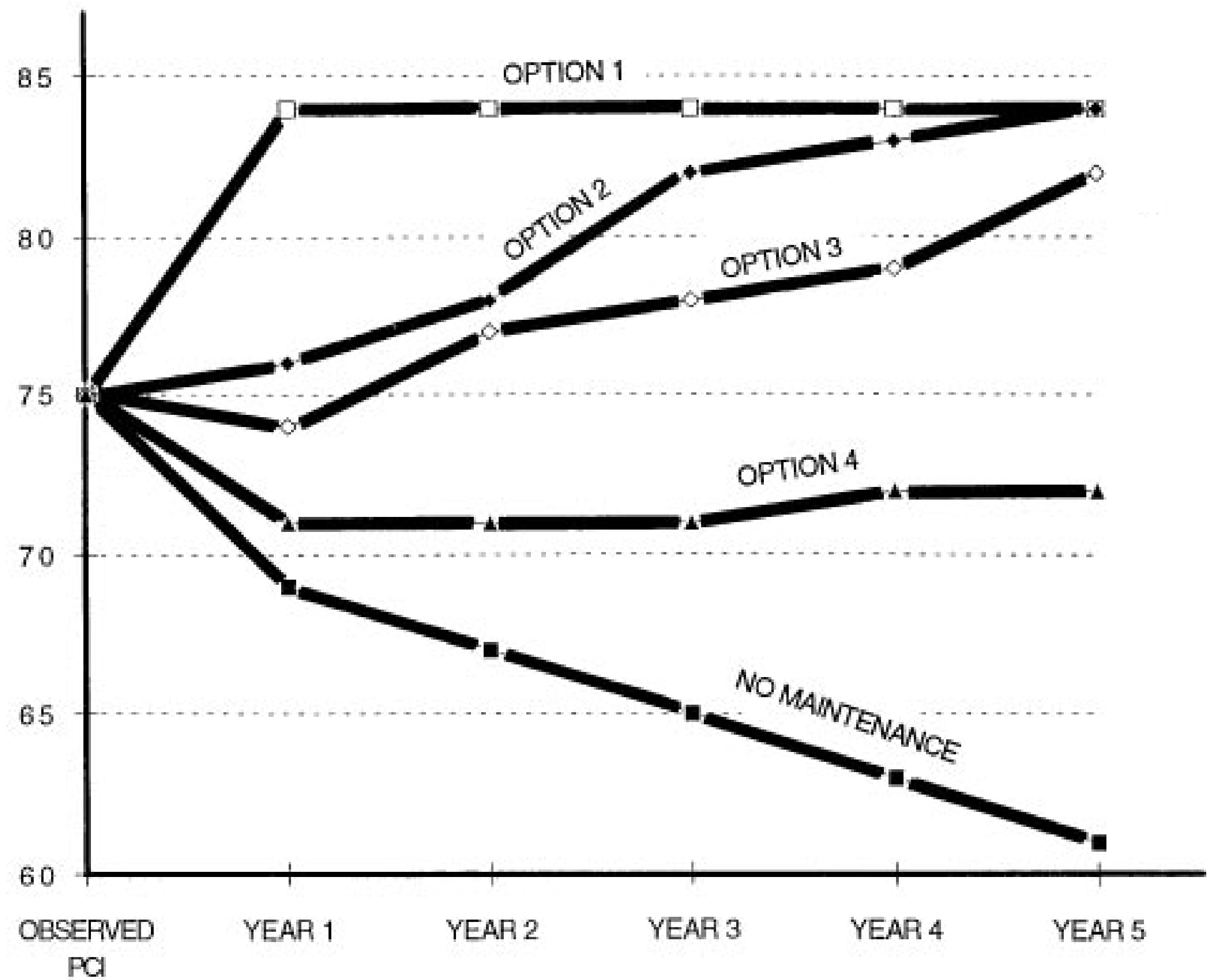


Figure D

IMPACT ON THE PAVEMENT CONDITION INDEX OF THE NO MAINTENANCE OPTION AND 4 OTHER OPTIONS



quality of the roadway network will decline. Correcting this deficiency requires the implementation of a cost-effective spending level to improve the roadway network, and a cost-effective maintenance and rehabilitation strategy. As a result of the data entered by the agency into the model, the condition of the current network now requires the city to spend roughly $7.0 million over the next five years to repair the network, based on the costs to fix roadways.

If no maintenance is applied to the network over the next five years, its condition will continue to deteriorate (down to an average PCI of 61 due to the acceleration of existing distresses identified in the analysis).

Section C compares projected revenues against the cost to fix the network. Generally, the cost to fix will initially be very high if past spending practices have resulted in deferred maintenance. Table 4 shows that the deficits resulting from a front-loaded repair program are from a program that spreads expenditures evenly over the five-year period. As shown in Table 4, based on the revenue assumptions applied, the agency's five-year needs call for spending roughly $7.0 million. Roughly 65 percent of this PMS needs repair program or $4.44 million is programmed in year one to catch up on deferred maintenance and reduce roadway repair costs in the other years. We estimate that the city is short roughly $5 million over the five-year period for roadway repair needs.

Section D reviews options and issues that the agency may wish to consider in revising their maintenance strategy. We have listed five items for consideration.

Section E compares budget levels and maintenance options. Utilizing the budget module permits the testing of alternative budget levels and splits between rehabilitation and preventive maintenance. Four options are tested an the impacts are evaluated.

Section F provides recommendations that the agency's staff may wish to consider as they continue to build and refine their pavement maintenance program and budget.

B. Next Steps

The results of this analysis are but a beginning in building an effective roadway maintenance program. You should, for example, check to validate your distress survey since it is possible that errors in survey data may have been overlooked. In addition, sections identified for treatment should require more detailed subsurface information before major rehabilitation projects are undertaken. You should evaluate the specific treatments and costs used to verify that they match the fixes and unit costs you would expect to use. You should also test other budget options, varying revenues, preventive/rehabilitation splits, and even repairs on specific roadways. Finally, we recommend that you prepare a brief memo to the council outlining the recommended five-year repair program. The memo should include the amount of revenue available for pavement repair, a list of roadways, the types of repairs to be completed by year, and a request for action.

C. Profile of Jurisdiction

Profile of Roadways

Total Centerline Miles: 79

Length by Functional Class — Centerline Miles

	Centerline Miles	**Lane Miles**
Arterials	15	31
Collectors	10	19
Residentials	54	108
Total	79	158

Replacement Cost: $71,700,000

Replacement Cost Per Lane Mile: $454,000

Sections: (The 158-lane miles were divided into roughly 431 sections.)

Arterials	34
Collectors	26
Residentials	371
	431

Conditions

Grade	**No. of Sections**	**PCI**	**%**
A,B	280	70-100	65%
C	70	50-69	16%
D	66	25-49	15%
E	15	24	4%
	431	75	= Average PCI for all roadways

IV. Budget Analysis Report: Evaluation and Discussion of Component Sections

A. Estimate of Roadway Revenues and Expenditures

Roadway Revenues

The agency's total roadway revenues by source from FY 81/82 to FY 87/88 are as follows:

Table 1

Total Roadway Revenues
($, Thousands)

	Year							7-Year	% of
	1981/2	1982/3	1983/4	1984/5	1985/6	1986/7	1987/8	Total	Total
Federal	0	0	0	0	0	0	0	0	0%
State	133	192	260	254	409	340	298	1,886	30%
Local	342	395	402	366	754	658	1,387	4,304	70%
Total	475	587	662	620	1,163	998	1,685	6,190	100%
Total (less SB 300)	475	587	662	620	1,025	970	1,685	6,024	100%
Growth Rate (%)	24	13	(6)	65	(5)	73		Ave. = 27.3	

Discussion

As shown in Table 1 above, total roadway revenues increased considerably during the seven-year period. During this time, the agency experienced an average growth rate of 27 percent in roadway revenue. In 1981/82, total roadway revenues were $475,000. By 1987/88, they had increased to $1,685,000. This large increase can be attributed to the agency claiming TDA Article 8 funds in 1985/86, 1986/87, and 1987/88. During this three-year period, close to $1.3 million was derived from Article 8 of the Transportation Development Act (TDA). These funds were instrumental in resurfacing many of the agency's roadways over the three year-period beginning in 1985/86. Local revenues consisting of both general purpose funds and TDA Article 8 funds amounted to 70 percent of the agency's total roadway budget. State revenue provided 30 percent of the budget. These funds were almost entirely derived from gas tax revenue, although there were increases in the state share in 1985/86 and in 1986/87. This was attributed to a one-time SB 300 allocation which was used for roadway overlay programs. The agency received no federal funds during the seven years. Future total revenues for this report were based on the average seven-year total of $860,571 and were projected based on a more modest 10 percent annual growth rate. See Table 4 for projection details.

Pavement Expenditures

The agency's pavement repair expenditures by type of repair from FY 8l/82 to FY 87/88 are as follows:

Table 2

Total Pavement Repair Expenditures
($, Thousands)

	Year							7-Year	% of
	1981/2	1982/3	1983/4	1984/5	1985/6	1986/7	1987/8	Total	Total
Reconstruction	0	1	0	0	52	107		1,125	58%
Patching	0	0	0	0	0	0	0	0	0%
Overlay/ Seals	30	35	179	0	236	332	6	818	42%
Total	30	36	179	0	288	439	971	943	100%
% of Total Revenues	(6%)	(6%)	(27%)	(0%)	(25%)	(44%)	(58%)	(31%)	

Discussion

In reviewing Table 2 (above), there are two different agencies to discuss. Of the 1,943,000 that went into pavement repair during the seven-year period, only $245,000 or less than 13 percent was expended in the first four years of the analysis. In FY 1985/86 through FY 1987/88, $1,698,000 or 87 percent was spent. During these last three years, $1,124,000 was spent on reconstruction. In comparison, nothing was spent in the first four years. This trend was similar for overlays/seals. In the last three years, $574,000 was spent, whereas in the first three years, only $244,000 was expended. The higher level of spending in the last three years can be attributed to the influx of TDA Article 8 funds which were used for resurfacing projects. While this complete reversal of spending practices can be attributed to better recognition of roadway network deterioration and then applying proper funding, it is unlikely that this trend can continue. It is also unlikely that the low level of expenditure that occurred in the first four years of this analysis will again become the norm. Therefore, for the purposes of projecting revenues available, the staff proposes to use 31 percent of total public works roadway revenues available for pavement repair purposes. Thirty-one percent is the seven-year average of total roadway revenues that were made available for pavement repair in FY 1981/82 through FY 1987/88. As a result, an estimated $1,971,000 is to be made available for pavement repair over the five-year period. This represents an average of 42 percent higher per year expenditure for pavement repair than the agency previously spent in the seven years starting in FY 1981/82 and ending in FY 1987/88. **Figure E** details projected and future road revenues and pavement repair expenditures.

B. Recommended Repair Strategy and Cost

The needs program generates the optimum treatments for a five year period. It also shows the resulting pavement condition (PCI) if the recommended treatments are followed. The summary for the agency is shown in Table 3. **Figure F** shows a breakdown of the five-year needs program of maintenance treatments for the city, compared to the historical program.

Discussion

As shown in Table 3, the current overall health of the network is considered to be in very good condition (75) based on the pavement condition index (PCI). Implementation of the optimum needs program increases the network PCI condition to a very good condition (84) by the fifth year. If no maintenance rehabilitation treatments are applied to the network in the next five years, the overall network condition will deteriorate to a fair condition (PCI of 61) by year five.

The needs program calls for spending roughly $7.0 million over the next five years based on the condition of the agency's network and the treatments and repair costs that reflect those utilized in the agency. Of that amount, roughly $6.4 million (92 percent) is programmed for rehabilitation treatments and $0.6 million (8 percent) is programmed for preventive maintenance treatments.

The optimum or recommended objective is to bring the roadway network up to a PCI level of around 85 (excellent) because that is the level at which it is the most cost effective to maintain the network over time. Anything significantly less than a PCI of 85 means more dollars are expended on more expensive repairs.

Figure E

AGENCY HISTORY AND PROJECTIONS OF REVENUES AND EXPENDITURES ($ THOUSANDS)

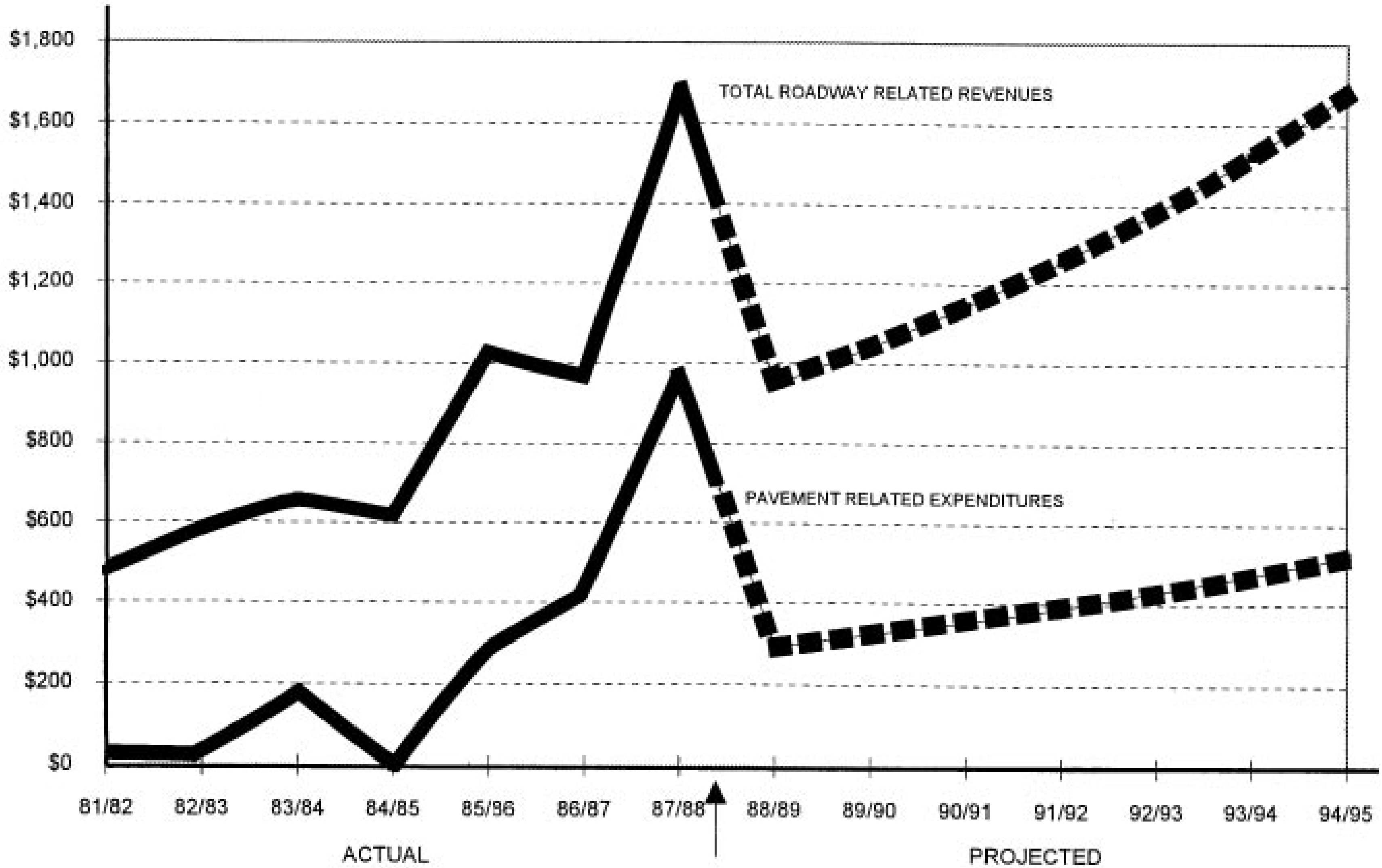


FIGURE F1

AGENCY ACTUAL EXPENDITURES 1981/82 - 1987/88

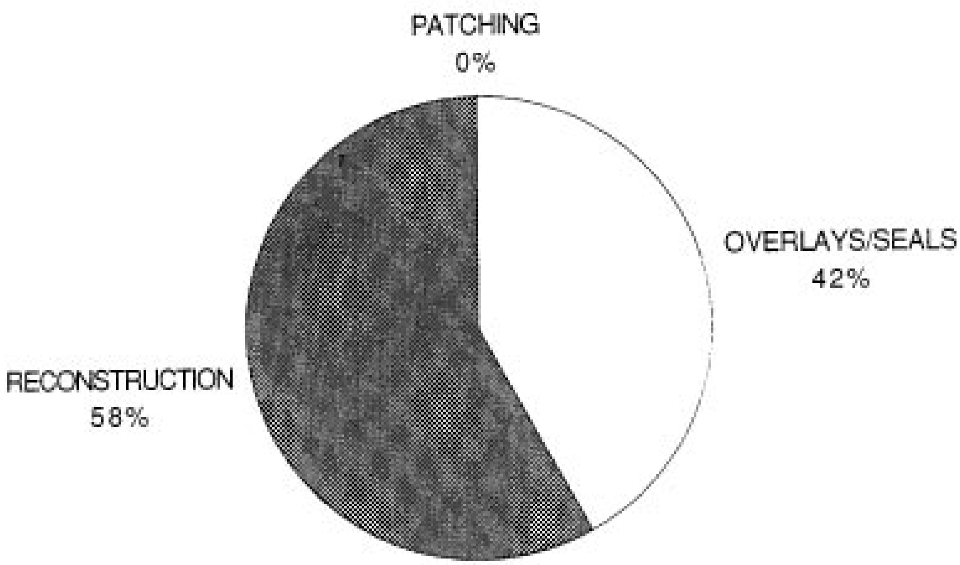
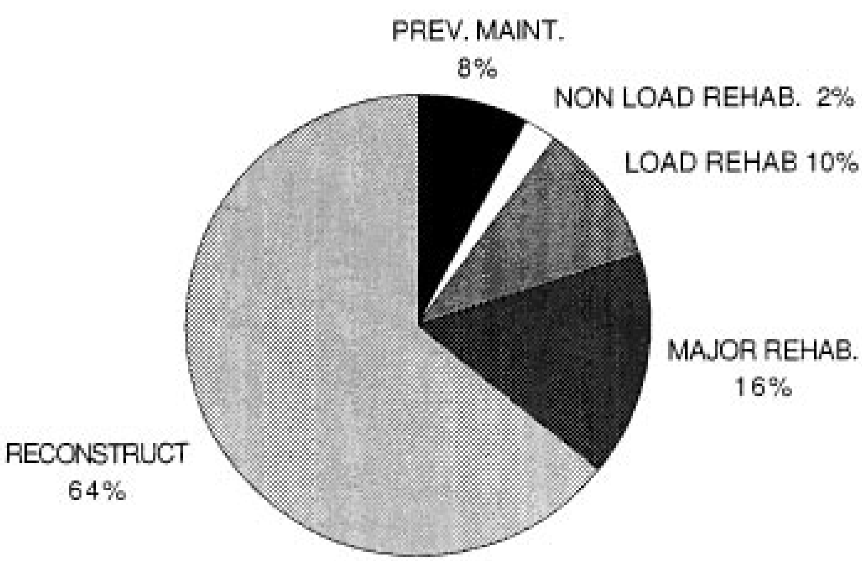


FIGURE F2

AGENCY RECOMMENDED TREATMENTS 1990/91 - 1994/95



This shift toward higher levels of spending on the pavement is the result of:

1. Catching up on prior deferred maintenance. Though the agency has applied the funding into roadway repair in FY 1985/86 to 1987/88, the neglect that occurred prior to this infusion of capital still persists.
2. An unbalanced repair program. Though considerable effort has been put into overlays and reconstruction, this implies that the agency has embarked on a "worst-first" strategy. Even though this is necessary to improve the level of the roadway network, special considerations should be given to a preventive maintenance program once the roadways have improved. Over time, this will bring down the costs of repair. If no preventive maintenance program is adopted, then the agency can expect to continue to pay for major rehabilitation projects at a much higher cost.

C. Revenues Compared to Needs to Determine Surplus/Deficit

Table 4 compares the revenues projected in Section A with the costs projected in Section B. The distribution of these costs over the five years is "front loaded." That is, basic pavement management concepts state that the best maintenance strategy is to bring the pavement sections up to a "very good" condition and keep them that way. Consequently, if some roadways have been allowed to deteriorate (deferred maintenance), there will be higher front end costs. In most cases, given limited levels of funding, the local government budget process is difficult to front load. Table 4 shows both the front loaded PMS needs scenario and one in which repair costs are spread evenly. Over the five year period, there is roughly a total deficit of $5.0 million. As a result, the estimate of the agency's revenues will cover roughly 28 percent of its total pavement repair needs over the next five years.

D. Major Issues/Options

- The deficit can be either:
  - * Deferred (thereby reducing the overall network condition and increasing maintenance costs in future years); or
  - * Addressed by reducing other nonpavement related expenses, additional local revenues, or some combination of the two.
- Additional public works revenues in year one to address backlog.

Table 3

PMS Recommended Treatments and Costs — Resulting PCI
($, Thousands)

Treatments (PM)	Year (1)	(2)	(3)	(4)	(5)	5-Year Total	% of Total
Seal Cracks	1	0	0	1	5	7	0%
Slurry Seal	370	99	2	98	17	586	8%
Total Cost (PM)	371	99	2	99	22	593	8%
Treatments (Rehab.)							
Slurry Seal	99	31	31	0	0	161	2%
Mill and Thin Overlay	261	250	90	61	0	662	9%
Thin AC Overlay (1.5 inches)	68	0	0	0	0	68	1%
Thick AC Overlay (2.5 inches)	16	0	0	0	0	16	0%
Heater Scarify and Overlay	590	180	209	0	55	1,034	15%
Reconstruct Surface	3,037	186	750	217	295	4,486	64%
Total Cost (Rehab)	4,071	647	1,081	278	350	6,427	92%
Total Cost (Rehab & PM)	4,442	746	1,083	377	372	7,020	
Percent. of Recommended Program	63%	11%	16%	5%	5%	100%	
Projected PCI Mean at Year One = 75 (A)	84	84	84	84	84	84	
No Maintenance PCI Mean at Year One = 75 (A)*	69	67	65	63	61	65	

*On a scale of 0-100:
70-100 = Excellent/Very Good
50-69 = Good/Fair
25-49 = Fair/Poor
0-24 = Very Poor/Failed

- Errors committed during roadway surveys and subsequent computer data entry can have appreciable affects on the assessed roadway condition and the subsequent costs of maintenance repair programs. At all stages of data acquisition and processing, it is prudent to check the data for errors, including quality control checks on pavement condition surveyors, and to carefully edit all data entered into the computer.
- Prior experience shows that treatment unit costs can significantly impact total pavement repair. These costs should be carefully reviewed to see that they represent typical costs incurred by the agency.
- Breaking the network down by functional classification (i.e., arterials, collectors, residentials) creates three networks within one to test various budget levels, maintenance strategies, and possible priorities. For example, the city might want to consider directing higher repair priorities to arterials.

E. Testing Alternative Budget Levels and Repair Strategies

The PMS budget options module allows the agency to test alternative maintenance/budget scenarios. A base year revenue estimate, a growth rate and a split between preventive (lighter maintenance applied to sections with PCI between 100 and 70) and rehabilitation (heavier maintenance applied to sections with PCI between (69 and 0) are user-specified. The PMS matches this budget with the PMS recommended fixes which are prioritized by section based on an effectiveness measure.

The process for each year starts with the rehabilitation budget in which projects are selected in priority order down to the dollar amount specified. If more sections require rehabilitation, stop-gap costs are assigned. These costs are taken from the preventive maintenance budget. The preventive budget then selects projects in priority order, as with rehabilitation, until the budget is exhausted. Projects not selected are deferred to the next year and the process repeats through each of the five years. Outputs by year include average network PCI as well as dollars going to rehabilitation, preventive maintenance, stop-gap, and deferred maintenance.

Four options have been tested. See the following pages for a brief summary and description of each option.

Table 4

Five-Year Roadway Related Revenue/Pavement Repair Summary Table ($, Thousands)

	Year 1	Year 2	Year 3	Year 4	Year 5	5-Year Total
Total Projected Revenues (10%)[1]	1,041	1,145	1,260	1,386	1,525	6,357
Revenues to Pavement Repair (31°L)[1]	323	355	390	430	473	1,971
Front Loaded						
Recommended PMS Program Five Years	4,442	746	1,083	377	372	7,020
Repair Program Surplus (Deficit)	(4,119)	(391)	(693)	53	101	(5,049)
Spread Evenly						
Recommended PMS PMS Program Spread Evenly	1,404	1,404	1,404	1,404	1,404	7,020
Repair Program Surplus (Deficit)	(1,081)	(1,049)	(1,014)	(974)	(931)	(5,049)

[1]Note the two key assumptions: a 10 percent revenue growth rate (which is less than the average annual growth rate from 1987/88) and 31 percent of revenues going to pavements for patching, sealing, overlays, and rehabilitation. The average seven-year revenue total of $860,571 was used in 1988/89 and was increased to reflect 1990/91 in year 1 above.

Table 5-1
Option 1
Budget Levels/Maintenance Options

0% Budget Increase Factor — 0% Interest — 5% Inflation

Year PM %	**8%**	**13%**	**0%**	**26%**	**5%**
Year Totals	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Budgets	$4,442,082	$746,588	$1,082,767	$377,386	$ 371,628
Rehabilitation	4,071,109	647,047	1,080,407	277,808	349,933
Prev. Maint.	370,973	99,541	2,360	99,578	21,695
Stop Gap	0	0	0	0	0
Deferred	0	0	0	0	0
Surplus PM	0	0	0	0	0

Category of Repairs	**Totals**
Rehabilitation	$ 6,426,304
Preventive Maintenance	$ 594,147
Stop Gap Maintenance	$ 0
Average Annual Deferred Preventive Maintenance Change	$ 0
Average Annual Surplus Preventive Maintenance Change	$ 0

Projected PCI Condition

	Latest PCI	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Network Mean	74.7	83.6	83.9	84.3	83.7	83.8

Discussion

This is the optimum budget level ($7.02 million) “front loaded,” as recommended by PMS. Points to highlight are: (1) the PCI level immediately rises to an average of 84 and remains at that level, and (2) there is no deferred maintenance in any of the five years. Note also that the rehabilitation/preventive maintenance split follows the exact splits recommended by the PMS.

Table 5-2
Option 2
Budget Levels/Maintenance Options

0% Budget Increase Factor — 0% Interest — 5% Inflation

Year PM % **Year Totals**	**9%** **Year 1**	**9%** **Year 2**	**9%** **Year 3**	**9%** **Year 4**	**9%** **Year 5**
Budgets	$1,404,090	$1,404,090	$1,404,090	$1,404,090	$ 1,404,090
Rehabilitation	1,274,830	1,276,554	1,276,664	1,277,356	1,264,493
Prev. Maint.	128,095	122,340	127,143	91,324	31,804
Stop Gap	1,165	5,172	0	0	0
Deferred	3,039,157	2,582,474	2,444,133	1,503,749	548,195
Surplus PM	0	24	283	35,410	107,793

Category of Repairs	**Totals**
Rehabilitation	$ 6,369,897
Preventive Maintenance	$ 500,706
Stop Gap Maintenance	$ 6,337
Average Annual Deferred Preventive Maintenance Change	$ -662,741
Average Annual Surplus Preventive Maintenance Change	$ 26,948

Projected PCI Condition

	Latest PCI	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Network Mean	74.7	76.3	77.5	82.4	83.1	83.8

Discussion

This is the optimum budget level ($7.02 million) as recommended by PMS, but spread evenly over the five-year period at $l.4 million per year. Of special note is that the PCI gradually climbs from 76 in the first year to 84 in the fifth year, but there is a significant amount of deferred maintenance ($3 million in year one, decreasing to $.55 million in the fifth year). About $6,000 is pulled from the preventive maintenance program to provide stop-gap maintenance on those sections where repairs are deferred.

Table 5-3
Option 3
Budget Levels/Maintenance Options

0% Budget Increase Factor		0% Interest		5% Inflation	
Year PM %	**9%**	**9%**	**9%**	**9%**	**9%**
Year Totals	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Budgets	$ 899,000	$ 899,000	$ 899,000	$ 899,000	$ 899,000
Rehabilitation	817,316	814,283	811,892	817,983	805,596
Prev. Maint.	71,432	77,940	85,220	80,798	92,975
Stop Gap	10,252	6,777	1,818	0	0
Deferred	3,553,334	3,678,659	4,184,706	3,946,267	3,708,236
Surplus PM	0	0	70	219	429

Category of Repairs	**Totals**
Rehabilitation	$ 4,067,070
Preventive Maintenance	$ 408,365
Stop Gap Maintenance	$ 18,847
Average Annual Deferred Preventive Maintenance Change	$ 38,726
Average Annual Surplus Preventive Maintenance Change	$ 107

Projected PCI Condition

	Latest PCI	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Network Mean	74.7	74.3	76.9	78.3	79.3	82.1

Discussion

This option represents a budget level of $4.5 million, roughly halfway between the required $7.02 million and the agency’s estimate of available revenues: $1.97 million. It improves the average PCI from a 74 in the first year to an 82 in year five. It also begins to curtail the increase of deferred maintenance by year five. Nonetheless, deferred maintenance is $3.7 million by the fifth year. About $9,000 is pulled from the preventive maintenance program to provide stop-gap maintenance on those sections where repairs are deferred.

Table 5-4
Option 4
Budget Levels/Maintenance Options

0% Budget Increase Factor   0% Interest   5% Inflation

Year PM %	**9%**	**9%**	**9%**	**9%**	**9%**
Year Totals	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Budgets	$ 323,000	$ 355,000	$ 390,000	$ 430,000	$ 473,000
Rehabilitation	293,031	322,576	352,596	391,216	428,892
Prev. Maint.	5,041	19,405	28,627	37,125	44,058
Stop Gap	24,928	13,019	8,777	1,642	0
Deferred	4,144,010	4,869,216	6,067,808	6,505,569	6,966,580
Surplus PM	0	0	0	17	50

Category of Repairs	**Totals**
Rehabilitation	$ 1,788,311
Preventive Maintenance	$ 134,256
Stop Gap Maintenance	$ 48,366
Average Annual Deferred Preventive Maintenance Change	$ 705,641
Average Annual Surplus Preventive Maintenance Change	$ 12

Projected PCI Condition

	Latest PCI	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Network Mean	74.7	70.8	71.0	70.6	72.2	71.7

Discussion

This option utilizes the agency’s estimated available revenues — $323,000 in year one, escalated by 10 percent per year up to $473,000 in year five. This option maintains the PCI in the low seventies, though the first year deferred maintenance is $4.1 million. This amount increases to $7 million by year five. Stop-gap maintenance increases to $50,000.

F. Recommendations

In evaluating PMS options, the following criteria should be considered.

1. A pavement condition index (PCI) that is increasing over the five-year period.
2. Deferred maintenance that is decreasing over time.

Clearly, the PMS recommended Option l provides the most cost-effective expenditure of funds. However, this would require the agency to generate an additional $5.0 million in revenues (in the next five years) beyond the $2.0 million estimate. Further, almost 63 percent of the total revenues of $7.0 million would be required in the first year. If the agency wants to consider this option, there are a number of funding strategies available, including assessment districts, bonding, and initiatives.

Option 2 spreads the five-year $7.0 million costs evenly by year. This is the second best option.

Option 3 tests the impact of a $4.5 million budget level which is between Option 2 and 4. This would be a minimally acceptable level since it begins to reduce the deferred maintenance, albeit slowly.

Option 4 tests the impact of a trend projection of the agency's revenues. It shows a significant deferred maintenance cost in the first year which grows throughout the five years. This is unacceptable.

We would recommend that the agency continue to evaluate other scenarios which test differing budget levels and differing maintenance program priorities. Given that the agency's pavement maintenance needs require more than triple the projected revenues, all of the following actions are necessary:

- Seek Additional Revenues
    * Spend existing pavement maintenance revenues more cost effectively.
    * Examine the feasibility of reallocating other public works revenues to pavement maintenance.
    * Seek additional funds.

With the passage of SB 975 in 1989, pavement maintenance can now be used under the benefit assessment act of 1982. This act allows the council to levy a benefit assessment pursuant to specified procedures to finance the maintenance of roadways or highways.

Also, if Prop. 111 passes (SCA 1) in June 1990, it is estimated that the agency will receive $153,000 in additional gas tax subvention revenues a year. Though this puts only a dent in the large shortfall, the amount will assist the agency in the long run.

- Evaluate maintenance Program Options
    - * Develop and fully fund the preventive maintenance program including the required stop-gap maintenance on deferred projects.
    - * Recommended treatments (particularly the heavier repairs like reconstruction) should be evaluated in more detail to build projects/ contracts.
    - * Link major repairs with utility schedules, if possible.
    - * Group projects of similar type, location, and year.
    - * Consider setting priorities on repairs so that the more heavily traveled roadways (arterials) are repaired first.

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Budget Options Report for a Board or CouncilPurpose

The purpose of the Executive Summary Network-Level Budget Options Report is to assist the agency in utilizing the results of the agency's Network-Level Pavement Management System (PMS). Specifically, we are trying to link the PMS recommended repair program costs to your budget and improve your overall maintenance and rehabilitation strategy. This report should help you to assess the adequacy of your revenues to meet the maintenance needs recommended by the PMS program. It should also help you in getting a maximum return for your expenditure by: (1) implementing a multi-year street rehabilitation and maintenance program, (2) developing a preventive maintenance program, and (3) selecting the most cost-effective repairs.

I. Summary of Findings

- The estimate of the agency's total Department of Public Works (DPW) street related revenues projected over the next five years is $6.36 million. Of that amount, $1.97 million is estimated to be available for pavement repair.
- Based on the survey of the agency's street network and past spending practices, the overall Pavement Condition Index (PCI) of the system is 75[1] or a "Very Good" condition. **Figure A** shows the current condition of the agency's streets — functional class by condition.
- **Using the most cost-effective strategies, the PMS Recommended Program will require an expenditure of $7.0 million over the next five years or roughly $1.4 million per year, if this expense is spread evenly.**
- **Comparison of the cost to fix the network with the projected estimated revenues indicates a deficit of $5.0 million over the five-year period, based on staff projections.**
- Various budget levels and maintenance options have been tested to illustrate and evaluate various levels of pavement repair expenditures

[1]On a scale of 0-100:

70-100	=	Excellent/Very Good
50-69	=	Good/Fair
25-49	=	Fair/Poor
0-24	=	Very Poor/Failed

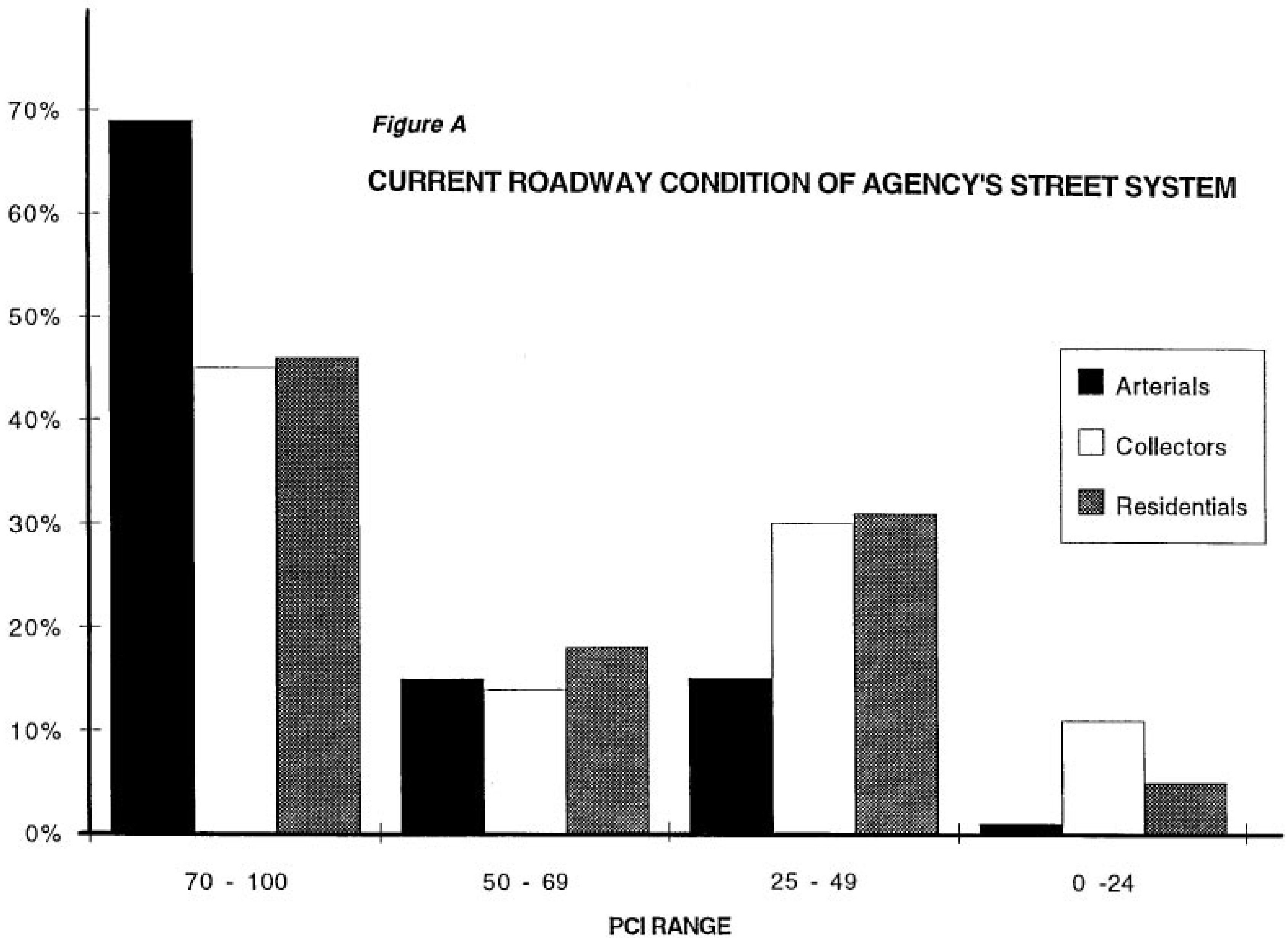


Figure A

CURRENT ROADWAY CONDITION OF AGENCY'S STREET SYSTEM

over a five-year analysis period. The four budget options programs tested are as follows:

Option 1 — The PMS Recommendation (heavy needs in first year)

Cost — $7.0 million over five years with $4.4 million in the first year.

Rehabilitation/Preventive Maintenance Split — Varies by year from 0 percent to 26 percent for preventive maintenance.

Result — PCI is raised, from 75 to 84 in the first year and then maintained at 84. There is no deferred maintenance in any year.

Option 2 — Modified PMS Recommendation (needs spread evenly over five years)

Cost — $7.0 million over five years at $1.4 million per year.

Rehabilitation/Preventive Maintenance Split — A constant 9 percent per year for preventive maintenance.

Result — PCI gradually rises to 84 by fifth year, and a deferred maintenance cost of cost $3.0 million in the first year has dropped to $.5 million by the fifth year.

Option 3 — Test Funding Level Between PMS Recommendation and Estimate of the Agency's Revenues

Cost — $4.5 million over five years at $0.9 million per year.

Rehabilitation/Preventive Maintenance Split — A constant 9 percent per year for preventive maintenance.

Result — PCI rises to 82 by fifth year, and deferred maintenance is $3.5 million in year one increasing slightly to $3.7 million by year five.

Option 4 — Constrained to Estimate of the Agency's Revenues

Cost — $l.9 million over five years; $0.32 million in first year projected at a 10 percent growth rate per year.

Rehabilitation/Preventive Maintenance Split — A constant 9 percent per year for preventive maintenance.

Result — PCI slightly decreasing to low 70s, and deferred maintenance of $4.1 million rises to $7.0 million by year five.

- **Figure B** is a chart showing the impact of the maintenance and rehabilitation options on the PCI of the street network over a five-year period. **Figure C** is a chart showing the impact on deferred maintenance of the street network by option over a five-year period.
- The future condition of the street network under selected options over a five-year production period will be:

		Years				
		1	2	3	4	5
No Maintenance Option:	PCI =	69	67	65	63	61
Option 1:	PCI =	84	84	84	84	84
Option 2:	PCI =	76	78	82	83	84
Option 3:	PCI =	74	77	78	79	82
Option 4:	PCI =	71	71	71	72	72

- **Figure D** shows the above table graphically.

Figure B

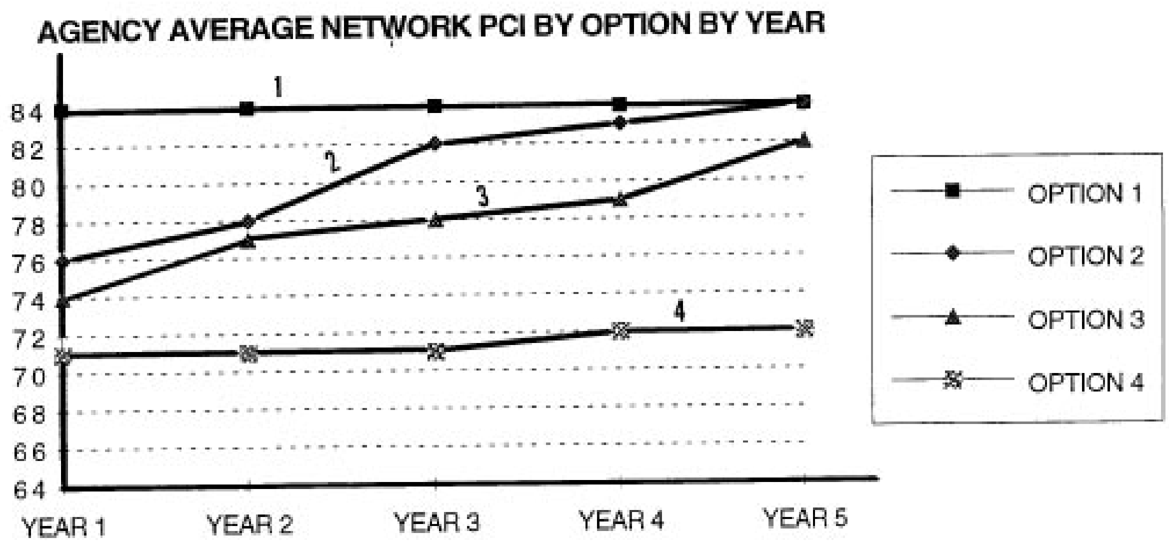


Figure C

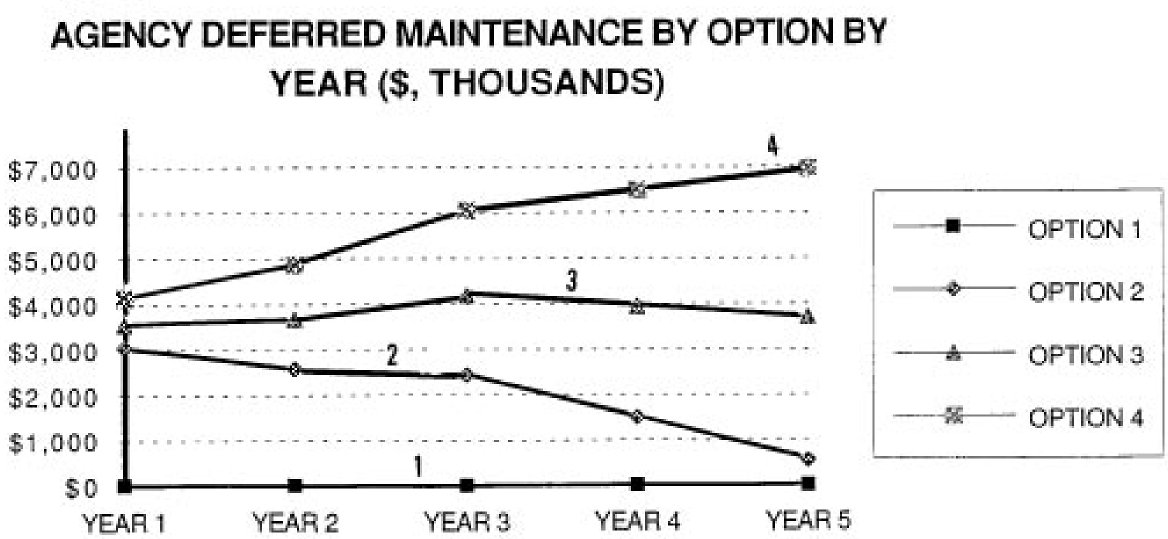
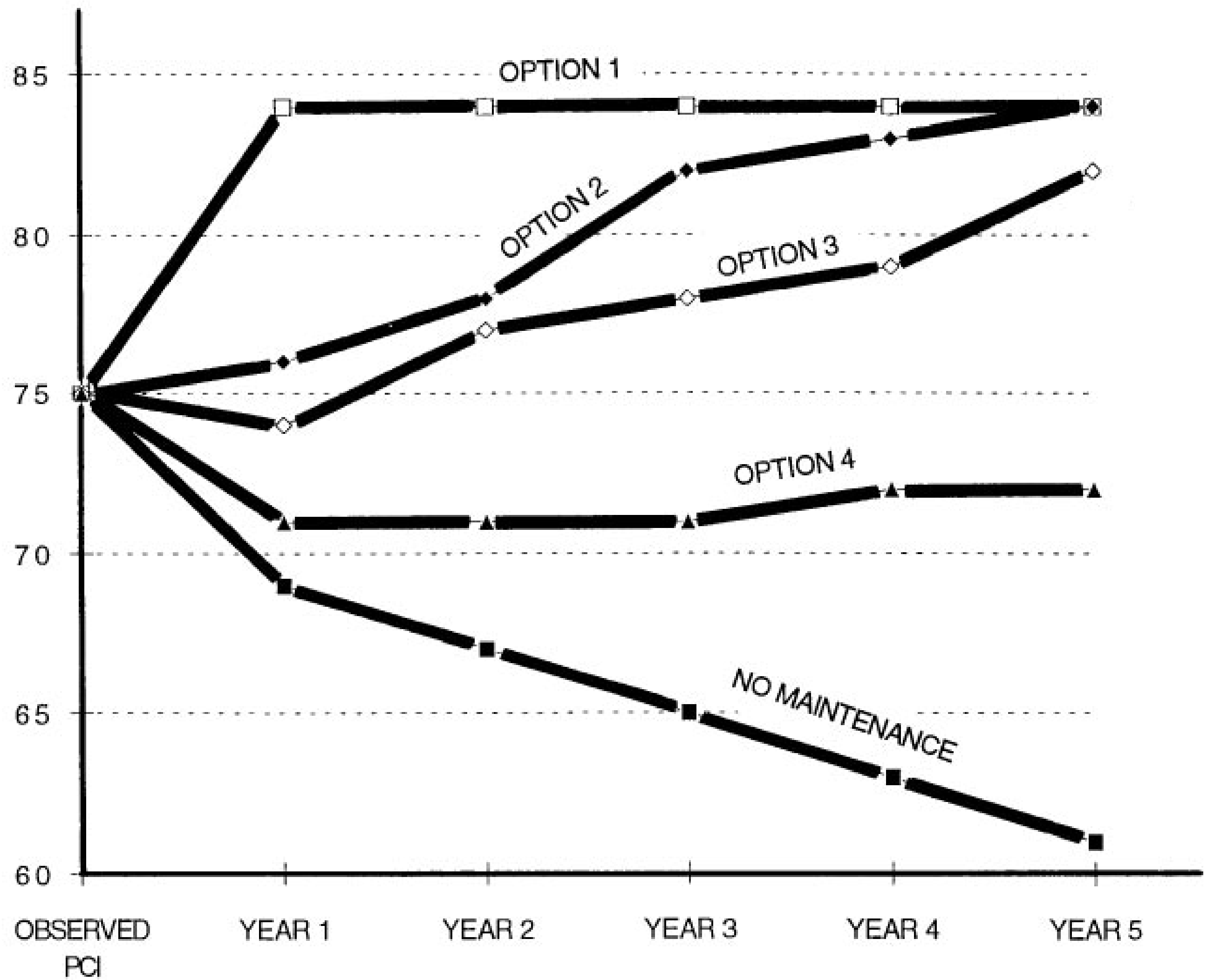


Figure D

IMPACT ON THE PAVEMENT CONDITION INDEX OF THE NO MAINTENANCE OPTION AND 4 OTHER OPTIONS



The following table shows the current profile of the agency's streets and roads.

Profile of Roadways

Total Centerline Miles: 79

Length by Functional Class — Centerline Miles

	Centerline Miles	Lane Miles
Arterials	15	31
Collectors	10	19
Residentials	54	108
Total	79	158

Replacement Cost: $71,700,000

Replacement Cost Per Lane Mile: $454,000

Sections: (The 158-lane miles were divided into roughly 431 sections.)

Arterials	34
Collectors	26
Residentials	371
	431

Conditions

Grade	No. of Sections	PCI		%
A,B	280	70-100		65%
C	70	50-69		16%
D	66	25-49		15%
E	15	24		4%
	431	75	=	Average PCI for all roadways

II. Recommendations

In evaluating PMS options, the following criteria should be considered:

1. A PCI that is increasing over the five-year period.
2. Deferred maintenance that is decreasing over time.

Clearly, the PMS recommended Option l provides the most cost-effective expenditure of funds. However, this would require the agency to generate an additional $5.0 million in revenues (in the next five years) beyond the $2.0 million estimated. Further, almost 63 percent of the total revenues of $7.0 million would be required in the first year. If the agency wants to consider this option, there are a number of funding strategies available, including assessment districts, bonding, and pavement maintenance special districts.

Option 2 spreads the five-year $7.0 million costs evenly by year. This is the second best option.

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  - * Develop and fully fund the preventive maintenance program including the required stop-gap maintenance on deferred projects.
  - * Recommended treatments (particularly the heavier repairs like reconstruction) should be evaluated in more detail to build projects/contracts.
  - * Link major repairs with utility schedules, if possible.
  - * Group projects of similar type, location, and year.
  - * Consider setting priorities on repairs so higher traveled streets (arterials) are repaired first.

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