



PAVEMENT MANAGEMENT SYSTEMS OVERVIEW

2.1 Module Objective

This module describes the basic components of a Pavement Management System, as well as provides some historical perspective on the evolution of PMS over the last 20 years. In addition, it will discuss how the products of that system can be used as tools to aid in the development and decision making process for the pavement maintenance and construction program.

Upon completion of this module the participants will be able to:

- § Describe the basic components of a PMS
- § Understand the evolution of PMS since the 1970's
- § List and describe some of the more prevalent products of a basic PMS
- § Be able to describe in some detail the current state of practice in PMS

2.2 Importance of the Transportation System

The United States has the largest transportation system in the world (1). It serves 260 million people and 6 million businesses. The sheer physical size of the transportation system is difficult to comprehend. There are over 6.4 million km (4 million miles) of roads. In 1995, cars and light trucks – the vast majority of personal vehicles – were driven over 3.5 trillion km (2.2 trillion miles) in the United States. Or in personal terms, the distance an average car traveled in 1995 equaled a journey nearly halfway around the earth.

Transportation is a major component of the economy, accounting for nearly 11% of the gross domestic product (GDP). It provides links between businesses, industries and consumers. Transportation and related industries employ 9.9 million people in the United States – a little more than 7% of the total civilian labor force.

The economic importance of the U.S. transportation system goes well beyond the nation's borders. It affects the ability of U.S. businesses to compete in the expanding global economy. Over time, international trade has grown in importance as a component of the U.S. economy. In 1995, total exports and imports of goods and services amounted to almost 25% of the GDP.

Trucks dominate the nation's freight transportation system, especially for shipping distances under 800 km (500 miles). Trucks moved nearly three-quarters of the value and almost 5.5 billion metric tons (6 billion tons) of freight of all shipments. Growth in truck traffic has been dramatic. According to the Census Bureau (1), the number of trucks increased by 24% from 1982 to 1992.

The truck fleet appears to be getting heavier and traveling further. Between 1982 and 1992, the number of trucks with operating weights above 36,000 kg (80,000 pounds) increased by 180%. The total number of vehicle-miles traveled in this class also rose by 193%. Multiple-trailer combination trucks, which doubled in number, traveled the furthest, averaging 126,000 km/vehicle (79,000 miles/vehicle) in 1992.

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The highway system in the United States is composed of :

- Interstate highways – more than 73,000 km (45,774 miles)
- Other NHS* roads – almost 180,000 km (111,237 miles)
- Other roads – over 6 million km (3.75 million miles)

* *NHS = National Highway System*

Governments spent \$116.5 billion on transportation in 1993. The federal share was about 31%, which included grants to state and local governments. Of the total, 60% of the expenditures was for highways.

Government revenues from gasoline taxes and other transportation-related taxes and fees totaled \$85 billion, covering 73% of all transportation expenditures in 1993. States collected about half of all revenues, the federal government a third, and the remainder is collected by local governments. 70% of the revenues were generated by highways.

The relationship between economic growth and transportation infrastructure is reciprocal. Historically, transportation has played an important role in determining the regional structure and spatial character of the U.S. economy and continues to do so today.

Evidence suggests that public investments in highways and other transportation infrastructure reduce the costs of transportation and output, and contribute to economic growth and productivity. At the same time, changes in the economy affect the use of transportation facilities and services by households and businesses.

In recent years, a good deal of research has been conducted on the contribution of public investment in transportation to economic growth and productivity in the U.S. A majority of these studies conclude that public investment in highways reduces the costs of transportation and production, and makes a positive contribution to total economic output. Similar studies in Europe and Asia produced comparable results. In particular, these studies suggest that the return on the investment of a dollar in highway infrastructure generally has been greater than the return on a dollar of private capital investment.

However, the benefits of the transportation system come with costs – accidents, pollution, congestion and so on. Although safety, energy efficiency and emissions controls have improved, transportation policies, regulations, and technological advances are still racing to keep up with the continual growth in travel and goods movement.

The ability of the transportation system to meet our logistical and mobility needs with a minimum impact on our pocketbook, our safety and the environment depends on informed decisions by public agencies, private enterprise and individuals. Because transportation and the world it serves are constantly changing, informed decisions require continual updating of our understanding of the transportation system, how it is used, what it contributes, and what it affects.

This snapshot captures a wide range of information on the U.S. transportation system and its influences. But the picture is moving. As awareness of the unintended consequences has grown, ways are being sought to measure the direct and indirect

costs of transportation and combine those measures into a framework that supports public decision-making. An understanding of both costs and benefits is necessary to enhance the efficiency and effectiveness of the transportation system, to reduce the negative side effects, and to consider equity – the distribution of benefits and burdens among groups in the population – in public decisions.

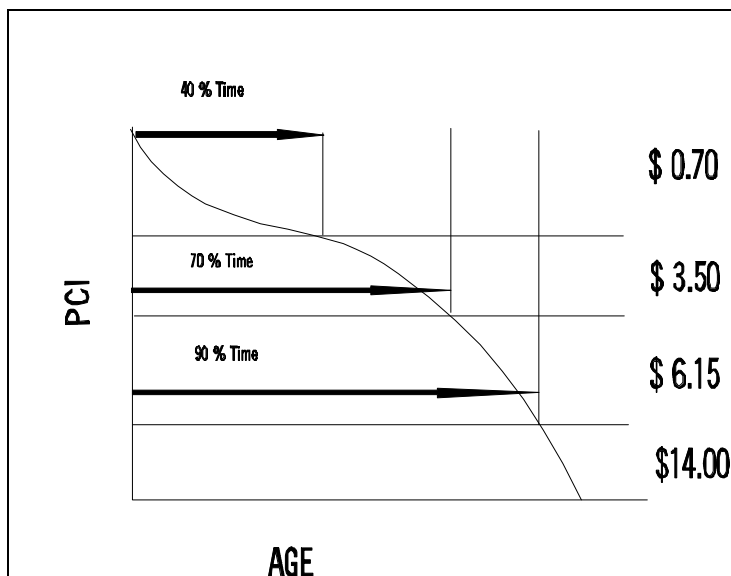
2.3 Importance of Pavements in Transportation System

From the previous section, it is apparent that transportation has an enormous impact on the U.S. economy, and on the lives of its residents. Pavements are just one part of the transportation system, and yet it is by far the most important component. Passenger-miles per person grew to 27,500 km (17,200 miles) by 1995. In terms of absolute distance traveled, the automobile overshadowed all other modes, growing by over 1.6 trillion passenger-km (1 trillion passenger-miles) between 1970 and 1995 (1).

The growth of trucks is of special importance to pavement engineers and managers since one major cause of pavement deterioration is truck traffic. (This is further discussed in Module 7.)

It is also true that all pavements deteriorate over time due to traffic and environment. Figure 2.1 is a curve that has often been used in presentations on pavement management systems (PMS). It shows the average rate of deterioration for an agency and the change in repair costs as the pavement deteriorates. It is evident from Figure 2.1 that if the earlier treatments were to be applied more often, the overall costs will be smaller if the pavement is repaired earlier rather than later.

Figure 2.1 Effect of treatment timing on repair costs (2).



Analysis by the Utah Department of Transportation indicates that it costs an agency less to have good roads than bad roads, if the roads are kept at any reasonable level of serviceability (2). This is based on the assumption that pavements will respond to preventive maintenance. Preventive maintenance is defined to include treatments

applied to prevent or reduce the rate of deterioration, and it is limited to treatments which have traditionally been considered maintenance such as surface seals and thin overlays which do little to change the structural capacity of the pavement.

For preventive maintenance to be effective, pavements must be adequately designed to withstand traffic loads initially. Preventive maintenance treatments applied to pavement surfaces inadequately designed may delay the required rehabilitation for a short period of time, but in the long run they will not be very cost-effective. Many agencies own pavements that carry traffic loads for which they were never designed, and these must be structurally improved before they will provide the desired performance. Many agencies also have a backlog of maintenance and rehabilitation needs that must be corrected before they can fully adopt a preventive maintenance approach. These agencies must develop a program that works to improve those pavements in poor condition and structurally inadequate while also trying to keep those few pavements in good condition from deteriorating to the point where the less expensive treatments will not be effective.

The FHWA has long recognized the importance of pavements and the need to properly manage the pavement network. Numerous training courses, seminars, workshops and technical assistance are provided to states and other interested agencies. They also serve as a conduit to the American Association of State Highway and Transportation Officials (AASHTO), and support and augment the National Cooperative Highway Research Program (NCHRP).

2.4 Historical Perspective

EARLY DEVELOPMENT: The earliest Pavement Management Systems (PMS) were developed in the mid to late 1970s as a direct result of the development of modern electronic computers and data base management systems. Prior to the use of electronic computers, in the late 1950's and the 1960's, agencies maintained their roadway route information on paper-based ledgers, strip maps, maps, and a system of archived files. This limited the amount of information that could be collected, stored, and retrieved.

The late 1950's and 1960's were also a time of intensive road building and pavement construction. Most agencies' construction programs were focused on the construction of new pavements rather than on the maintenance and preservation of their existing pavements. However, by the mid-1960's, some states had begun to change their construction program's emphasis from new pavement construction to pavement preservation (3).

At the same time, most state highway agencies converted to a computer-based roadway information system that was developed and maintained by a management information services group within each agency. These systems contained computer based files which contained basic roadway inventory data such as route number, location indicator, functional class, number of lanes, pavement type, width, shoulder type etc., at specific project, political, and accounting boundaries. The early management systems were mostly accounting driven. For example, the early maintenance management systems developed information on workforce time, equipment, and materials by specific task, time and location and construction management systems were developed for more automated contract accounting and contract payments systems.

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Agencies have always managed some form of pavement preservation activity which could be considered pavement management. In most larger agencies, such as a state highway agency, the Agency was subdivided into regions, districts, or areas which normally managed the day to day road maintenance planning, design and construction projects. An Agency's pavement maintenance or rehabilitation project was developed from a list of projects developed at the regional level. The list of projects may have been developed based on a wide range of criteria ranging from perceived pavement condition (not measured) and engineering experience, to political necessity. In many cases, the list was developed based on relative pavement condition, maintenance activities, and engineering experience. Each region was allocated a specific amount of funds for each program cycle for their construction program, usually based on their proportion of highway miles of each function class and also with traffic levels sometimes factored in. Planning level cost estimates were developed for each project on the list, and projects were selected from the list until the allocated funds were consumed. The lists and projects were adjusted or massaged a bit to develop the actual construction program. As contract plans were prepared and awarded, some additional adjustments in the program were always required based on the final cost and scope of each project.

In the mid-1960's, a few agencies began to develop pavement condition surveys, and used the information from the surveys to help develop the project lists. The pavement condition data was stored and manipulated as part of the agencies management information system (4,5). By the mid-1970's a "systems" approach to managing pavements began to be envisioned and actively developed (6,7,8). Within a couple of years, several states and the US Army Corps of Engineers had developed and implemented a full PMS (10,11,12).

AASHTO GUIDELINES: In 1985, the American Association of State Highway and Transportation Officials published their first "Guidelines on Pavement

24). These Guidelines were prepared between 1982 and 1983 by members of the AASHTO Joint Task Force on Pavements who were involved in the development and implementation of a PMS in their respective state. The 1985 AASHTO "Guidelines" provided only minimal guidance as the body of the text consisted of only seven pages which introduced, defined, and supported the development and implementation of PMS.

Though only a few states were involved in actively developing and implementing PMS's in the early 1980's, a much larger number had developed, implemented, or adopted a PMS by the mid to late 1980's. In NCHRP Synthesis of Highway Practice 135 "Pavement Management Practices" (17) it was reported that, "Of the 53 agencies responding to the survey, 35 have some form of a pavement management system or process and 11 have either a partial system or they are in the development process." The remaining agencies indicated that they were planning on doing so. By 1994, NCHRP Synthesis 203 (18) reported that 58 of 60 agencies (50 states, 9 Canadian provinces and the District of Columbia) had a PMS in place.

In 1989, the FHWA established a policy that all states must have a PMS to manage their Federal Aid Primary Highway System (Interstate and Principal Highways) (16).

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As a result of this policy, all states were required to have, and to use, a PMS as a one of the many conditions for federal funding.

In 1989, AASHTO formed a small Task Force on Pavement Management. Their task was to guide the development of a new and more complete set of guidelines on PMS. The new guidelines were prepared by Fred Finn and Dale Peterson through a special NCHRP project. The new "1990 AASHTO Guidelines for PMS" provided a more detailed set of descriptions and recommendations than the 1985 guide but the new guidelines were still limited in size as the authors were, from the beginning, limited to only 35 pages by the Task Force (15). The final guidelines totaled 48 pages with the body of the text consisting of a concise but complete 34 pages. The primary scope of the 1990 Guidelines for PMS was to:

- § Describe the characteristics of a PMS.
- § Identify the components of a PMS and the role of each component.
- § Describe the steps recommended for development, implementation and operation of a PMS.
- § Describe the products of a PMS which can help management in making informed decisions based on sound principles of management and engineering
- § Define the role of communications in a PMS.

The 1990 AASHTO Guidelines for Pavement Management Systems still provide a very good description of a basic Pavement Management System and the typical modules that usually make up a PMS. The Guidelines will be used later in this section to provide an overview of the basic components of a pavement management system.

ISTEA: The scope of federal and state involvement in PMS expanded when Congress passed the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and required all states to have a PMS that covers all Federal-aid highways by 1995. The most significant aspect of this law was the expanded network coverage. FHWA's 1989 policy covered 313,700 centerline miles and ISTEA tripled that coverage, increasing it to 916,200 centerline miles. This expanded coverage translated into a need for significant coordination among state and local governments. For example, of the 916,200 miles covered, 365,200 are under local jurisdiction. In December 1993, FHWA issued a regulation covering all management systems. Section 500, Subpart B, of the regulation describes the ISTEA requirements for PMS. The following is a summary of the more notable issues of the regulation as described below (16):

- § The regulation is non-prescriptive;
- § Federal-aid funds are eligible for the development, implementation, and annual operation of a PMS;
- § States must develop their work plan by October 1994, designed to meet the implementation requirements;
- § Standards are included for the National Highway Systems (NHS);
- § The PMS for the NHS must be fully operational by October 1995;
- § The states have full flexibility to develop the standards for the PMS that cover the non-NHS routes;
- § The PMS for non-NHS routes must be fully operational by October 1997; and
- § PMS information must be used as input into the development of the metropolitan and statewide transportation plans and improvement programs.

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Section 500.207, PMS Components, contains the components of a PMS for highways on the National Highway System (NHS). There are three primary components: data collection, analyses, and update. The components under data collection included the following:

- § *Inventory*: physical pavement features including the number of lanes, length, width, surface type, functional classification, and shoulder information;
- § *History*: project dates and types of construction, reconstruction, rehabilitation, and preventive maintenance;
- § *Condition survey*: roughness or ride, pavement distress, rutting, and surface friction;
- § *Traffic*: volume, vehicle type, and load data; and
- § *Data base*: compilation of all data files used in the PMS.

The components under analyses include the following:

- § *Condition analysis*: ride, distress, rutting, and surface friction;
- § *Performance analysis*: pavement performance analysis and an estimate of remaining service life;
- § *Investment analysis*: an estimate of network and project level investment strategies. These include single- and multi-year period analyses and should consider life-cycle cost evaluation;
- § *Engineering analysis*: evaluation of design, construction, rehabilitation, materials, mix designs, and maintenance; and
- § *Feedback analysis*: evaluation and updating of procedures and calibration of relationships using PMS performance data and current engineering criteria.

The 1991 ISTEA act and the subsequent FHWA regulations on management systems were modified in 1995 by the National Highway System Act. This legislation reduced the management systems requirements and reconfirmed that the requirements for PMS were non-prescriptive.

In a recent national workshop on pavement management (New Orleans, July 1997), a proposed resolution to support pavement management was discussed and drafted.

Discussion on the resolution centered on the following issues:

- PMS is good business practice
- Objective measures and protocols for pavement condition are essential
- Local/regional criteria are necessary and appropriate
- Transparent modeling and analysis is desirable
- Need for top level management support

2.5 Basic Concepts of a Pavement Management System

The following is a brief description of the components of a Pavement Management System. This description is taken almost verbatim from the 1990 AASHTO Guidelines for Pavement Management Systems (15). Though the text of the Guidelines was prepared several years ago it still provides a very good overview of the basic components and characteristics of a PMS.

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TYPICAL MODULES OF A PAVEMENT MANAGEMENT SYSTEM

(FROM CHAPTER 2 OF AASHTO GUIDELINES FOR PMS) (15): A Pavement Management System is designed to provide objective information and useful data for analysis so that highway managers can make more consistent, cost-effective, and defensible decisions related to the preservation of a pavement network. While a PMS can not make final decisions, it can provide the basis for an informed understanding of the possible consequences of alternative policies.

Two major levels of pavement management decisions should be included in a PMS; network and project. Network-level decisions are concerned with programmatic and policy issues for an entire network. These decisions include: establishing pavement preservation policies, identifying priorities, estimating funding needs, and allocating budgets for maintenance, rehabilitation, and reconstruction (MR&R). Project-level decisions address engineering and technical aspects of pavement management, i.e., the selection of site-specific MR&R actions for individual projects and groups of projects. A comprehensive PMS includes components to assist in both network and project-level decisions.

Figure 2.2 shows a schematic representation of the typical modules of a PMS. These modules are:

- § Database which contains, as a minimum, the data required for PMS analysis;
- § Analysis methods to generate products useful for decision-making; and,
- § Feedback process which uses on-going field observations to improve the reliability of PMS analysis.

The remainder of this course will discuss each of these modules in detail.

The main choices for an analysis method, in an increasing order of sophistication, are: pavement condition analyses, priority assessment models, and network optimization models. A SHA may choose one of these methods for direct implementation or may develop the system in stages, starting with a simple method and upgrading to a method with a higher level of sophistication and capability, if and when deemed desirable based on agency needs and available resources. Both the required database and the feedback process will be affected by the choice of an analysis method. These two modules of a PMS must be designed carefully, taking into consideration the current and the potential future choice of the analysis method. Each PMS module is described below in terms of its purpose and input-output characteristics.

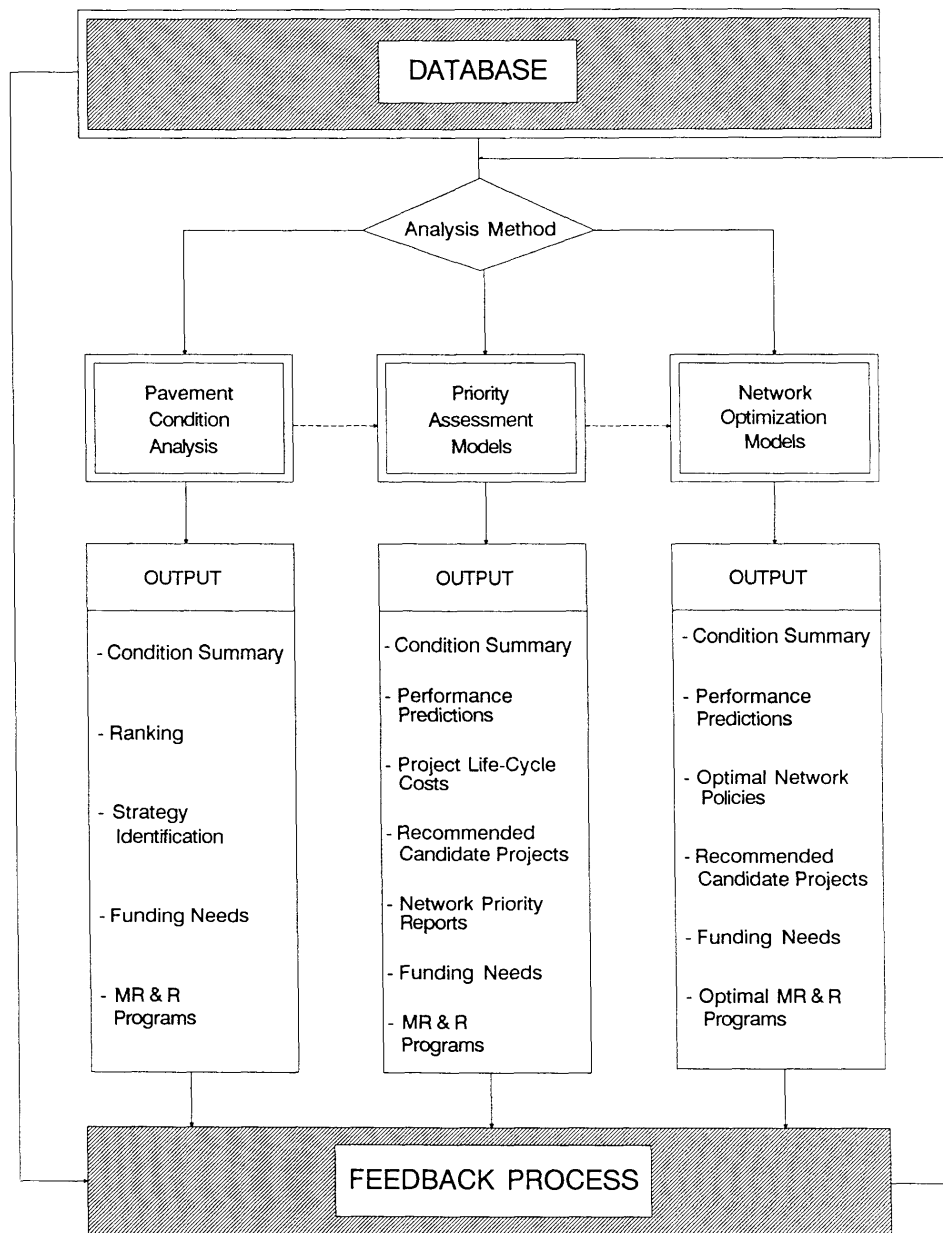


Figure 2.2: A Schematic Representation of PMS Modules

Database: The database is the first building block of any management system, since the analysis used and recommendations made by a management system should be based on reliable, objective, and timely (current) information. The major categories of input data essential for a PMS are:

- § Inventory,
- § Information relative to pavement condition,

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- § Construction, maintenance and rehabilitation history,
- § Traffic, and
- § Cost data.

A number of optional categories could include information concerning design, materials, accidents by location, and geometrics.

The database module supports the information needs of the other two PMS modules; i.e., analysis method and feedback process. It may also be useful to other information systems which may be or have been developed by a SHA. By using the information in the database, useful reports can be generated, such as:

- § *Deficiency reports*, which identify pavement segments with a given type of distress (such as cracking, rutting, faulting, roughness, etc.) exceeding a specified threshold level
- § *Performance histories*, which display the variation of a given type of distress as a function of age and traffic for specific pavement segments
- § MR&R actions
- § *Pavement inventory* by type and area as examples. A method of ranking pavements based on severity and extent of specific types of distress can be developed based solely on information in the database.

Analysis Method: A variety of methods are available to analyze pavement performance and cost data to identify cost-effective MR&R treatments and strategies. “Treatment” refers to a single action selected to correct specific pavement deficiencies. A strategy can refer to a plan involving a combination of treatments to maintain the network in a serviceable (acceptable) condition for specified time (analysis period); it can also apply to a series of treatments for maintaining a project in a serviceable condition for a specified time. The analysis methods can be divided into three broad categories based on the degree of formal analysis used to determine cost-effective MR&R strategies. The three categories, with an increasing degree of formal analysis, are: (1) pavement condition analyses, (2) priority assessment models, and (3) network optimization models.

The choice of an appropriate analysis method depends on a SHA’s needs and expectations from a PMS, and the resources (data, staff, computers, funds, etc.) available for development and eventual long-term usage. Also, the methods of analysis are not necessarily unique to any one of the three categories indicated. For example, user benefits and agency costs, discussed herein under the priority assessment method could, and often do, apply to pavement condition analysis and would, in most cases, apply to optimization models.

At the start-up of a PMS, a SHA may choose the option of staged development by initially selecting an analysis method compatible with resources and needs and subsequently upgrading to a method with increased capabilities. An agency can, of course, decide to proceed directly to its ultimate goal if resources are available.

It should be noted here that the three analysis methods represented a cross-section of the analysis methods that were used by various SHA’s at the time the AASHTO Guidelines were prepared. Though all three levels are still valid, most SHA’s have now progressed to using the second and third analysis method, and many

are developing the capacity to use the third analysis method (network optimization models). In a 1996 FHWA survey of state PMS practice, 14 states indicated that they were currently using the Network Optimization Method, and 17 additional states indicated that the Optimization Method was under development.

Pavement Condition Analysis: This method of analysis combines the pavement condition data for individual distress types, with or without roughness, into a score or index representing the overall pavement condition. The pavement condition score is generally expressed on a scale of 0 to 100, with 100 representing the best pavement condition and 0 representing the worst pavement condition. Alternate methods can be used to develop a combined index or score; however the 0 to 100 scale is the most prevalent. The calculation of the pavement condition score requires an assessment of weighting factors for different combinations of the severity and extent of each distress type. A combined index has several useful applications:

- § It is a relatively simple way to communicate the health of the system to upper management, planners, and legislators
- § Used as one factor, or the only factor, in a priority rating scheme
- § Used as a technique for estimating average costs to maintain, rehabilitate, or reconstruct a candidate project; e.g., pavements with condition score of 50 will, on average, require x dollars to repair.

The outputs from this module can include:

- § Ranking of all pavement segments according to types of distress and condition scores as a function of traffic or road classification
- § Identification of MR&R strategies, which define a set of criteria (e.g., combinations of different distress levels and traffic) for assigning a particular action to each pavement segment
- § Estimates of funding needs for the selected treatments.

The outputs are indicative of current needs based on current conditions. A prediction model is not necessary for this module; however, multi-year strategies and costs are not available from such systems unless assumptions are made regarding rates of deterioration and associated costs.

Priority Assessment Models: This analysis method uses a “bottom up” approach in which optimal MR&R strategies for individual projects are first determined based on life-cycle costs (17) over an analysis period of 20-30 years, or at least one major rehabilitation treatment. Projects can then be prioritized, at the network-level, using a variety of methods. The benefit/cost ratio and measure of cost effectiveness are the two most prevalent ways to prioritize; however, alternate schemes are possible. The project-level analysis includes models to predict pavement conditions as a function of such variables as age, present pavement condition, traffic, environment, performance history, and the treatment selected. Alternative strategies, including current and future actions, are evaluated for each segment and compared based on life-cycle costing analysis, benefit-cost ratio or cost-effectiveness, and the strategy with the highest priority over an analysis period is identified.

Benefits, when applied to a PMS, are generally categorized in one of three ways:

- § Road user benefit.
- § Agency benefits.
- § A combination of user and agency benefits.

Road user benefits are defined (19) “...as the savings in vehicle operation costs, travel time value, accident costs...that users of improved highway facilities...will enjoy.”

Benefits can be quantified as the difference between user costs without improvements and user costs with improvements. The benefits divided by agency costs for improvement would reflect the benefit-cost ratio. At a project level, the strategy which provided the highest ratio would receive the highest selection priority. In a similar way, the set of strategies that would maximize benefits for the network, for a specific budget, would be used as a strategic planning tool to program network improvements (i.e., maintenance, rehabilitation, and reconstruction).

Agency costs include: (1) annual maintenance costs, (2) rehabilitation or reconstruction costs required during the analysis period, and (3) salvage value at the end of the analysis period. Costs used in evaluating a benefit-cost ratio are usually based on their net present worth or converted to equivalent uniform annual costs.

Road user benefits should be given some consideration when evaluating priorities of individual segments. Although methods for calculating user benefits have been developed, credible dollar values have not been established for U.S. conditions. User benefits are implicitly included in a PMS when specifying level-of-service goals or performance standards for different functional classes of highways.

Similar to the benefit-cost analysis, cost-effectiveness has been used to rank or prioritize the selection of projects. The difference is that a proxy, in terms of performance, is used to represent the benefit associated with a particular strategy. Performance or benefit can be measured in terms of the predicted area under a pavement condition (serviceability) versus time curve and cost is expressed as the equivalent uniform annual cost of MR&R treatments. Thus, the cost per unit of serviceability can be used as a cost-effectiveness ratio.

The output of this analysis method can include:

- § A prioritized listing of projects requiring maintenance, rehabilitation or reconstruction.
- § Costs for MR&R treatments.
- § Estimates of funding needs in order to achieve specified network performance standards.
- § Single-year and multi-year programs which identify segments recommended for maintenance, rehabilitation, or reconstruction, and the type, timing and cost of recommended treatments.

Optimization Models: Optimization models provide the capability for a simultaneous evaluation of an entire pavement network. The objective is to identify the network MR&R strategies which maximize the total network benefits (or performance), or

minimize total network costs subject to such network-level constraints, such as available budget and desired performance standards. A network MR&R strategy defines the optimal treatment for each possible combination of performance variables such as: roughness, physical distress, traffic, environment, and functional class. This is a “top down” approach in which optimal network strategies are first determined and specific treatments for individual projects are then identified considering site-specific conditions and administrative policies.

Techniques of optimization, although somewhat new to highway engineers, have been used extensively in business decisions and are described in proceedings of the North American Conferences on Pavement Management. Optimization models in a PMS are used to analyze various management strategies and tradeoffs at the network level. For example, given a fixed network budget, should extensive and often expensive, treatments be applied on a smaller portion of the network, or should moderate, less expensive treatments be applied on a larger portion of the network?

The outputs from optimization models are essentially the same as those obtained from the prioritizing model, with only slight variations. For example, the optimization model does not identify segment priorities; instead, it identifies an optimally balanced MR&R program for an entire network to meet specified budget and policy constraints.

FEEDBACK PROCESS: Pavement management systems, similar to any other engineering tool, must be reliable in order to be credible. The feedback process is crucial to verify and improve the reliability of a PMS.

A measure of PMS reliability can be achieved by comparing:

- § Actual costs of maintenance, rehabilitation, and reconstruction (available through contract bids and agency records) with those used in the PMS analysis.
- § Field observations of pavement conditions and traffic with those predicted by PMS models.
- § Actual performance standards achieved with those specified in the PMS analysis.
- § Actual projects rehabilitated or reconstructed and the treatments applied with those recommended by the PMS.

If significant discrepancies are found between actual data and PMS projections, relevant PMS models and parameters should be revised appropriately.

At the start-up of a PMS, historical performance data may not be available to calibrate PMS models. Such calibration may need to be performed using engineering judgment and experience. With time, PMS models can be systematically calibrated using data from pavement condition surveys and construction records, thus improving the reliability of, and confidence in, PMS recommendations.

It should be noted that feedback information can also be useful:

- § For agency research programs.
- § To evaluate the influence of construction on performance.
- § As a measure of the effectiveness of methods used for design of new and rehabilitated pavements.

2.6 Network and Project Level Pavement Management Systems

(From Chapter 3 AASHTO Guidelines for PMS) (15)

It is important to recognize that pavement management systems can be applied at two levels: network and project. At the network level, the primary objective is to provide information pertinent to establishing network budget requirements, allocating funds according to priorities, and scheduling MR&R actions. At the project level, the primary objective is to provide a first estimate of the preferred MR&R action for each project, its cost, and expected life cycle. In this chapter some important aspects of each level will be discussed, including products and applicable technology.

NETWORK LEVEL PMS: Specific products required to meet the objectives of a network level PMS include the following as a minimum:

- § Information concerning the condition or health of the pavement network.
- § Establishment of MR&R policies.
- § Estimation of budget requirements.
- § Determination of network priorities.

Evaluating the Overall Health (Condition) of the Network: The range of pavement conditions may be divided into discrete categories (qualitative) such as very good, good, fair, and poor. The proportion of segments (mileage) in a network in each of these categories can be used as indicators of the overall health of the network. These indicators can be plotted against time to identify trends (i.e., is the proportion in the poor condition constant, decreasing or increasing?).

Numerical values obtained from combined condition indices can be used as an alternative (quantitative) measure of the health of the system. The choice between qualitative and quantitative representations is a management decision.

Establishment of Maintenance, Rehabilitation and Reconstruction (MR&R) Policies: Four methods are available for establishment of MR&R policies:

- § Matrix.
- § Decision tree.
- § Life-cycle costing analysis.
- § Optimization.

The *matrix* method matches a set of specific distresses with a set of appropriate MR&R treatments. The selection of a specific MR&R treatment is based on the dominant treatment which will correct all of the pavement deficiencies. The association between distress and treatment is based on engineering judgment accumulated from years of agency experience.

For a *decision tree*, important variables such as specific distress types, traffic, and functional classes, would be considered in selecting MR&R treatments. A tree-like diagram is developed which displays different combinations (branches) of selected variables at various levels. For each combination, an appropriate MR&R treatment is assigned in the same manner as that used for the matrix method (i.e., agency experience and engineering judgment).

The *life-cycle cost* method selects the MR&R treatments based on the least life cycle cost of a combination of treatments (strategy) required during the analysis period. Alternative strategies can be evaluated as part of this method. The cost components included in this method of analysis are: (1) construction, (2) maintenance between major rehabilitation treatments, (3) cost of rehabilitation treatment, and (4) salvage value at the end of the analysis period. In order to compare alternative strategies, life cycle costs are calculated using either present worth or equivalent uniform annual costs. An appropriate discount rate must be assigned in order to obtain credible comparisons.

The *optimization* method requires identification of an objective function, decision variables and constraints. For the PMS analysis, the objective function is usually one of the following:

- § Maximization of user benefits.
- § Maximization of network performance standards.
- § Minimization of total present worth costs. Decision variables are the set of MR&R treatments. The constraints may include the total available budget, minimum network performance standards and/or minimum performance standards for different areas (i.e., districts). The optimization method identifies estimates of both short-term and long-term budgets needed in order to preserve the pavement network at or above prescribed standards.

Budget Requirements: The PMS will provide an estimate of budget requirements to preserve the pavement network at prescribed levels of performance. In most cases, the PMS will provide a one-year and multi-year estimate of requirements. In many cases the budget requirements will exceed the funding available. In such cases, one of the methods of prioritizing or optimizing will be needed in order to prepare a candidate MR&R program.

Determination of Priorities: There are many methods for establishing priorities, however, only the five most common are listed here. Alternate methods can be developed based on agency policies and administrative decisions. The five methods include:

- § Matrix.
- § Benefit-cost ratio.
- § Condition index.
- § Cost-effectiveness.
- § Maximizing benefits.

The *matrix* method can be based on such factors as condition and traffic (i.e., the highest priority is given to those pavements that are in the worst condition with heaviest traffic).

The *condition index* method can be based on relative scores usually ranked from 0 (worst) to 100 (best). Priorities can combine condition score with such factors as functional class or traffic in order to develop a final list of projects.

The *benefit-cost ratio* procedure determines the benefit cost effectiveness ratio for each project segment where those segments with the highest benefit-to-cost ratio would have the highest priority. Whereas the previous methods are likely to favor a worst-first

policy, the benefit-cost ratio could provide high priorities for pavements in fair-to-poor condition rather than always starting with worst condition.

The *cost effectiveness* procedure is similar to the benefit-cost ratio, except that the objective function is to maximize the performance as a function of cost. Performance, in this case, can be estimated from the area under the serviceability-time curve obtained from pavement prediction models. Those sections with the largest area above specified levels of service per unit cost would have high priorities. Costs are agency costs. This method does not require a worst-first approach.

The *maximization of benefits* is inherent in most optimization methods. However, methods for maximizing benefits can also be developed with prioritization and life cycle costs. For example, that group of projects from all candidate projects, which maximizes the combined benefit-cost ratio or cost effectiveness for a specified budget would be selected for MR&R treatments.

PROJECT LEVEL PMS: Once the results from the network MR&R program are established, it will be necessary to prepare plans and specifications for individual construction projects. Since the network level analysis only provided target MR&R treatments and expected costs for individual segments, additional information will be required before designs are finalized.

Detailed site-specific information pertinent to non-destructive test results, material properties representative of on-site materials and drainage considerations as well as detailed condition survey information are commonly required for the final design and cost estimate and for preparation of plans and specifications. Based on the additional information, the target MR&R treatments could be recommended from a project level PMS.

The objective function of a project-level PMS would usually be the same as that for a network; minimize life cycle costs, maximize benefit-cost ratio, etc. The project level PMS could consider additional MR&R treatments, which could be applicable or necessary, at a particular site. It could also use more accurate unit costs estimates based on project location. Thus, there would be some chance that the project level PMS would recommend an action different from that of the network system.

DATA COLLECTION FOR PMS (FROM CHAPTER 4 AASHTO GUIDELINES FOR PMS) (15): A pavement management system must have usable, accurate, and timely (current) information in order to produce credible results.

Inventory and identification data are generally obtained only once. Updates are required only when pavements are reconstructed to new standards and dimensions. Roadway geometrics, pavement type, location, and design traffic loads are other examples of data that do not require a yearly update. Information relative to pavement condition, actual traffic, surface friction, and others which may change with time, are collected on an established schedule or frequency. Data obtained for a network level analysis are generally less intensive and not as detailed as that needed for a project design (i.e., for preparation of plans and specifications).

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INVENTORY DATA: Inventory data are required for even the simplest pavement management system. Project identification including pavement type, route, functional classification, location (either tied to a GIS, Geographic Information System, or to an identifiable reference system such as mile post, link mode or state coordinates) is essential.

Specific types of information to be collected should be carefully considered during the planning phase. Information required for analysis, interpretation, and for preparation of reports, should be included in the inventory. Information not considered necessary for the PMS should be avoided. Some items to be considered for inclusion as part of the inventory are:

- Route number
- Functional classification
- Length
- Pavement type
- Pavement width
- Number of traffic lanes
- Shoulder type
- Shoulder width
- Layer thickness
- Construction history
- Rehabilitation history
- Maintenance history
- Sub-grade classifications
- Material properties
- Material sources
- Joint spacing
- Load transfer
- Resilient modulus
- Provision for drainage
- Climatic factors (precipitation, freeze-thaw)

In order to assure accurate locations for each item in the inventory, it is essential that a common reference system be used for all information gathered for a pavement regardless of the source of the data. The history of the construction, rehabilitation, and maintenance of the pavement is very desirable and may be required for the systems with more complex analysis procedures. The inclusion of information relative to material properties and sources, as part of the pavement history, provides a basis for evaluating design procedures and possible need for modifications.

Traffic: Traffic and load information is important for three reasons:

- § To determine priorities
- § To develop, calibrate, and use pavement performance models.
- § To select the maintenance, rehabilitation, or reconstruction treatment.

The types of traffic data required include:

- § Average annual daily traffic (to establish priorities).
- § Equivalent 18-kip single axle loads (for predictions and treatments).

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PAVEMENT CONDITION SURVEY: Monitoring pavement condition over time is essential for a PMS. Condition surveys provide information needed to evaluate the health of the network and the condition of any specific segment. Condition survey data collected over time will also be required if and when prediction models are to be developed.

There are four basic types of pavement condition information:

- § Ride quality or roughness.
- § Physical distress.
- § Structural capacity.
- § Safety.

Ride Quality: One of the major accomplishments of the AASHTO Road Test (1956-1960) was that it developed a concept or method for evaluating the performance of a pavement. The concept was based on the principle that the prime function of a pavement was to serve the traveling public. In turn, ride quality was used as a measure of how well pavements could serve the public (20). Studies made after completion of the Road Test have consistently indicated that ride quality could be correlated to pavement roughness. It has also been shown that roughness is not only a measure of user satisfaction (or dissatisfaction), but can also be related to user costs (i.e., vehicle operating costs and speed profiles).

Road roughness should be considered as a fundamental requirement for a pavement management system. There is a wide range of methods of measurement used to evaluate road roughness, either subjectively (ride quality) or objectively (roughness). For a SHA, the use of automated measuring devices to measure and record roughness is considered preferable to subjective ratings. Local government agencies, which do not have access to automated devices, have found subjective estimates of ride quality to be a useful measure of functional performance.

Methods for measuring roughness and interpreting roughness vary and are constantly changing as both equipment and analytical capabilities improve. Both response type roughometers, designed to measure vertical movement between the axle and frame of a vehicle (or trailer) and profilometers, designed to measure the longitudinal profile, have been used to evaluate roughness.

For comparison between agencies, the conversion to the International Roughness Index (IRI) could be considered as a useful means of summarizing roughness measurements (21).

Physical Distress: Physical distress is a measure of the road surface deterioration caused by traffic, environment and aging.

There are no national standards for procedures to be followed or equipment to be used for identifying pavement distress. It is, however, acknowledged that the type and cost of maintenance, rehabilitation and reconstruction will be significantly influenced by the type, extent and severity of distress.

Types of distress can generally be categorized into three classes:

- § Fracture (cracking).
- § Distortion (rutting corrugations, faulting).
- § Surface wear or deterioration (raveling, spalling).

Specific descriptions of distress related to asphalt or portland cement concrete pavements may vary depending on the types of distress encountered in a particular area. However, the SHRP Distress Identification Manual has started to provide a form of national standard (22). In addition, the FHWA is in the process of developing pavement condition data collection procedures under the "Pavement Performance Data Collection and Processing" project.

Methods for evaluating distress can vary widely, ranging from "windshield" surveys from a moving vehicle to automated equipment designed to measure and record distress in a prescribed way. The decision as to which method to use should be made as an integral part of the PMS development. The primary factors to consider are: applicability, cost, productivity, quality and quantity of the information obtained. The most important of these considerations are applicability, quality and quantity. For example, is there a sufficient amount of useful information and does the information represent field conditions?

Structural Capacity: Structural capacity is the ability of a pavement to accommodate traffic loadings with little or no cracking or deformation. The most convenient method of identifying structural capacity is through the use of non-destructive testing (NDT) equipment. Measurements of deflection, curvature, and joint efficiency can be used as an indication of structural capacity. Methods of interpretation have been developed by individual state agencies, industry and associations.

The inclusion of structural capacity and non-destructive testing in a PMS database will vary depending on the cost and usefulness of information acquired. Most network level pavement management systems do not include a routine requirement for non-destructive testing to evaluate structural capacity. However, most systems do require site specific evaluations of structural capacity, as well as estimates of remaining life, before deciding on an optimum maintenance and rehabilitation strategy at the project level.

Safety: The primary role of the pavement with regard to safety, independent of factors related to alignment or geometrics, is the ability of the pavement to provide an adequate friction between the road surface and the tire. The measure of friction is normally obtained with either the ASTM locked wheel trailer or a Mu-meter. Since most state agencies are required to periodically obtain friction measurements, such measurements should be included in the PMS database.

Pavement management systems should also include data with regard to accident locations with provisions for reporting locations with high accident rates.

Segments with low friction values and/or high accident rates should be identified in PMS reports. Such identification will allow the agency to make an in-depth evaluation

on a case-by-case basis and to evaluate the need for, and scheduling of, a corrective action.

Historical: An important aspect of condition measurements is the ability to create a historical accounting of the rate of deterioration over time and under accumulated traffic loads (feedback). An understanding of what has happened in the past provides the basis for predicting what may happen in the future. The performance of different pavement or treatment types under various traffic or environmental conditions helps answer questions about what works, where it works, and why it works. Conversely, what doesn't work, where it doesn't work and why it doesn't work can also be identified to some degree from historical records. Historical condition data, under a wide range of conditions in the field, provide very useful information for research and can be used as a feedback to improve a pavement management system.

Frequency: Pavement condition can be determined at different frequencies such as annual or biennial. Factors that will determine the frequency are pavement age, rate of change in performance, cost of obtaining data, and the need for timely data.

Sampling coverage, whether partial, total, or random, should be designed to be representative of in-service conditions and should be extensive enough to track pavement performance at the network level.

Quality Control: Good quality control of inventory and condition data is essential to the success of a pavement management system. The data must be accurate, repeatable, consistent from location to location and from year to year, and representative of what actually exists in the field. Training of personnel, calibration of equipment and documentation of each, is necessary to assure long term confidence in the system and its results or output.

Methods should be developed to monitor the quality of information in the database. The most likely procedure would be to include a quality assurance requirement based on random sampling of information. Particular attention should be given to route locations, pavement areas and pavement conditions, since these items will play a major role in selecting MR&R actions and for prioritizing projects.

2.7 Current State of Practice in PMS

The state of the practice has evolved considerably since NCHRP Synthesis was completed in 1987 (17). As previously mentioned, the survey found that *“Of the 53 agencies responding to the survey . . . 35 have some form of a pavement management system or process and 11 have either a partial system or they are in the development process. The seven agencies that do not have a pavement management system and are not in the process of developing one all said they plan to establish one. Some of the weaknesses in present pavement management systems as identified by some of the agencies are: organization, life cycle costs, ability to predict performance, and the integration of pavement management systems with other data systems within the agency.”* Many states have already gone through significant improvements to their PMS to satisfy ISTEA requirements.

NCHRP Synthesis 222 (23) provides a very good review of the more current state practice. In the summary, the following observations were made:

“Highway agencies use a number of different pavement management methodologies to select projects and recommend preservation treatments for their highway networks. In some cases, agencies have highly sophisticated computerized processes in place. In other cases, agencies make decisions based on more traditional approaches to managing the network, including visual ratings and panel decisions regarding preservation actions. In light of the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991, which mandated the use of management systems (to include pavement management systems) for the selection of cost-effective strategies to improve the performance of transportation systems, many highway agencies evaluated their methodologies to determine whether they had the tools necessary to provide this type of information. However, it should be noted that the passage of the National Highway System (NHS) legislation in 1995 made the use of management systems optional rather than mandatory....

Three predominant methodologies are discussed in this synthesis: pavement condition analysis, priority assessment models, and network optimization models. (Please note that these are the three basic methodologies described in the 1990 AASHTO Guidelines) “Based on data collected from a survey of agencies, pavement condition analysis was the most common methodology, with almost one-half of the agencies indicating use of this approach to some extent. The remaining agencies were equally divided among the use of network optimization models, priority assessment models, or some other approach to pavement management. With primarily three predominant methodologies being used, there are many similarities among agencies in the basic pavement management components of data collection and analysis. Even so, similar objectives for these components resulted in dramatically different data requirements and analytical techniques among agencies.

Although pavement management has been practiced since the late 1970s, many of the agencies are still using manual and subjective approaches. Several highway agencies indicated that their pavement management systems are fully automated; however, the majority of agencies indicated that only a portion of their system is automated. Of those agencies, many reported that they would probably never fully automate their systems.

ISTEA has greatly influenced the pavement management practices of a number of agencies. Agencies with previously certified PMS were required to be rectified by the Federal Highway Administration (FHWA), a process that required agencies to upgrade their existing capabilities. Issues that agencies were required to address in this regard included adding multi-year analysis, developing and using prediction models, providing PMS coverage for non-National Highway System federal-aid highways (including city and county streets) incorporating life-cycle costs, and considering alternate project or network strategies.”

In addition to the NCHRP Synthesis 222, the FHWA conducted a survey of all the states in 1996 to document in some detail the status of their existing pavement management systems.

The following tables summarize responses to the 1996 survey and provides a detailed summary of the current practice in PMS.

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Table 2.1 Pavement Management System - PMS Database: Inventory Data +

	Yes	Under Development	Considering In Future	No	No Answer
1. Pavement Type	51	1	0	0	0
2. Pavement Width	44	6	2	0	0
3. Shoulder Type	37	9	5	1	0
4. Shoulder Width	36	8	6	2	0
5. Number of Lanes	50	1	1	0	0
6. Layer Thickness	30	16	5	1	0
7. Joint Spacing	17	10	6	18	1
8. Load Transfer	16	7	6	22	1
9. Sub-grade Classification	15	13	8	16	0
10. Material Properties	9	14	18	10	1
11. Resilient Modulus	3	12	16	19	2
12. Drainage	12	7	13	20	0

Table 2.2 Pavement Management System - PMS Database: Project History

	Yes	Under Development	Considering In Future	No	No Answer
1. Construction	41	11	0	0	0
2. Rehabilitation	39	13	0	0	0
3. Maintenance	28	18	6	0	0

Table 2.3 Pavement Management System - PMS Database: Condition Survey

	Yes	Under Development	Considering In Future	No	No Answer
1. Ride	50	2	0	0	0
2. Rutting	48	2	0	2	0
3. Faulting	31	8	4	8	1
4. Cracking	50	1	1	0	0
5. Surface Friction	39	7	3	3	0
6. Network-Level Deflection	5	9	15	22	1

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Table 2.4 Pavement Management System - PMS Database: Distress Data

	Yes	Under Development	Considering In Future	No	No Answer
1. High Speed Windshield Survey at 30 to 55 MPH	9	1	1	41	0
2. Low Speed Survey at 0 to 10 MPH	18	0	0	33	1
3. Combination of High and Low Speed	13	0	0	39	0
4. 35 MM Film Viewed at a Workstation	1	0	1	49	1
5. Videotape viewed at a Workstation	20	5	6	20	1
6. Distress Identification Manual with Pictorial References Used to Calibrate Extent and Severity	37	2	4	9	0
7. Fully Automated. Specify Equipment **	4	5	18	24	1
** See Distress Equipment Report					

Table 2.5 Pavement Management System - PMS Database: Traffic/Load Data

	Yes	Under Development	Considering In Future	No	No Answer
1. Does the PMS contain:					
a. Annual ESAL's	21	18	10	3	0
b. Forecast ESAL's	11	16	15	10	0
c. Cumulative ESAL's	10	18	17	7	0
2. Does the PMS have an ESAL flow map that is route specific?	7	14	19	11	1

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Table 2.6 Pavement Management System – Investment Analysis: Prioritization Summary

	Yes	Under Development	Considering In Future	No	No Answer
1. Does the PMS office/unit produce a multi-year prioritized list of recommended candidate projects (this is considered a "first cut" list)?	31	20	0	1	1
2. What method does the PMS use to produce the multi-year prioritized list of projects?					
a. Subjective	4	1	0	44	3
b. Objective					
1. Priority Model	24	9	1	17	1
2. Incremental Benefit Cost	10	9	6	24	3
3. Marginal Cost Effectiveness	8	6	5	31	2
4. Optimization					
a. Linear Programming	8	10	6	26	2
b. Non-Linear Programming	2	1	6	40	3
c. Integer Programming	0	2	5	42	3
d. Dynamic Programming	1	2	6	39	4
e. Other (Specify)	9				43
3. If the answer to questions 2(b) is Yes or Under Development, who developed the Software?					
In House:	16				
Contractor:		35			
No Answer:				1	
4. Check the factors used to prioritize projects					
a. Distress	46	5	1	0	0
b. Ride	41	7	2	2	0
c. Traffic	38	12	0	2	0
d. Functional Class	33	9	3	7	0
e. Skid	19	7	7	18	1
f. Structural Adequacy	14	9	11	17	1
g. Other (Specify)	20				32

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Table 2.7 Pavement Management System – Investment Analysis: Pavement Performance Monitoring and Projection Summary

	Yes	Under Development	Considering In Future	No	No Answer
1. Does the PMS monitor pavement performance?	37	13		1	1
2. Check all the pavement indices used to monitor pavement performance:					
a. Ride	38	9	3	2	2
b. Distress	42	7	2	1	1
c. Combined Index	26	10	4	12	12
d. Other (Specify)	16				36
3. Is load data (cumulative ESAL's) used to monitor pavement performance?	8	20	20	4	0
4. Does the PMS generate pavement performance curves?	25	21	5	1	0
5. Are the curves developed for?					
Family of Pavements	27	16	6	3	0
Each Pavement	19	13	11	9	0
6. Does the PMS monitor and predict performance using?					
Markov Transition	7	7	7	30	1
Semi-Markov Transition	1	2	9	39	1
7. Does the PMS monitor and predict performance using another method?	35			17	**
** No Answer counts as a no					
8. Does the PMS compute the Remaining Service Life of the network?	14	29		9	0
9. If the answer to questions 8 is Yes or Under Development, who developed the software?					
In House: 1					
Contractor: 0					
No Answer: 0					

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Table 2.8 Pavement Management System – Investment Analysis: Preservation Treatment Summary

	Yes	Under Development	Considering In Future	No	No Answer
1. Does the PMS assign a preservation treatment to a candidate project?	35	17		0	0
2. If the answer to question 1 is Yes or Under Development, which groups of treatments does the PMS cover?					
a. Reconstruction	36	10		1	5
b. Rehabilitation	40	12		0	0
c. Maintenance	33	13		1	5
3. What method is used to assign a preservation treatment to a candidate project?					
a. Subjective	5	1	1	44	1
b. Objective					
1. Matrix	8	6	2	35	1
2. Decision Tree	18	14	5	15	0
3. Cost Benefit	10	9	7	25	1
4. Optimization Method Listed Previously	14	17	5	15	1
5. Other (Specify)	10				42
4. If the answer to question 3(b) is Yes or Under Development, who developed the software?					
In House: 15			Contractor: 36		No Answer: 1
5. Does the PMS do a life-cycle analysis for the recommended preservation treatments?	20	26		6	0
6. If the answer to question 5 is Yes or Under Development, who developed the software?					
In House: 18			Contractor: 30		No Answer: 4

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Table 2.9 Pavement Management System – Investment Analysis: Products and Update

	Yes	Under Development	Considering In Future	No	No Answer
Products					
A. Is the PMS's multi-year prioritized list of recommended projects used as input in the development of					
1. Pavement Preservation Program	35	14		3	0
2. Statewide Transportation Improvement Program (STIP)	31	18		3	0
3. Transportation Improvement Program (TIP)	29	18		5	0
B. Is the PMS's multi-year prioritized list (first cut) compared to the final approve list of pavement preservation projects for reasonableness?	24	15	11	2	0
Update					
A. Does the SHA annually evaluate and update the PMS relative to the agency's policies, engineering criteria, practices, experience, and current information?	33	13		5	5

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