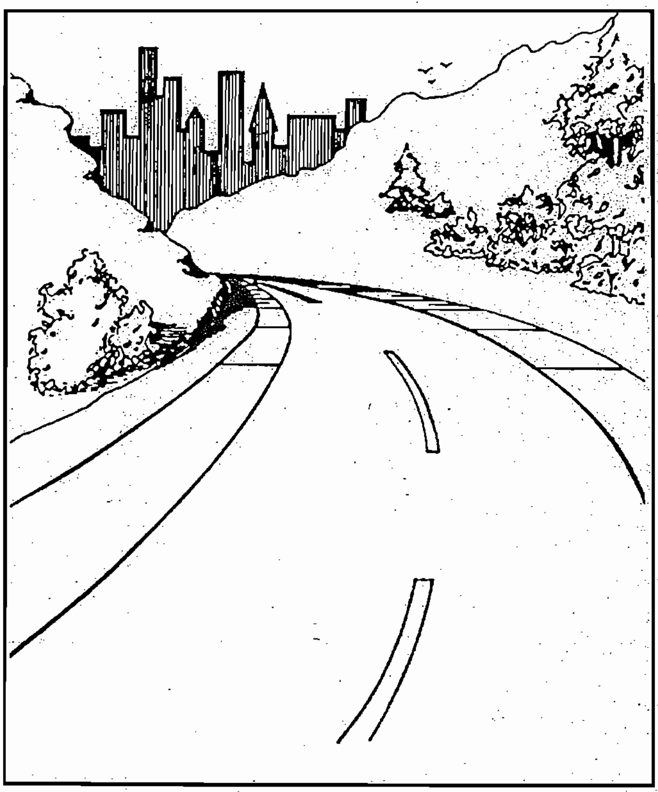
AASHTO Guidelines for Pavement Management Systems

July 1990



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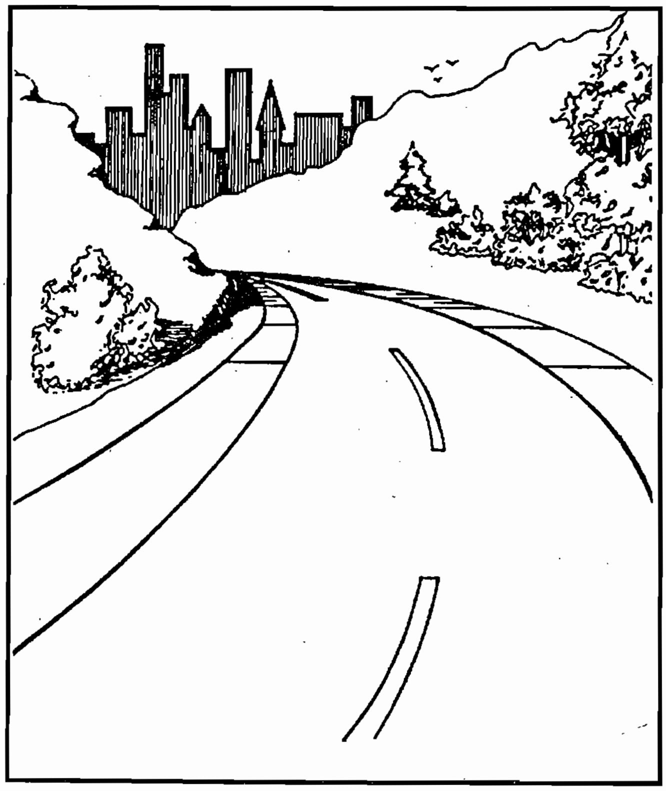

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Executive Summary

A continuing challenge for federal, state and local agencies in the United States is the preservation of the investment that has been made in the nation's highways. The preservation of the pavements within the highway network will require informed and cost effective decisions based on sound principles of management and engineering. A pavement management system (PMS) can help upper management (decision-makers) to make the kinds of decisions required to maximize the effectiveness of every dollar available for the preservation of pavements. Problems related to rising costs, reduced resources, increased utilization of the pavement network, budget needs that far exceed revenues and a changing emphasis to preservation are some of the issues which can be addressed by a well-planned and implemented PMS.

The Federal Highway Administration (FHWA) has defined a PMS as "a set of tools or methods that can assist decision-makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition" (1).

The primary goal of these "Guidelines" is to describe the characteristics of a pavement management system, the various parts or components of a PMS which are required for its development and implementation and how the products of the PMS can be used as a strategic planning tool for middle and upper management as well as for applications to pavement engineering.

The elements and products of a pavement management system can include the following: (1) an inventory of pavements in the network, (2) a database of information pertinent to past and current condition of pavements, (3) budget requirements needed to preserve the pavement network to acceptable levels of performance, (4) methods of prioritizing expenditures, and (5) a basis for communications of agency plans both within the agency and to groups and organizations not an integral part of the agency but who might be interested in such plans. There can be additional products of a PMS depending on the needs of the agency and design of the PMS.

Pavement management activities are not new. Governmental agencies at all levels have, out of necessity, been required to make decisions regarding the type and timing of maintenance, rehabilitation and reconstruction of pavements. The decision process was usually based on a traditional approach; i.e., based on local experience (usually undocumented) and subjective preferences often influenced by political necessity. These procedures, which worked well while funds were more readily available, are becoming less acceptable as funds become increasingly limited. The result is a need for more defensible procedures such as those that are available from a PMS.

The technology needed to develop and implement a pavement management system is available for both state highway agencies and for local governments (2, 3, 4). Research and development of such technology for application to pavements started in the late 60's and is an ongoing development by local, state and federal agencies. The fact that many state and local agencies have developed, implemented and are maintaining such systems is evidence that these procedures are achievable and considered to be beneficial for efficient and effective decision-making (2, 3).

The information contained in these Guidelines includes: (1) a description of the components of a PMS, (2) steps that can be followed for development or enhancement of an existing PMS, (3) uses of a PMS at the network level for strategic planning and project level for engineering applications, and (4) a description of the products available from a PMS.

The guidelines emphasize that a PMS is a tool to assist upper management in making informed decisions relative to maintenance, rehabilitation and reconstruction of existing pavements within a highway network. It should be recognized that pavements are part of a larger roadway system which includes bridges and non-pavement features which must also be maintained. A PMS can stand alone or can be designed to be included as a part of a total roadway management system.

Chapter 1 Introduction

The highway network in the United States represents a multi-billion dollar investment essential for the movement of goods and people and represents one important factor contributing to the overall growth and economy of the country.

A primary responsibility of top management within a state highway agency, as well as local government entities, is to provide a network of serviceable and safe pavements at a minimum of cost both to the agency and for the road users. To adequately meet this responsibility, management requires well-documented information in order to make defensible decisions based on sound principles of management and engineering. A pavement management system (PMS) is one resource available for both management and engineers to help in making informed decisions.

The Federal Highway Administration (FHWA) defines a PMS as "a set of tools or methods that (can) assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in a serviceable condition" (1). There are other descriptions applicable to a PMS; for example, the 1986 edition of the AASHTO *Guide for the Design of Pavement Structures* (5) goes on to indicate 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."

A somewhat simplistic description of a PMS is that it will help make cost-effective decisions relative to "what, where and when." *What* treatment is most cost-effective, *where* treatments are needed and *when* is the best time (condition) to program a treatment.

The products (reports) and information that can be obtained and utilized from a PMS include:

1. An inventory of pavements in the network by location, type, functional classification, mileage, pavement area, etc.

2. A comprehensive database of information relative to pavement condition, accidents, traffic, construction, maintenance and rehabilitation histories plus any additional quantifiable information as may be needed or specified.

3. The current "health" (condition) of the pavement network based on systematic and defensible procedures for obtaining pavement condition information.

4. The "projected health" of the network over time, as a function of the funds available.

5. The budget required to bring the total network from its current condition to desired condition levels.

6. The budget requirements to maintain network at specific levels

of performance for multiple years, i.e., 5 to 20 or more, depending on level of sophistication included in PMS.

7. Specific programs for single or multi-year planning horizons.

8. Methods for prioritizing expenditures when funding is less than required to meet specific performance objectives.

9. A basis for communication between groups within an agency; e.g., planning, design, construction and maintenance.

10. A basis for communication with groups outside an agency; e.g., legislature, local governments, media, public interest groups, etc.

11. A basis for comparing alternate preservation strategies for maintenance, rehabilitation and reconstruction (MR&R) of pavements in the network.

In other words, a pavement management system can be applied in the areas of planning, budgeting, scheduling, performance evaluation and research. It can be used for prioritization, funding, setting strategies, selecting alternatives, identifying problem areas, communications with legislature and public and providing general and specific pavement information all of which are useful to decision-makers and upper management.

In the mid-1960's results of research in the area of project management indicated that a "systems" approach would be useful in selecting cost-effective procedures to preserve individual or site specific projects. Later, in the 70's these project management procedures were expanded to the network and eventually referred to as pavement management systems.

Early efforts to develop pavement management systems were slow. Most of the development was considered research with only limited support by agency administrators. It became evident that support from upper management, from legislatures or other political groups, was essential. As pressure increased to develop more defensible budgets and the need for more information on the condition of pavements developed, more support from upper management became available. With this support, activities have changed from research to development and implementation.

The technology required for development and implementation of a pavement management system are readily available to state highway agencies (SHA)(2, 3, 4). A wide range in specific components, data requirements, data acquisition methods, analysis and output capability exists among systems; however, the general framework of pavement management systems follows a similar, if not identical, pattern. These guidelines provide the basics of design, development and implementation of a "generic" PMS.

Pavement management systems must be designed to meet the needs of the user agency. Most SHA will have unique requirements, set by policy or influenced by environment, which must be incorporated in a PMS. Consideration should also be given to long term objectives for a PMS and the possible need to enhance or update the development of a state's existing PMS. Three examples which could influence the need for change are: (1) the initial decision to develop PMS in stages, (2) enhancements available as a result of the development of a database, or (3) improvements in technology including methods of analysis and development of computer hardware and software.

Chapter 2 of these guidelines describes a set of possible building blocks for development of a PMS. Depending on needs, resources and requirements, an agency may elect to develop its PMS in stages. However, in making such a decision the agency should have a long-term plan to achieve its long-term objectives.

Technology, through research and development, can be expected to provide increasing capabilities and procedures for enhancing pavement management systems; specifically, (1) increased capacity and capability of computer hardware, (2) development of software capable of producing graphical representations of PMS output, (3) implementation of geographical information systems, (4) improved performance modelling techniques, (5) knowledge based expert systems, and (6) possibly most important, increased long-term performance information for development of reliable prediction models related to the variety of maintenance, rehabilitation and reconstruction procedures available to preserve the pavement network.

In addition to pavements, state highway and local government agencies are also charged with the responsibility to maintain structures, non-pavement elements and such other appurtenances as are required for an effective transportation network. The development of a road management system including structures management, maintenance management (non-pavement elements), and pavement management can provide important tools for managing the entire highway infrastructure.

The primary scope of these "Guidelines" is to:

1. Describe the characteristics of a PMS.

2. Identify the components of a PMS and the role of each component.

3. Describe the steps recommended for development, implementation and operation of a PMS.

4. Describe the products of a PMS which can help management in making informed decisions based on sound principles of management and engineering.

5. Define the role of communications in a PMS.

Chapter 2 Description of a Generic Pavement Management System

Typical Modules of a Pavement Management System

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 cannot make final decisions, a PMS 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. Additional information concerning network and project level PMS is provided in Chapter 5.

Figure 1 shows a schematic representation of the typical modules of a PMS. These modules are: (1) a database which contains, as a minimum, the data required for PMS analysis; (2) analysis methods to generate products useful for decision-making; and (3) a feedback process which uses on-going field observations to improve the reliability of PMS analysis.

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.

Database

This is logically 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: (1) inventory, (2) information relative to pavement condition, (3) construction, maintenance and rehabilitation history, (4) traffic, and (5) cost data. A number of optional categories could include information concerning design, materials, accidents by location, and geometrics.

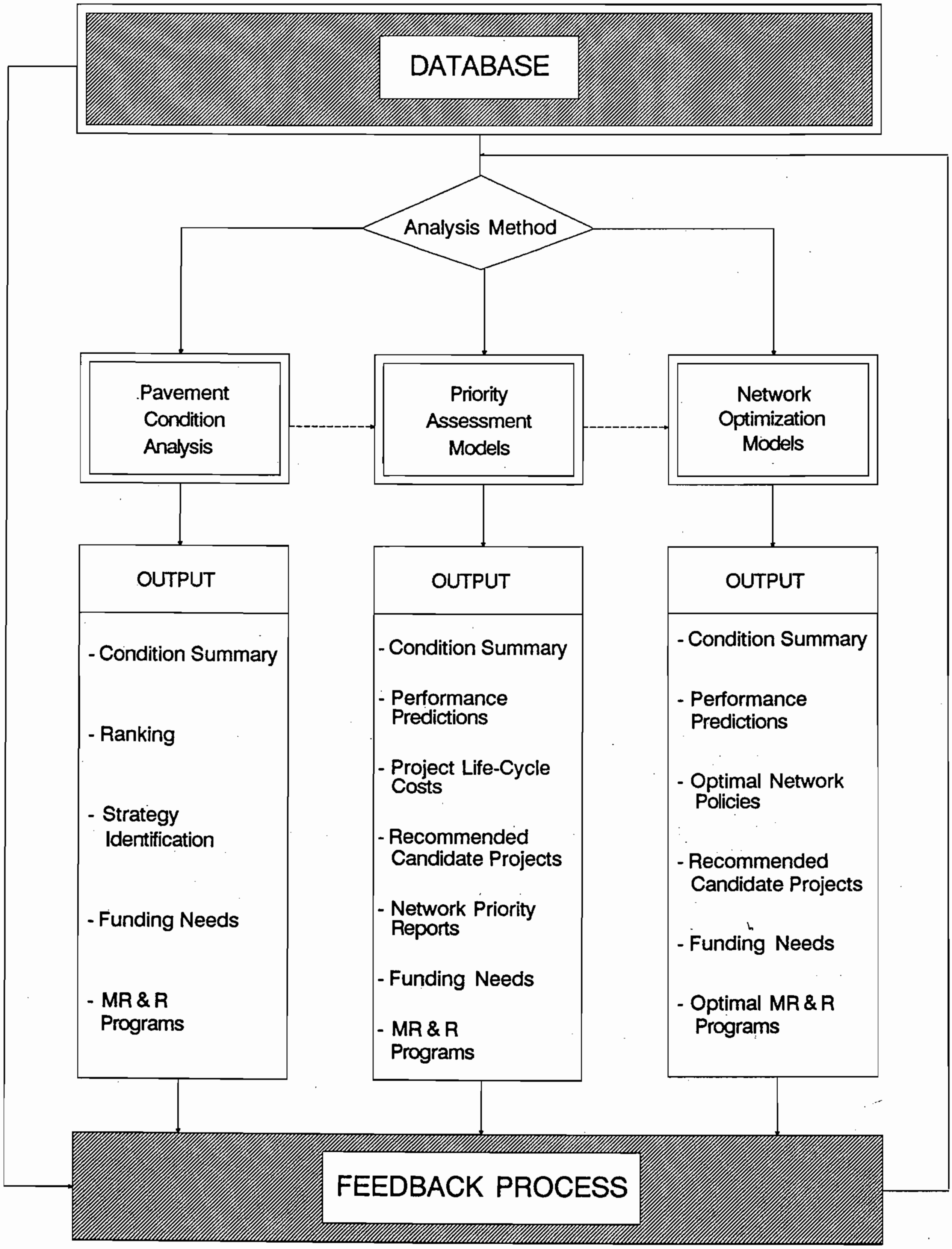

Figure 1. A Schematic Representation of PMS Modules

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. Using the information in the database, useful reports can be generated such as: (1) deficiency reports, which identify pavement segments with a given type of distress (such as cracking, rutting, faulting, roughness, etc.) exceeding a specified threshold level, (2) performance histories, which display the variation of a given type of distress as a function of age and traffic for specific pavement segments, (3) MR&R actions, and (4) 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 and to identify cost-effective MR&R treatments and strategies. A 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 a 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.

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: (1) as a relatively simple way to communicate the health of the system to upper management, planners and legislators, (2) as one factor or the only factor in a priority rating scheme, and (3) 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: (1) ranking of all pavement segments according to types of distress and condition scores as a function of traffic or road classification; (2) 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; and (3) 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 (6) 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: (1) road user benefits, (2) agency benefits, or (3) a combination of user and agency benefits.

Road user benefits are defined (see AASHTO *A Manual on User Benefit Analysis of Highway and Bus Transit Improvements - 1977* (7)) "...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 provides 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 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 in 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.

Cost-effectiveness has been used to rank or prioritize the selection of projects similar to a benefit-cost analysis except 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 versus time (serviceability) 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: (1) a prioritized listing of projects requiring maintenance, rehabilitation or reconstruction, (2) costs for MR&R treatments, (3) estimates of funding needs in order to achieve specified network performance standards, and (4) 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

The 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 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 (3). Optimization models in a PMS are desired 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 some 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: (1) for agency research programs, (2) to evaluate the influence of construction on performance, and (3) as a measure of the effectiveness of methods used for design of new and rehabilitated pavements.

Summary

In the previous sections of this chapter an effort has been made to describe a generic pavement management system framework. Three alternate approaches are described which will provide information useful as a strategic planning tool. The choice of which system to develop remains with upper management taking into account agency policies and resource constraints. It is worth repeating that the PMS is a resource for the decision-maker and does not replace the kinds of judgment and considerations necessary from engineering and management which cannot be included in a PMS but are necessary for final decisions.

While pavement management systems are not required to be identical, they should be similar in terms of results and products. For example, the database should include an inventory, condition information (past and present), and traffic data as a minimum. The inclusion of information pertinent to safety or pavement design, maintenance history and costs could be considered optional, depending on how the database is to be used by management and engineering. Each system should include a method for ranking prioritized network-level needs (either directly or implicit in procedures) and for estimating the budget requirements for current conditions. The PMS should provide information concerning the past and present condition of the network in order to provide some indication of the health of the pavement network.

Chapter 3 Network and Project Level Pavement Management Systems

Background

It is important to recognize that pavement management systems can be applied at two levels: network and project. At the network level the primary object 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

Chapter 1 has enumerated a number of products available from a 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; for example, 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: (1) matrix, (2) decision tree, (3) life cycle costing analysis, and (4) 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: (1) maximization of use benefits, (2) maximization of network performance standards, or (3) 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; e.g., 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

Five methods of establishing priorities are identified herein; however, alternate methods can be developed based on agencies policies and administrative decisions. The five methods include (1) matrix, (2) benefit-cost ratio, (3) condition index, (4) cost-effectiveness, and (5) maximizing benefits.

The *matrix* method can be based on such factors as condition and traffic; i.e., highest priority given to pavements in 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 was described in Chapter 2. Using this method 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 benefit-cost 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 have been established, it will be necessary to prepare plans and specifications for individual construction projects. Since the network level analysis only provides 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 a 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 can be recommended from a project level PMS.

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

Chapter 4 Data Collection

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 once only. 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.

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 and 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
- Subgrade Classifications
- Material Properties
- Material Sources
- Joint Spacing
- Load Transfer
- Resilient Modulus
- Provision for Drainage
- Climatic Factors (Precipitation, Freeze-thaw)
- Construction History
- Rehabilitation History
- Maintenance History

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 construction, rehabilitation, and maintenance of the pavement is very desirable and may be required for some systems. 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 in specifications.

Traffic

Traffic and load information is important for three reasons: (1) to determine priorities; (2) to develop, calibrate, and use pavement performance models; and (3) to select the maintenance, rehabilitation, or reconstruction treatment.

The type of traffic data required includes (1) average annual daily traffic (to establish priorities) and (2) equivalent 18-kip single axle loads (for predictions and treatments). Detailed information describing methods for collecting and computing traffic and load information can be found in the AASHTO *Guide for Design of Pavement Structures"* (5) and the FHWA *Traffic Monitoring Guide* (8).

The traditional procedures for weighing and classifying trucks have been static weighing and visual classification. In recent years instrumentation has been developed to dynamically weigh vehicles using weigh-in-motion (WIM) equipment and to classify vehicles using automatic vehicle classification (AVC) equipment. The "Traffic Monitoring Guide" gives a brief description of weigh-in-motion equipment and automatic vehicle classification equipment.

Pavement Condition Survey

Monitoring pavement condition over time is essential for a pavement management system. 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: (1) ride quality or roughness, (2) physical distress, (3) structural capacity, and (4) safety.

Ride Quality - One of the major accomplishments of the AASHO Road Test (1956-1960) was to develop 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 is to serve the travelling public. In turn, ride quality was used as a measure of how well pavements could serve the public (9). Studies made, after completion of the Road Test, have consistently indicated that ride quality can 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 are a wide range of methods of measurement to evaluate road roughness, either subjectively (ride quality) or objectively (roughness). For 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.

Within any particular agency, any of the response or profilometric equipment can be used. The pros and cons of each need to be carefully considered since the reliability of the measurement and utility of the data (correlation to ride quality) will vary.

For comparison between agencies, the conversion to the International Roughness Index (IRI) could be considered as a useful means of summarizing roughness measurements (10).

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.

The types of distress can generally be categorized into three classes: fracture (cracking), distortion (rutting, corrugations, faulting), or surface wear or deterioration (raveling, spalling). Specific descriptions of distress related to asphaltic or portland cement concrete pavements may vary depending on the types of distress encountered in a particular area.

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 choice of method 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 the right kind of 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 to identify structural capacity is by 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.

The choice of including non-destructive testing as a measure of structural capacity should be made as part of the planning stage in the development of a PMS.

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. General requirements for safety are described in the FHPM (1) covering pavement management and design policies.

Pavement management systems should also include data as 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 been happening 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. 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 condition since these items will play a major role in selecting MR&R actions and for prioritizing projects.

Chapter 5 Database Management System

Automated Data Processing

A computerized Database Management System (DBMS) is essential for efficient storage, retrieval, and processing of data necessary for various PMS analyses. Excellent commercial DBMS software packages can be purchased for all levels of computer hardware, from mainframe to mini to micro computers. With the technology available, there is no need for an agency to develop any new DBMS software. However, several factors should be carefully evaluated to select the appropriate hardware and software for the DBMS to support a pavement management system. These factors include compatibility, capacity, access, support, flexibility, convenience, efficiency, and security. A brief discussion of each of these factors is provided below.

Compatibility

The PMS database may need to interface with other databases already in place or under planning. Examples of related databases include those for accidents, traffic, structures, and non-pavement elements and features. Conversely, other databases and systems may need to access the PMS database as well as results of the PMS analysis. Compatibility between the various databases is desirable to enable an efficient exchange of information. Compatibility can be enhanced by using the same DBMS software for all databases which need to interact. With regard to the hardware, the same software may be supported both on mainframe and microcomputers. In that case, the software would not pose any constraints on the choice of the hardware.

Capacity

The PMS database will grow large, particularly since data from past cycles of condition surveys may be retained in order to build performance histories and develop prediction models. The user should ensure that sufficient space is available in the computer to store the expanding database.

Access

Ease of access to the PMS database is highly desirable. If multiple users access the same hardware and software concurrently, the impact on access time and response time should be evaluated. Restrictions as to who can enter and edit data should be determined when designing the database.

Support

If the use of a central (mainframe) computer is planned for the PMS database, and this requires the approval and support of a central Data Processing Department, the resource capabilities and commitment of that department should be evaluated. If the desirable level of support is not available, alternative hardware and software choices should be investigated. For example, if the level of support is not available, a dedicated microcomputer for the PMS database would be appropriate.

Flexibility

The DBMS software must allow the user to add new data items and to delete or modify existing data items with minimal changes in the initial design of the database. Software is available to provide this type of flexibility. The initial structure of the database should be designed carefully with consideration of potential future expansions. For example, the design should leave room for those variables in which data are not currently available, but are anticipated in the future. When such data do become available, the user will be able to directly enter the data in the designated fields without having to change the structure of the database.

Convenience

The DBMS software should be easy to learn and operate. Such user-friendly features as menu choices, interactive data processing, ad-hoc reporting capabilities, and clear error messages and warnings are desirable. The experience of other users, particularly those without extensive computer backgrounds, should be reviewed in order to evaluate the user-friendliness of the software under consideration.

Efficiency

The hardware and software combination for the DBMS should be able to process large amounts of data efficiently. The average response time for standard data processing tasks should be estimated. The user should make sure that the estimated response time is acceptable.

Security

The DBMS software should be capable of controlling access to different portions of the database. Some users may be given read only access. Some portions of the database may be defined as restricted and only designated users with approved passwords should be able to access the restricted data. This is to prevent any tampering (accidental or not) of the data from unauthorized users.

It must be recognized that the database is not indestructible and that poorly trained users could easily corrupt the database. Security and accessibility need to be balanced.

Quality Assurance Procedures for the Database System

A high degree of confidence can be placed in the PMS recommendations only if the input data used in the PMS analysis are accurate and consistent. The DBMS can be useful in checking whether the data meet predefined criteria for validity. Data checking procedures should be an integral part of the DBMS.

Two levels of data checking may be considered: checking for data errors and checking for suspect data. Data errors can be identified by specifying a valid format and range for each of the input data items. The DBMS should provide error messages identifying the type of error encountered and possible causes of the error. Suspect data are the values of input data items that are within the specified valid range, but at the extreme end of the range or inconsistent with other data.

Chapter 6 Development and Implementation

Role of Management

Pavement management is viewed differently by upper management and by technical level personnel. Management is often concerned with the effectiveness of pavement management from the perspective of the public who are concerned with such factors as mobility and user costs. Management also deals with societal impacts on the governmental process through public pressures, values, and emotions that often define what is or is not politically acceptable. They must therefore employ laymen's terms in communicating with government leaders and with the public. The technical side of PMS, on the other hand, uses well-defined terms and vocabulary in dealing with and describing pavements, their performance and needs. A PMS is designed as a strategic planning tool for upper management and as an engineering tool for technical decision-makers.

Since pavement management systems are no longer an option for a SHA but are a requirement under Federal-Aid Highway Program Manual (FHPM) 6-2-4-1 (1), it is recommended that SHA personnel familiarize themselves with the requirements of that document.

Management plays a critical role in the development of a PMS. Management needs to identify administrative and policy issues that could affect the implementation of a PMS. Performance standards, budget planning policies, budget distribution policies, social and environmental issues and legislative strategies all influence the structure and development of a PMS. Management must provide the decisions and internal policies to support the development, implementation and operation of a PMS and to assure its continuation.

Management must also decide where the PMS activities are to be located within the SHA's organization. The location for PMS activities within a SHA should be determined on an individual agency basis. Pavement management, to be successful in a SHA, must have the commitment and support of top management and, therefore, personnel assigned responsibility for the operation of a PMS should have ready access to and cooperation from top management. It can be a stand-alone unit that reports directly to top management or a unit that is incorporated into an existing division. The most common divisions for housing the PMS unit are planning, maintenance and materials.

Management is concerned with four major areas related to pavements; financial, technical, organizational and political. Historically most of the developments in pavement management have been technical in nature with limited attention to the policy making needs of middle and upper management. A PMS should help management understand and answer policy questions regarding pavements. Management must have a basic understanding of what its PMS is and what it does and be aware of how to use the information from the system. It is not necessary that management understand the technical details of the system.

Development Steps

There are seven suggested steps involved in the development, implementation, and operation of a pavement management system. These are adaptable to developing a new system or improving an existing one. **They are not all inclusive. Each SHA should develop its own strategy for developing or improving a PMS.**

Step One - Beginning

There is no longer an option whether to have a PMS or not since one is required according to FHPM 6-2-4-1. Nevertheless, in those cases where a new system is to be developed or an existing system is to be changed, top management will need to make the decision to begin. There must be a strong commitment from top management so that a successful beginning can be made. It should be approached as something that will be beneficial to the SHA. The effort should be geared to overcoming any resistance to change that may exist in the organization. Others must understand that the PMS is supported by top management.

The PMS needs to be coordinated throughout the SHA's organization, and each unit needs to know how it fits into the overall scheme. A commitment of the required resources must be made to provide the necessary skilled personnel, equipment, and funds to develop, implement and operate the PMS. With top management providing the driving force, it is easier to have the full concurrence of the various divisions in the overall process.

Step Two - Organize a Steering Committee

A steering committee or a task force should be organized to provide guidance and direction to the effort. The steering committee should consist of top ranking personnel from the various divisions or offices in the SHA who have an interest or involvement with pavements. Organizational and political problems are minimized by involving a large cross section of key personnel in developing and implementing a PMS. It is important that the needs of the users of PMS information be considered before implementation. Top management should charge the committee with their goals and responsibilities including a time frame and provide them with the major policies of the SHA as they relate to pavement management. They should be given the authority to act. Some of the responsibilities of the committee include defining PMS objectives, evaluating the status of present practices for managing pavements, identifying needed outputs, identifying data requirements, and recommending appropriate changes to current practices necessary for implementing and utilizing the PMS.

Step Three - Appoint PMS Staff

Unless PMS staff already exist, they should be appointed in order to establish and operate the PMS and to work with the steering committee to provide any needed technical support to help satisfy the SHA's needs and expectations. One person should be the lead PMS engineer with the full time responsibility for managing, coordinating and operating the PMS. This person should be a strong advocate of PMS and should be given the necessary authority to make decisions and to accomplish the assigned tasks. He/she should also be aware of the need to cooperate and work with the various divisions within the SHA during and after development of the PMS.

Step Four - System Selection or Development

This step is for the purpose of developing, selecting, or modifying a system for managing pavements to meet the requirements and objectives as prepared by the steering committee and approved by top management. Considerations include identifying and evaluating the components needed in the system; estimating the cost of development, implementation and operation; selecting the equipment and methodology for monitoring pavement condition; accessibility of data required for the system; ability to communicate through system outputs; and system flexibility. The requirements for the desired PMS should be defined and compared with what the SHA currently uses and needs. Steps should then be taken to accomplish the needed tasks. Three basic requirements are: good data, good analysis, and an effective communication strategy.

A pavement management system can range from simple to complex, manual to automated, practice-driven to technically optimal. A PMS should be considered as a dynamic system which can be built incrementally or in phases using a modular approach so modules can be added at some future time. The system should be consistent with the size and style of the organization. It should not be built so fast that the agency and its staff have a difficult time adjusting. It should be kept as practical as possible, avoiding unnecessary technical complexity and it should be user friendly in the operation phase.

Step Five - Demonstrate the PMS

Demonstrating the PMS on a limited scale is very desirable so the system can be fine-tuned and modified as needed before full scale implementation. This step will also provide the opportunity to work any bugs out of the data collection and analysis components; for those who are uncertain or who do not understand, to observe or be involved; and for top management and the steering committee, to observe and recommend any desired changes. It allows potential users to become familiar with the capabilities of a PMS and provides feedback to ensure that the development is on track with the needs of the agency.

Step Six - Full Scale Implementation

This step involves the full scale implementation of the PMS. The pavement management team or staff established earlier is very important to successful implementation. People are the most important resource for the operation of a PMS. Personnel must be trained, qualified, experienced, and dedicated. There must be reasonable continuity in staffing with a commitment to build and maintain key pavement management staff. On-going management support during implementation and operation is essential to long-term success. Prepublicity about the PMS and its benefits is helpful and personnel training is a must.

Step Seven - Follow Up

The system should be reviewed periodically to make certain that it is achieving the original objectives. Follow up provides the opportunity to identify and make improvements in the system. Feedback is essential to the long-term success of a PMS and to maximize benefits from it.

A pavement management system must be flexible enough to allow for improvements or modifications over time. It should be considered as a dynamic system, not static. However, frequent changes should be minimized. Major changes should not be made more often than once every five years, but minor changes can be made as required. Minor changes or enhancements that simplify or streamline the process or improve economics analysis with no adverse effects on results should be made as needed. Changes which would significantly affect the database requirements, prediction models, economic analysis and type of report required, would be considered major modifications and should not be made more frequently than five-year intervals in order to completely evaluate PMS performance and identify all of the improvements needed for a useful PMS. Changes in PMS should only be made when considered necessary by the PMS staff and agreed to by the Steering Committee.

Chapter 7 Communications

General

Communication is very important to the success of developing, implementing, and operating a PMS. Unless the results from a PMS are effectively communicated to all levels and divisions within a SHA, to the elected officials, and to the public, their potential utility will never be fully realized. Computer graphics, management reports and special audio-visual presentations can be effective tools for describing the products from a PMS.

A properly functioning PMS provides the basis for communicating policy and program planning to all parties concerned with plans for preserving the investment in a pavement network. In this regard, PMS planners must bear in mind that some of the outputs from a PMS should be understandable by the "lay public"; i.e., the non-engineer.

Communications can broadly be divided into two categories: (1) those internal to the SHA, and (2) those dealing with organizations external to the SHA.

Internal Communication

Lines of communication within a SHA must be open both vertically between management levels and horizontally between different divisions or units within the agency. Communication must be multi-directional. A PMS must be well coordinated throughout the SHA so that each unit providing input understands what information is needed and when. For those who use the output it is important that they understand how to effectively apply the information to their respective requirements. A PMS simply cannot be well coordinated without good understandable communication. The management of pavements crosses over many boundaries within the SHA organization. How well each of these organizational units work with each other will determine how successful pavement management will be. Organizational units must understand each others needs and products which can only be achieved through good communications.

Communications within a SHA must flow vertically from engineering to management as necessary for decisions and as required for programming. Information must also flow horizontally between divisions or sections within an agency in order to be sure that coordination between groups can be achieved. Thus, the overall requirements for a PMS should include some provision for communications.

Several units (traffic, maintenance, design, planning and materials) can be affected by recommendations from a PMS. These units may have specific comments which would ultimately affect management decisions regarding implementation of specific plans contained in the output. In order to avoid potential conflicts, the PMS outputs need to be circulated first horizontally and then vertically in order to keep each group involved. Figures 2 and 3 are used to illustrate the types of communication and flow of information required in order to maximize the effectiveness of a PMS.

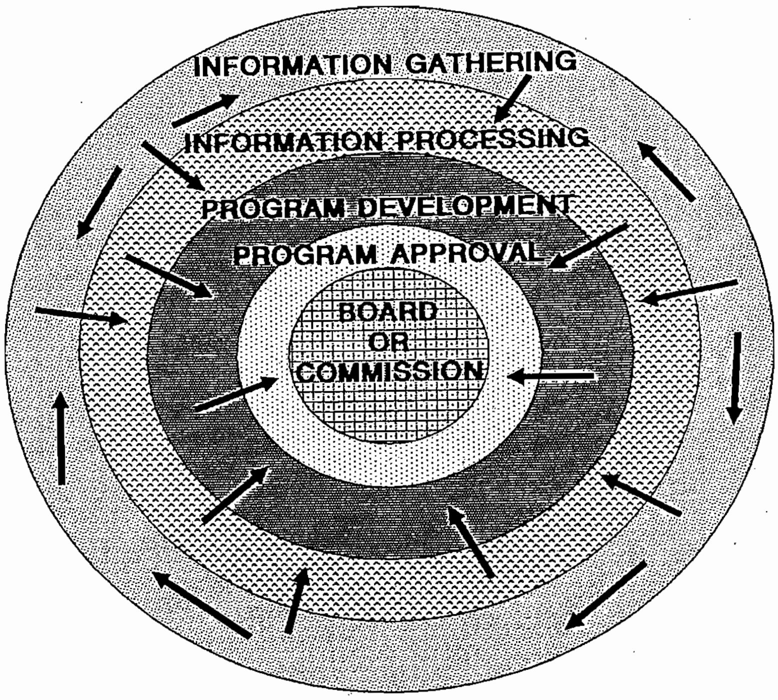

Figure 2. Program Development

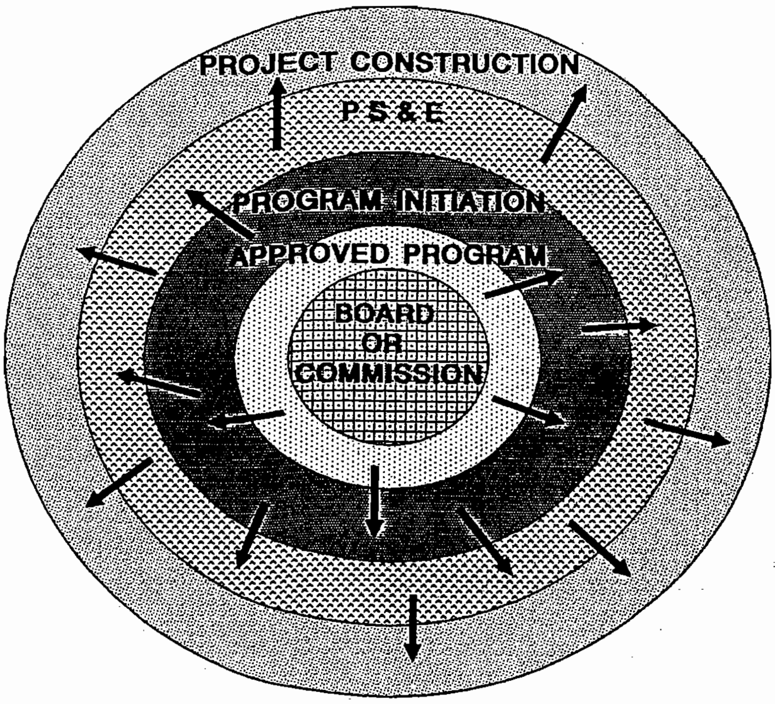

Figure 3. Implementation (Project Design)

In Figure 2, program development can be divided into five (5) levels starting with data gathering and proceeding to management through various levels of decision-making.

1. Program development first requires the gathering of information required to "drive" a PMS. This includes such items as traffic, pavement condition data, etc. as discussed in previous chapters.

2. Information gathering then leads to information processing; i.e., entry into computer programs taking into consideration the needs and concerns of the various units within the SHA. At this level, it can be expected that PMS outputs will be available for further evaluation and interpretation by those units which will eventually be involved in implementation.

3. The third level represents the preparation of one-year and multi-year plans for MR&R treatments by projects. Again, communications between SHA units are necessary to avoid misunderstandings regarding recommendations being transmitted to upper management.

4. The fourth level involves management and requires approval and setting of policy for development of MR&R programs.

5. Finally, PMS information should be communicated to any Boards or Commissions who need to be informed, or from whom approval is required for final programming. Such information must be provided in a timely manner to allow for necessary consideration by those agencies or organizations who could be affected by SHA planning.

Once the pavement improvement program is developed and approved, it is implemented through the actual development or design of the individual projects. Figure 3 illustrates the outward migration of the approved program to satisfy the needs for individual projects through design and construction. The coordinated development of programs including potential strategies is toward the center of the circle as shown in Figure 2 with each level contributing to the ultimate objective. The design of each project then moves outward from the center as shown in Figure 3.

When a PMS is developed and implemented, it may affect the way things are done in certain areas of a SHA. Internal communication is an extremely important consideration when new or modified procedures for planning and programming are initiated. There must be effective communication and interaction between the idea developers, the operating units who will apply the ideas, and the administrators who will be providing the support for developing and implementing the PMS. Potential pitfalls and hurdles need to be recognized and then communication strategies and packages developed to assure successful implementation.

Because of the technical nature of the data and the analysis it is desirable to translate the findings from the PMS into clear terms that are understandable to decision-makers who may not be technical experts or engineering professionals. It may be desirable at times to utilize the skills of communication experts to assist in developing reports from pavement management. The information must be timely, it must be accurate, and it must be understandable in order to be useful to upper management or to other approval authorities. Informed decisions are an indication that the message was understood and is being acted upon in a proper manner to the benefit of the agency and the user.

It is important that the pavement requirements of the different SHA organizational units be obtained and updated periodically so the PMS can be improved or enhanced as appropriate and be of better service to the SHA.

Reports should be prepared for specific useful purposes designed for the potential users in their language. This then helps assure that the right message is being given and will be used to better manage pavements. Generally the project level PMS requires more technical information because of the specific actions being planned and taken on individual projects, and the network level requires more summarized information because of its use by administrators and legislators.

External Communications

A SHA often finds it necessary to communicate with the legislature, with the news media or with the general public. A PMS can provide a wealth of pavement information that can be used as the basis for informing others of pavement conditions and needs. Legislators and the public need to be reminded periodically that pavements do wear out and that funds for maintenance, rehabilitation and reconstruction must be made available if the SHA is to continue to meet transportation needs.

A PMS is a very powerful information source which has the potential to convince legislators and taxpayers of the need to provide adequate funding for preserving the pavements as part of the overall transportation system. Data from the PMS can be effectively used to communicate pavement needs to elected officials. The information must be communicated in clear and understandable terms. The governing Board or Commission and the legislature must understand the needs and then endorse and support the program by providing an adequate level of funds. Good understandable communication is the medium for explaining to the decision-makers what is needed to preserve the pavement network as part of the overall transportation system. How the public understands what is taking place is almost as important as the act itself.

Good reliable and understandable information can go a long way in gaining support for the highway program and should give a good understanding of the status of the pavement infrastructure, its cost and performance.

Chapter 8 Products of a Pavement Management System

The previous chapters of these Guidelines have placed a considerable emphasis on the development and utility of a PMS. As a concluding portion of the Guidelines, Chapter 8 has been provided to summarize the products that can be obtained from a PMS.

The products, usually in the form of reports or computer outputs, will be useful to management, engineers, boards and commissions, legislators, media and other interested groups. In order to be effective, the reports will need to be tailored for use by these groups (see Chapter 7). For management, information pertinent to budget requirements and project scheduling may be of primary interest, whereas engineers may be more interested in MR&R recommendations for specific projects; legislators may need information on performance of the network and consequences of alternative funding levels. All such information can be made available from a PMS as may be required by a SHA. The level of sophistication and type of reports will vary between SHA and may be influenced by the amount of resources that can be made available to design, implement and maintain the PMS.

An example list of the types of reports available from a PMS includes the following:

1. The current condition of pavements, by segments.

2. Budget requirements to meet performance objectives, current and future.

3. Condition of pavements as a function of planned budget(s), current and future.

4. Site specific plans for MR&R actions.

5. Answers for "what if" questions, e.g., what if the budget is reduced, what if PMS guidelines are changed, what if performance standards are modified, what if new MR&R actions are used, and many more.

6. Priorities for allocating funds for MR&R actions by pavement segments.

7. History of MR&R actions by segment and by year.

8. Historical cost of MR&R actions by segment and by year.

9. Summary of traffic by route and location.

10. Estimated MR&R costs by segment.

The number and types of reports need to be carefully controlled and distributed; otherwise, the potential users could be overwhelmed with information. Reports for management and eventually by legislators need to have a summary character with a minimal of details.

The reports enumerated above are an indication of the type of information available from a PMS. While not so obvious, the

PMS will also result in a number of benefits for the SHA and for the public in general.

Agency benefits will be reflected in maximizing the effectiveness of each dollar available for MR&R. User benefits will be reflected in an MR&R program that provides a maximum level of service for funds (taxes) available to the agency. Specific examples of benefits will include:

1. Minimizing the cost required for MR&R actions for individual pavement segments.

2. Allocating funds fairly on the basis of established procedures and priorities.

3. Consistent agency-wide procedures for evaluating and measuring pavement condition.

4. Availability of timely information relative to pavement condition, MR&R actions and costs.

5. Central database of information relative to pavements.

6. Ability to evaluate the consequences of deferred maintenance.

7. Scheduling of timely MR&R actions.

8. Ability to answer "what if" type of questions.

9. Basis for communications internal and external to SHA.

10. Recognition of user benefits.

Potential products from a PMS will exceed those listed above. SHAs should make a conscious effort to document the benefits of products available from a PMS.

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Glossary of Terms

1. *ALTERNATIVES* - The various choices of treatments available for providing a solution to a pavement deficiency or problem.

2. *ANALYSIS PERIOD* - The period of time for which the economic analysis is to be made.

3. *BENEFIT/COST ANALYSIS* - Technique intended to relate the economic benefits of a solution to the costs incurred in providing the solution.

4. *COST-EFFECTIVENESS* - The situation that exists when the benefits exceed the costs for a given treatment, strategy, or improvement or when the benefit cost ratio is greater than one.

5. *FRICTION NUMBER (SKID NUMBER)* - The number that is used to report the results of pavement friction tests conducted in accordance with ASTM Standard E274.

6. *INTERNATIONAL ROUGHNESS INDEX (IRI)* - An index resulting from a mathematical simulation of vehicular response to the longitudinal profile of a traveled surface using the quarter-car simulation model described in E1170 and a traveling speed of 50 miles per hour (80 km per hour). Units are in inches per mile or meters per kilometer.

7. *LIFE-CYCLE COSTING* - An economic assessment of an item, area, system, or facility and competing design alternatives considering all significant costs of ownership over the economic life, expressed in terms of equivalent dollars.

8. *NETWORK LEVEL* - The level at which key administrative decisions that affect programs for road networks or systems are made. Sometimes referred to as the program level.

9. *NETWORK LEVEL ANALYSIS* - Evaluation of pavement to enable the selection of candidate projects, project scheduling, and budget estimates.

10. *OPTIMIZATION MODEL* - A mathematical description or algorithm designed to compare alternative strategies and to identify the relative merits of each strategy according to assigned decision criteria, such as safety, cost, etc.

11. *OPTIMUM STRATEGY* - The strategy among the alternatives considered that is expected to maximize the realization of management goals subject to the constraints imposed.

12. *PAVEMENT CONDITION* - A quantitative representation of distress in pavement at a given point in time.

13. *PAVEMENT DISTRESS* - The physical manifestations of defects in a pavement.

14. *PAVEMENT MAINTENANCE* - All routine actions, both responsive and preventative, which are taken by the state or other parties to preserve the pavement structure, including joints, drainage, surface, and shoulders as necessary for its safe and efficient utilization.

15. *PAVEMENT MANAGEMENT SYSTEM* - A set of tools or methods that assist decision-makers in finding cost-ef-

fective strategies for providing, evaluating and maintaining pavements in a serviceable condition.

16. *PERFORMANCE* - Ability of a pavement to fulfill its purpose over time.

17. *RECONSTRUCTION* - Construction of the equivalent of a new pavement structure which usually involves complete removal and replacement of the existing pavement structure including new and/or recycled materials.

18. *REHABILITATION* - Resurfacing, restoration, and rehabilitation (3R) work undertaken to restore serviceability and to 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, including shoulders, to a condition of structural or functional adequacy.

19. *PAVEMENT STRUCTURAL CAPACITY* - The maximum accumulated traffic loads that a pavement can withstand without incurring unacceptable distress.

20. *PREDICTION MODEL* - A mathematical description of the expected values that a pavement attribute will take during a specified analysis period.

21. *PRESENT SERVICEABILITY* - The current condition of a pavement (traveled surface) as perceived by the general public.

22. *PROJECT LEVEL* - The level at which technical management decisions are made for specific projects or pavement segments.

23. *PROJECT LEVEL ANALYSIS* - Evaluation of pavement to select the type and timing of rehabilitation or maintenance.

24. *RESPONSE-TYPE ROAD ROUGHNESS MEASURING SYSTEM* - Roughness measuring systems that measure a vehicle's response to the longitudinal profile.

25. *ROUGHOMETER* - A road meter that measures the unidirectional vertical movement of damped, leaf-sprung wheel relative to the road meter's trailer frame during travel to yield a measure of roughness.

26. *RUT* - The maximum longitudinal concave depression in the wheel path deviating from the wheel path surface plane that may influence vehicle use of the pavement and is independent of slope.

27. *SALVAGE VALUE* - The value of the pavement at the end of the life cycle or analysis period. Salvage value can be either positive or negative depending on whether material has some economic value or whether the cost of demolition or removal exceeds its economic value.

28. *SERVICEABILITY* - The ability of a specific section of pavement to serve traffic in its existing condition.

29. *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 or it could be a set of maintenance rehabilitation or reconstruction actions selected to preserve the entire network at specified levels of performance.

30. *TREATMENTS* - Materials and methods used to correct a deficiency in a pavement surface.

31. *USER COSTS* - Those costs that are accumulated by the user of a facility. In a life-cycle cost analysis these could be in the form of delay costs or change in vehicle operating costs.

32. *WEIGH-IN-MOTION* - The process of estimating a moving vehicle's gross weight and the portion of that weight that is carried by each wheel, axle, and/or axle group, by measurement and analysis of dynamic forces applied by its tires to a measuring device.

Acronyms

FHWA - Federal Highway Administration

FHPM - Federal-Aid Highway Program Manual

PMS - Pavement management system

MR&R - Maintenance, rehabilitation and reconstruction

SHA - State highway agency

WIM - Weigh in motion

AVC - Automatic vehicle classification

NDT - Non-destructive testing