NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 215

PAVEMENT MANAGEMENT SYSTEM DEVELOPMENT

TRANSPORTATION RESEARCH BOARD
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AREAS OF INTEREST:
- ADMINISTRATION
- FACILITIES DESIGN
- PAVEMENT DESIGN AND PERFORMANCE
- (HIGHWAY TRANSPORTATION)
- (AIR TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation Research Board

This report will be of interest to people of a number of disciplines in transportation and other agencies. It describes the concept of pavement management and provides an analysis of pavement management system (PMS) development and implementation. From the administrator's standpoint, a PMS is a tool that can be used effectively to provide the desired level of pavement service at the lowest over-all or long-term cost. A PMS permits the comparison of a large number of design, construction, and rehabilitation options from a total cost standpoint at both the project level and the network level.

Systems engineering in its broad sense is a codified procedure for attacking complex problems in a coordinated fashion. This permits realistic decisions to be made and justified on the basis of specified decision criteria. As applied to pavements, it is becoming recognized as the PMS concept. A PMS should be capable of considering all relevant factors and selecting pavement design, maintenance, and rehabilitation strategies with lowest predicted total cost over a prescribed life-cycle analysis period. Such elements as initial construction, routine maintenance, periodic rehabilitation, interest on investment, salvage value, and roadway user costs should be taken into account.

Substantial amounts of money have been expended in recent years in the NCHRP, the FHWA contract research program, individual state HP&R programs and by foreign agencies on PMS research and development. A workshop was held in Tumwater, Wash., November 8-10, 1977, for representatives of agencies involved in PMS development. Major findings of the workshop were:

1. Although many PMS schemes have been proposed, no highway agency has a completely operational PMS.
2. The immediate need is for a simplified PMS to assist in the planning and management of rehabilitation activities for existing pavements.

Under NCHRP Project 20-7, Task 15, the ARE, Inc., research team was assigned the responsibilities for (1) preparing a synthesis-type report on PMS research and development and (2) developing a simplified PMS framework suitable for assisting highway agencies in programming rehabilitation of existing pavements. This report constitutes fulfillment of the first responsibility. It goes beyond the normal synthesis or state-of-the-art report by describing a total PMS framework and then reviewing existing methodology within the context of the framework. The parts of the framework that are realistically achievable now are identified, as well as those in need of further development.

The over-all framework presented in this report constitutes the foundation for development of a simplified PMS. A working document prepared by the research agency provides another step in this development, detailing characteristics for input, models, and output; providing alternative PMS viewpoints; discussing specific existing technology that is promising for future PMS applications; and recommending a research plan for achieving and implementing a PMS. Further research in this field is under way and programmed both in the NCHRP and by other agencies.

Implementation of the PMS concept does not depend on full development of a complete or total PMS computer package. As indicated by the Tumwater workshop participants, many agencies are using the concept on an evolutionary or staged basis. Further development and early implementation of PMS components or modules, particularly at the network level, should be of considerable interest and value to transportation officials. Pavement maintenance and rehabilitation is likely to account for a major portion of available transportation funds in future years. An operational PMS will be a valuable tool for selecting network programs that will have the least total cost or greatest benefit over a chosen analysis period.

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The research report herein was conducted under NCHRP Project 20-7 by Austin Research Engineers, Inc., Austin, Tex. Drs. W. Ronald Hudson and Ralph Haas were the co-principal investigators. The other author of this report is Dr. R. Daryl Pedigo, Engineering Analyst, Austin Research Engineers, Inc., who served as Project Coordinator. Dr. Freddy L. Roberts, Austin Research Engineers, contributed significantly to the research effort for this project and assisted in preparation of this report. Special thanks are extended to Dr. Robert L. Lytton, Texas Transportation Institute, Texas A & M University, and Dr. Ronald L. Terrel, Professor of Civil Engineering, University of Washington, for their valuable and instructive comments; and to Dr. B. Frank McCullough, Austin Research Engineers, and Fred N. Finn, Ben Lomond, Calif., for their important contributions to this research effort.

PAVEMENT MANAGEMENT SYSTEM DEVELOPMENT

SUMMARY

Pavement management, in its broadest sense, encompasses all the activities involved in the planning, design, construction, maintenance, and rehabilitation of the pavement portion of a public works program. A pavement management system (PMS) is a set of tools or methods that assist decision-makers in finding optimum strategies for providing and maintaining pavements in a serviceable condition over a given period of time. 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.

The detailed structure of a PMS depends on the organization of the particular agency within which it is implemented. Nevertheless, an over-all, generally applicable framework can be established without regard to detailed departmental organization. This report outlines a rather complete, long-term concept of pavement management, and also provides guidelines for more immediate application based on existing technology.

It is convenient to describe pavement management in terms of two generalized levels: (1) the network management level, sometimes called the program level, where key administrative decisions that affect programs for road networks are made, and (2) the project management level where technical management decisions are made for specific projects. Historically, most formal pavement management system development has occurred at the project level. More recently, extensive development in maintenance management and data management methodologies has added to the pressure for development of a total pavement management system; one where all activities are included and explicitly interfaced with each other.

Pavement management systems can provide several benefits for highway agencies at both the network and project levels. Foremost among these is the selection of cost-effective alternatives. Whether new construction, rehabilitation, or maintenance is concerned, a total PMS can help management achieve the best possible value for the public dollar.

At the network level, the management system provides information pertinent to the development of a statewide or agencywide program of new construction, maintenance, or rehabilitation that will optimize the use of available resources.

Considering the needs of the network as a whole, a total PMS provides a comparison of the benefits and costs for several alternative programs, making it possible to identify that program which will have the least total cost, or greatest benefit, over the selected analysis period.

At the project level, detailed consideration is given to alternative design, construction, maintenance, or rehabilitation activities for a particular section or project within the overall program. Here again, by comparing the benefits and costs associated with several alternative activities, an optimum strategy is identified that will provide the desired benefits or service levels at the least total cost over the analysis period.

At any management level, a cost-benefit comparison may be listed for each strategy considered, providing documentary evidence to support the value of proposed activities.

An operational pavement management system also provides an efficient means for continual evaluation of existing techniques and procedures. In the area of data collection, for example, significant savings may be achieved through the collection and storage of only that information which will be effectively used. In addition, systematic data collection and good prediction models within a total pavement management system can provide the basis for special studies, such as an evaluation of the effects of increased vehicle load limits.

In order to realize the full benefits of such a management system, proper information for each management level must be collected and periodically updated; decision criteria and constraints must be established and quantified, where possible; alternative strategies must be identified; predictions of the performance and costs of alternative strategies must be made; and optimization procedures that consider the entire pavement life cycle must be developed. Moreover, the proper implementation of all of these management activities, and the use of the optimum strategies selected, is essential to the full realization of such benefits.

Implementation of a total PMS can begin immediately, utilizing existing technology. Some states have already taken steps in this direction, with considerable development having occurred at the project level. The greatest current need is for comparable development at the network level.

Implementation should proceed in several steps, with the initial system including some working models or procedures in each of the major subsystems of the total framework. The implementation is most easily accomplished through such a stepwise procedure if the PMS is developed around a modular concept. The system may be initially applied to a single management area, such as rehabilitation programming, with additional areas to be added later. Successful implementation begins with a management decision to implement, followed by continuing management support of the activities. In all cases, gratified and interested personnel are the key to success. The PMS team must include people from each activity area (design, maintenance, etc.) plus new personnel with expertise in such areas as computer programming, optimization, economics, and field measurements.

CHAPTER ONE - INTRODUCTION AND DEFINITIONS

SCOPE AND OBJECTIVES

This report provides a review of the current status of pavement management system (PMS) development and implementation. It is based on existing literature, discussions with various people actively involved in pavement management, and the experience and opinions of the authors. It is intended to outline a total, long-term concept of pavement management and to provide a framework for more immediate application. It is also intended to recognize the various functions of people involved in pavement management and to convey how the activities of such people are involved in a comprehensive pavement management system. While a generalized PMS concept is presented, a simplified version is also presented that can be achieved with present technology within a period of three to five years. A critical review of existing practices and models and an explicit identification of their strengths and needs are required in order to identify both the total and simplified systems. This not only makes it possible to identify what part of the total framework is realistically achievable now, but also provides a basis for further developments and implementation.

The report is addressed to two major management levels and the people who function at these levels:

1. Administrative levels, where decisions are made regarding a program, or set of projects, and the budgets and priorities appropriate to the program.

2. Technical management levels, where decisions are made on "best" design, monitoring of in-service pavements, "best" maintenance procedure, etc., for an individual project.

It is possible, of course, that for some highway agencies, particularly smaller ones, decisions at both levels are made by the same individual. As well, some activities, such as maintenance management, involve decisions in both the administrative and detailed technical areas.

The remaining sections of this chapter provide a general background pavement management system development and some key, working definitions. Subsequent chapters present a new total concept or framework for pavement management, an assessment of existing practices with respect to this framework, and a simplified framework that is realistic for immediate application. The total concept represents an ideal goal, while the simplified framework provides the basis for the major tasks to be accomplished within subsequent phases of this project.

INTRODUCTION TO PAVEMENT MANAGEMENT

Pavement management is not a new concept; management decisions are made as a part of normal operations every day in highway agencies throughout the nation. The idea behind a pavement management system is to improve the efficiency of this decision-making, expand its scope, provide feedback as to the consequences of decisions, and ensure the consistency of decisions made at different levels within the same organization.

Every highway department must decide how to spend its available budget most wisely. Many states have approached this problem by evaluating their existing pavement, determining immediate needs, and funding as many of the needed projects as the budget will allow. Some states have established different procedures for determining needs and for prioritizing those projects that are selected as "needed." This process is repeated each time the state legislature is scheduled to allocate funds. An over-all priority list may be generated on the basis of a computerized analysis of all projects within the department, or it may simply be an amalgamation of individual lists prepared by various districts.

Consider rehabilitation programming, for example. In this case, the typical priority list is based on the current condition or serviceability of a project. This current condition of a pavement is clearly dependent on its history in terms of structure, load, environment, and other factors. It is also clear that the current condition is a result of decisions made in previous years, and that decisions made now will have an effect on the condition of the pavement in the future years. Thus, current decisions should be made in the light of both their immediate effects and their expected future effects.

Of course, the need for implementation of a PMS is not as apparent if an unlimited budget for rehabilitation is available. If adequate funds are available, and if there are no other constraints that provide reasons to optimize, it is sufficient to evaluate sections each year and schedule required rehabilitation whenever the need is observed. Otherwise, the proposed actions should be carefully evaluated not only with regard to current needs and costs, but also with regard to the consequences of each action on future needs and costs. Suppose, for example, that funds are available to do approximately 1/3 to 1/2 of the required overlays within a district. Should one then place the design overlay thickness on some of the projects and totally ignore others? Should one place thinner overlays on all projects? Which projects are to receive less-than-desirable treatment?

Questions such as these are best answered on the basis of the predicted effects of each of the alternative actions under consideration. For example, if all pavements are given a thin overlay, there will be an immediate improvement in all projects. However, some of these projects may require further rehabilitation within a short period of time because of their relatively rapid rate of deterioration. If these same projects occur each year on the needs list, and new projects are added as well, the situation can only get worse. On the other hand, if certain pavements receive the design overlay thickness while others are virtually ignored, the overlaid pavements should not reappear on the needs list during the next several years. During each of these next years, it may then be possible to fully rehabilitate other sections, so that with new projects included the "needs" list may get shorter each year — or at least may not get longer. However, those pavements that have been ignored will undoubtedly deteriorate, so that the over-all condition of the pavements within the district may be considerably worse during the first few years than that achieved with the first strategy. In order to distinguish which of these tradeoffs is most desirable, one must be able to predict the future consequences of these alternative overlay schemes.

The prediction of future consequences of present actions may be made informally in the decision-maker's head as part of the "engineering judgment" that is utilized in decision-making. It is possible to make reasonable predictions in this manner. One great disadvantage in this is that if the predictions later turn out to be in error, one cannot pinpoint the source of error in a projection made on the basis of intuitive logic. If, on the other hand, the consequences are predicted utilizing specified methods and procedures, it will be possible in future years to analyze the previous prediction and determine which portions of the procedure require modification. In this way, it will be possible to continuously update and improve the prediction procedure.

Another consideration to be taken into account in making the best possible use of available resources is the interrelationship between the various divisions of the highway department. Decisions are often made independently by separate groups within an agency. This is to a large extent desirable for the smooth operation of a large agency. Also, many of the activities of, for example, a maintenance division are quite distinct and separate from the activities of a design division. However, it is often the case that decisions made within one area will affect the operations in another area. For instance, a designer may assume certain routine maintenance levels over a 20-year period in designing a new pavement. At the same time, the maintenance division may be considering modifications in the routine maintenance levels for this class of pavement. Thus, there is a need for communication and interaction during the decision-making process, so that maintenance people consider design assumptions in their planning and so that designers select realistic levels of maintenance. This need for supplying information between divisions continues during the life cycle of the pavement. Information on performance and cost to deliver performance are important in validating design procedures and assumptions.

Similarly, the information used in the decision-making process by the various divisions of the highway department must be consistent. If one division is projecting a 5 percent annual increase in traffic on all interstate highways in the network, and another division is projecting a 10 percent annual growth, the "best" decisions chosen by the two divisions may very well conflict with one another. All decision-makers should have access to data sets that are consistent and up-to-date.

This does not mean that all decisions are to be made using exactly the same data. It is impossible, for example, to consider detailed project information in making decisions concerning an entire highway network, if for no other reason than the sheer volume of data involved could not be efficiently handled. In addition, the kinds of criteria and constraints that must be considered for network programming will not be the same as those considered in, for example, choosing an appropriate overlay design for an individual project. Each decision-making group will in general have its own unique data requirements, both in type and detail.

The detailed structure of a pavement management system depends on the organization of the particular highway department within which it is implemented. There is considerable variation in the organizational structure of highway departments in the various states, so that no attempt can be made to establish a generally applicable organizational structure for a pavement management system. Each of these agencies must, however, consider the same basic types of data, make the same types of decisions, and carry out the same basic activities. Pavement management can be adequately described in terms of these activities and the flow of information that they require. Thus, the over-all framework for pavement management systems can be established as generally applicable without regard to detailed departmental organization. Such an over-all framework is developed in Chapter Two and employed in the analysis of existing pavement management practices in Chapter Three.

HISTORICAL BACKGROUND

Much of the current interest in, and development of, pavement management systems is derived from the realization by highway agencies that investments of billions of dollars in paved roads require sound management to achieve the most cost effective use of limited available funds. In a somewhat more specific sense, the following factors summarized in Table 1 have provided impetus to these developments:

1. Dramatic increases in the total highway investment as a result of the road building boom of the 1950's and 1960's.

2. Significant developments during the past two or three decades in pavement technology, in systems analysis methodology <u>per se</u>, in information growth, and in the capability to quickly and easily process data and solve relatively complex problems through computer development, etc., resulting in development of techniques for efficiently coordinating all these new methods and information.

3. Direct applications of systems analysis methods to the design component of pavement management, starting in the mid-1960's, plus extensive use of modern management methods, resulting in the development and implementation of "maintenance management systems."

4. Recent recognition that extensions to the highway network are becoming less significant and that more emphasis should be placed on preserving the existing investment through proper rehabilitation and maintenance, performed at the proper time.

5. Recent concerns over energy consumption and costs, initiating reconsideration of the direct effect of pavement condition on vehicle operating costs.

6. Increased emphasis in recent years on the in-service monitoring of pavements for riding comfort, structural capacity, condition, safety, etc., plus significant improvements in the technology and efficiency of performing such measurements.

7. Major growth during the past couple of decades in management methods,

8. Inflationary trends over the past decade, leading to increased maintenance and construction costs, relative to the available funds.

9. The energy shortage, and shortages of maintenance and construction materials in recent years.

The growth of total investment in pavements, as represented by the road building boom of the 1950's and 1960's, may not have contributed directly to pavement management system development; however, it must surely have given at least an indirect push to such development. As investment becomes larger, there is usually an accompanying awareness of

TABLE 1. FACTORS PROVIDING IMPETUS TO PAVEMENT MANAGEMENT SYSTEM INTEREST AND DEVELOPMENT

YEAR 1950 1960 1970 1980	FACTOR
	1. Road building boom of 1950's and 1960's
	2. Developments in pavement technology, systems methods, information growth, data handling capabilities, computers, etc.
	3. Direct application of systems analysis to design component of pavement management
	4. Increased emphasis on management of existing network; i.e., rehabilitation and maintenance needs
	5. Recognition of direct effect of pavement condition on user costs
	6. Increased emphasis and capability in pavement monitoring as a management tool
	7. General growth in management methods and awareness
	8. Increased maintenance costs with decreased availability of funds (inflation)
	9. Energy and material shortages

the need to manage it properly. This is certainly the case for industry and the same pressures are expected to motivate state, federal, and local agencies.

Major improvements in pavement technology, information systems, systems methodology, processing and analysis capabilities through the use of computers, etc., may not have contributed directly to pavement management system development. However, the increased use of these techniques made it imperative that coordination and proper use be made of this vast amount of technology and information; i.e., there developed a need to manage the technology itself, in addition to the need to manage the investments in pavements. The effects of computers, for example, have been literally monumental, a fact which may be especially apparent to those who worked in the pavement field in the precomputer era. Designers in the precomputer era were able to consider only a very limited number of options; now it is possible to structurally analyze and economically evaluate hundreds of possible alternatives. The capability to generate and consider alternatives is basic to any type of management activity.

Direct applications of systems analysis and operations methods to the structural design component of pavement management, starting in about the mid-1960's, provided the central core for subsequent developments in pavement management systems. In fact, the initial terminology used was "pavement design systems," followed by "pavement design and management systems" (in the late 1960's), and subsequently the term "pavement management" was used to represent the entire spectrum of management activities. The widespread implementation of maintenance management systems during this period undoubtedly assisted in at least providing an awareness of the term "management" and its potential for the pavement field. As well, the actual activities in maintenance management, involving programs, budgets, performance standards, priorities, work activities and accomplishments, budget control, records, etc., provided valuable input to pavement management system development.

In the 1970's, many highway agencies began to allocate more funds to preservation of investment, through rehabilitation and maintenance, than to new construction and expansion of their networks. A growing awareness of the fact that they did indeed have large existing investments in pavements, and that these had to be "managed" just like any other large investment, certainly assisted in providing a receptive climate for continued development of pavement management systems.

It was also in the 1970's, largely through efforts of the World Bank and other agencies, that pavement conditions were shown to have a direct and significant effect on vehicle operating costs. This fact, coupled with energy concerns, not only brought a new dimension to the pavement management field but also provided a basis for calculating benefits and thereby a realization that pavement investments could be managed to yield optimum value to society.

The foundation for pavement management is in many ways pavement evaluation; i.e., the periodic monitoring of pavements in-service. Management decisions depend on supporting information, which must itself be manageable. Continual improvements in measurement technology ranging from structural to roughness, and processing, storing and retrieving the data acquired have assisted markedly in this aspect of manageability.

Finally, pavement management system development has undoubtedly been inherently influenced during the past decade by a significant growth in, and awareness of, modern management methods. This is reflected in the many organizational studies conducted by state transportation agencies and some significant reorganizations that occurred during this time.

DEFINITIONS

One of the conclusions of the Pavement Management Workshop at Tumwater, Washington, in November 1977 (1) was that "although pavement management has been a term used frequently by highway engineers during the past few years, there appears to be no clear-cut agreement as to what it is or should be." What is clear, however, is that some definitions are necessary both for this report and for subsequent efforts in the pavement management field.

The following set of definitions is intended to provide a common and consistent basis for the use of certain fundamental terminology in the pavement management field. This list is not, however, intended to be all-inclusive and those terms considered to enjoy reasonable agreement among most agencies and people in the field are not repeated.

An obvious omission from this list is "pavement". The authors define "pavement" to include shoulders as well as all structural elements of the roadway (i.e. all layers). Also, the load-carrying capacity of the subgrade is implicitly included in this definition. On the other hand, the authors feel that "pavement" can be defined broadly or narrowly by the individual highway agency in establishing the pavement management system. The framework presented in this report is flexible enough to incorporate a wide range of definitions.

1. Pavement management involves the identification of optimum strategies at various management levels as well as the implementation of these strategies. It is an all-encompassing process that covers all those activities involved in providing and maintaining pavements at an adequate level of service. These range from initial information acquisition to planning and programming of maintenance, rehabilitation and new construction, to the details of individual project design and construction to periodic monitoring of pavements in-service.

2. A pavement management system (PMS) is a tool that provides decision-makers at all management levels with optimum strategies derived through clearly established rational procedures. A PMS evaluates alternative strategies over a specified analysis period on the basis of predicted values of quantifiable pavement attributes, subject to predetermined criteria and constraints. It involves an integrated, coordinated treatment of all areas of pavement management, and it is a dynamic process that incorporates feedback regarding the various attributes, criteria, and constraints involved in the optimization procedure.

3. A strategy is 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 serviceable condition for a specified period of time.

4. An optimum strategy is that strategy among the alternatives considered which is expected to maximize the realization of management goals subject to the constraints imposed.

5. An attribute is a property of a pavement section or class of pavements that provides a significant measure of the behavior, performance, adequacy, cost, or value of the pavement.

6. An attribute, criterion, constraint, or other variable is called quantifiable if it can be adequately expressed in numerical form.

7. An analysis period is a specified interval of time (or accumulated number of load applications) over which alternative strategies are to be evaluated. This is generally on the order of 20 years; i.e., a complete life cycle.

8. Pavement management activities and PMS components may be characterized by the administrative level at which they occur. The project level is characterized by predominantly technical management concerns, such as detailed design decisions, regarding individual projects. The models utilized at this level require detailed information on individual sections of pavement. The network level primarily involves programming decisions for large groups of projects or an entire highway network. The latter is sometimes referred to as the program level. Here, the models employed are geared to less detailed or "average" data for the entire set of projects under consideration.

9. A prediction model is a mathematical description of the expected values that a pavement attribute will take during a specified analysis period.

10. An optimization model is 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. An economic model is a mathematical description of the expected costs, benefits, or both, associated with the elements of various strategies, for a specified analysis period.

CHAPTER TWO - A TOTAL PAVEMENT MANAGEMENT SYSTEM CONCEPT

STATEMENT OF A PAVEMENT MANAGEMENT SYSTEM

The concept for a total pavement management system put forth in this report is intended to have the widest possible scope. It may be considered ideal in that sense, but certainly is consistent with, for example, Steger's report on Pavement Management to AASHTO Region 3, 1978 (2). He pointed out that the scope of the Tumwater Workshop was limited to only two aspects of pavement management systems: (a) approaches to pavement monitoring, and (b) decision-making for resurfacing, restoration and rehabilitation work; and that a complete system would consider "...all pavement related activities together, including planning, design, construction, maintenance, monitoring, and rehabilitation." Haas and Hudson (3) have similarly stated that "A pavement management system consists of a comprehensive, coordinated set of activities associated with the planning, design, construction, maintenance, evaluation and research of pavements," and the Roads and Transportation Association of Canada (4) has stated that "a pavement management system encompasses a wide spectrum of activities including the planning or programming of investments, design, construction, maintenance, and the periodic evaluation of performance."

Clearly, these definitions of a pavement management system are wide ranging in scope and consistent with the definition of Chapter One which includes all the activities concerned with the provision of pavements.

Thus, the question of what comprises a total pavement management system can, in general terms, be answered as follows:

> A total pavement management system consists of a coordinated set of activities, all directed toward achieving the best value possible for the available public funds in providing and operating smooth, safe, and economical pavements. This is an all-inclusive set of activities, which may be classified in terms of major subsystems. A pavement management system must serve different management needs or levels and it must interface

with the broader highway, airport, and/or transportation management system involved.

The following sections consider this statement in terms of some of the essential features of a pavement management system. They then translate this statement into a total framework, identify the key interior subsystems and interface components, and identify the management levels served by each subsystem.

SOME ESSENTIAL FEATURES OF A PAVEMENT MANAGEMENT SYSTEM

A pavement management system must be capable of being used in whole or in part by various levels of management in making decisions regarding both individual projects and an entire highway network. All types of decisions should be considered by the general pavement management system, including those related to information needs, projected deficiences or improvement needs for the network as a whole, budgeting, programming, research, project design, construction and maintenance, resource requirements, monitoring, etc.

All functions involved in providing pavements are essential to a comprehensive pavement management system, but not all functions need be active at the same time. In planning future construction, for example, it is necessary to consider individual project design in only a very approximate way. Thus, a pavement management system can be viewed as a set of connected modules or "building blocks." In this sense, a pavement management system may be likened to a kaleidoscope: the whole thing exists at all times, but what part of it one sees depends on how one looks at it.

In addition to defining a pavement management system, it is useful to list some of the essential requirements:

1. Capability of easily being updated and/or modified as new information and better models become available.

2. Capability of considering alternative strategies.

3. Capability of identifying the optimum alternative.

4. Capability of basing decisions on rational procedure with quantified attributes, criteria, and constraints.

5. Capability of using feedback information regarding the consequences of decisions.

Each of these characteristics of a PMS implies the need for certain secondary requirements. For example, in order to consider alternative rehabilitation strategies, the pavement management system must have access to a list of possible activities appropriate to the R-R-R program within the state agency. These may be provided separately for each decision to be made, or a general list of candidate strategies may be set up in advance for application to broad categories of decision problems. A more sophisticated system might generate its own list of feasible strategies from some built-in general concepts.

The next step is to evaluate each strategy. An optimum strategy can be chosen only if it is possible to compare the consequences of individual strategies. This leads to several requirements. First, it is necessary to identify important attributes of the pavement or network of pavements under consideration. These attributes will form the value system by which the management system can judge the effects of any strategy. For example, the average skid number of the pavement is a possible choice as an attribute, and the system may be set up to discard all strategies that will lead to an inadequate skid resistance. There are two additional requirements that are implied in this example. Clearly, the pavement management system must be able to predict the effect of each activity on each attribute. This is necessary because it is not feasible to test alternative strategies in the field each time before making the optimum choice. In formulating this prediction, it will be necessary, in most cases, to know the current values of these attributes. Also, the predictions will to some degree be based on past experience. Thus, the attributes must be measurable by some reproducible, reliable means, usually involving established engineering or economic techniques.

Another aspect of the decision-making process is that it must involve logical decisions based on justifiable criteria. The pavement management system must base its recommendations on an analysis of quantifiable standards and constraints. Thus, actual numerical values must be supplied to the system either by retrieval from a preestablished data base or by direct input for each decision to be made.

Exactly what information must be supplied is dependent on the scope and use of the individual PMS, but a general requirement is that the system should consider the entire range of factors that has an impact on the decision at hand. The optimization procedure must reflect as nearly as possible the needs, values, and constraints that the users of the pavement management system are faced with.

A TOTAL FRAMEWORK FOR PAVEMENT MANAGEMENT

The definition of a total pavement management framework should begin in a highly summarized form for overview purposes. Figure 1 starts this definition in terms of two major levels of pavement management. Successive levels of detail may then follow.

The two basic levels of pavement management considered in Figure 1 are: (1) the network management level where, essentially, key administrative decisions are made, and (2) the project management level, where decisions are made essentially in terms of technical management. There are, of course, a number of technical activities at the first level and certain administrative activities at the second level. The interface of the pavement management system with the broader highway or transportation system management, of which it is a part or a "subsystem," is shown only in conceptual form.

Figure 2 is an expansion of Figure 1. It provides a summary framework for pavement management but only lists the key activities, rather than showing their interrelationships, for an initial, easily readable format. An alternative view of this structure is provided in Figure 3. Here, the central role of the data base or data management system is illustrated, and various activity areas are identified at both the project and network levels. This figure gives an overview of the interaction of the various activities, and points out that the data base is a source of information for each activity as well as a storehouse for feedback from each activity.

A total PMS functions at all management levels from the most fundamental project level to the highest administrative level. At each of these levels, different types of decisions are called for involving varying types and amounts of data, different criteria, and different constraints. Consequently, the detailed structure of the various parts of the total system may be expected to vary considerably from level to level and from activity to activity within any level. The basic flow of information or sequence of actions within levels is the

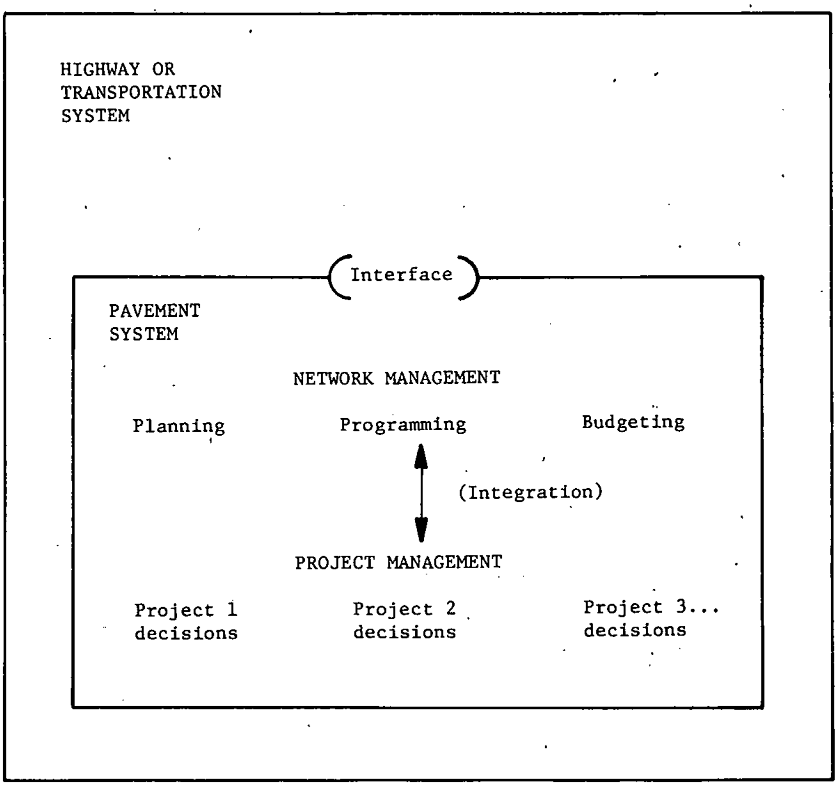

Figure 1. Pavement Management Levels

same, however. This is true for all management levels and for each activity (i.e., design, maintenance, budgeting, etc.) within a given level.

This similarity of information flow forms the basis for our total PMS framework, and is illustrated in Figure 4. Three basic subsystems are identified: "information," "analysis," and "implementation." The concept is that in making a decision, pertinent information is gathered and the consequences of the available choices are analyzed in the light of this information. Based on this analysis and on other nonquantifiable considerations (perhaps political) and constraints, a decision is made. Once made, the decision is implemented, and the results of the decision are recorded in the data bank and passed on to other management levels.

This concept is applied to a two-level PMS in Figure 5. Three major subsystems are shown at the network management level and three at the project management level. Also shown as subsystems, but not specifically classified as network or project, are the data file and research studies. These encompass both project and network level activities. There are several activities or criteria that are not shown as parts of the subsystems, per se; for example, budget constraint, decision criteria, etc. Although these are, of course, key parts of the management system, they are applied to the results of outputs of subsystems and it is therefore considered more useful to separately identify them. Those activities listed within the subsystems of Figure 5 are only meant to be illustrative and not all-inclusive. A more comprehensive listing and discussion are presented in subsequent sections.

The interface of the pavement management system of Figure 5 with the higher level transportation system management occurs at the network management level; specifically, where "committed" projects come forward and where the optimized or prioritized program is submitted for review and approval. Any such program and its associated costs would likely go forward to the higher level of management as a recommendation, be evaluated with respect to the over-all transportation program and objectives as well as the sector (i.e., highway, airport) budget allocation, and then be suitably modified if any program revisions were required.

The subsystems shown in Figure 5, and the key management activities that are applied to the outputs of these subsystems, are discussed in more detail in the following subsections.

<u>Network Management Level Subsystems and Management Activities</u>

The network management level subsystems and their components, plus the other key management activities at this level, are briefly described as follows.

<u>Information Subsystem</u>

This subsystem involves the collection of those data necessary to determine the existing condition of the network as a whole, data relating to traffic and other factors, and the processing of the data, all directed toward providing the basic foundation for conducting the network analysis. The essential activities and types of data collected for this subsystem include the following:

1. Determination of what attributes of the pavement should be measured and/or what types of information need to be acquired.

2. Identification of homogeneous sections or links in the network.

3. Geometric and other characteristics of the sections.

4. Traffic measurements or estimates, accidents, etc., for each section.

5. Field measurements for structural capacity, ride quality, surface condition, skid resistance, etc., on a sample or mass inventory basis and to a degree of accuracy and/or frequency appropriate to the class of road involved, agency resources, etc.

6. Estimate of approximate unit costs for new construction, rehabilitation construction, and maintenance.

7. Identification or inventory of available resources (materials, contractor "capacity," physical plant, etc.).

8. Identification of desirable or stated criteria on minimum ride quality, minimum skid resistance, etc.

9. Identification of "committed" improvements or projects from general

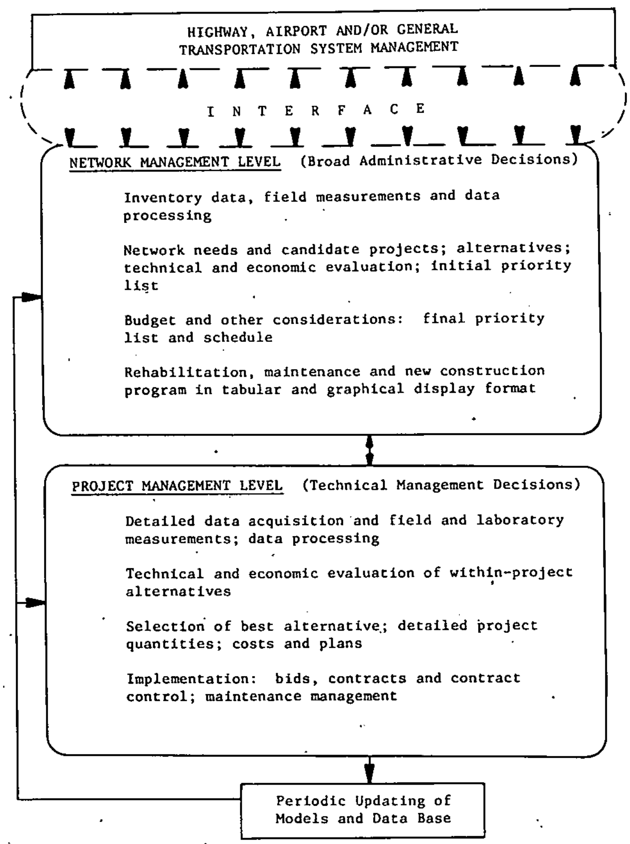

Figure 2. Summary Framework for a General Pavement Management System Concept

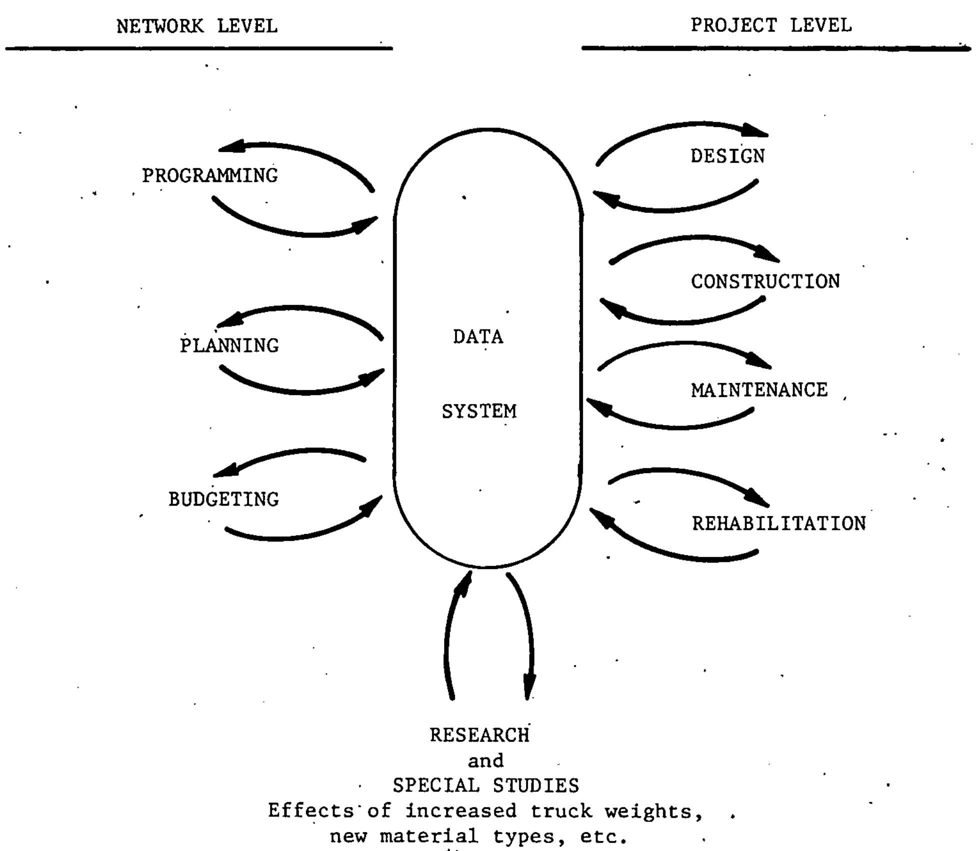

Figure 3. Activities of a Pavement Management System

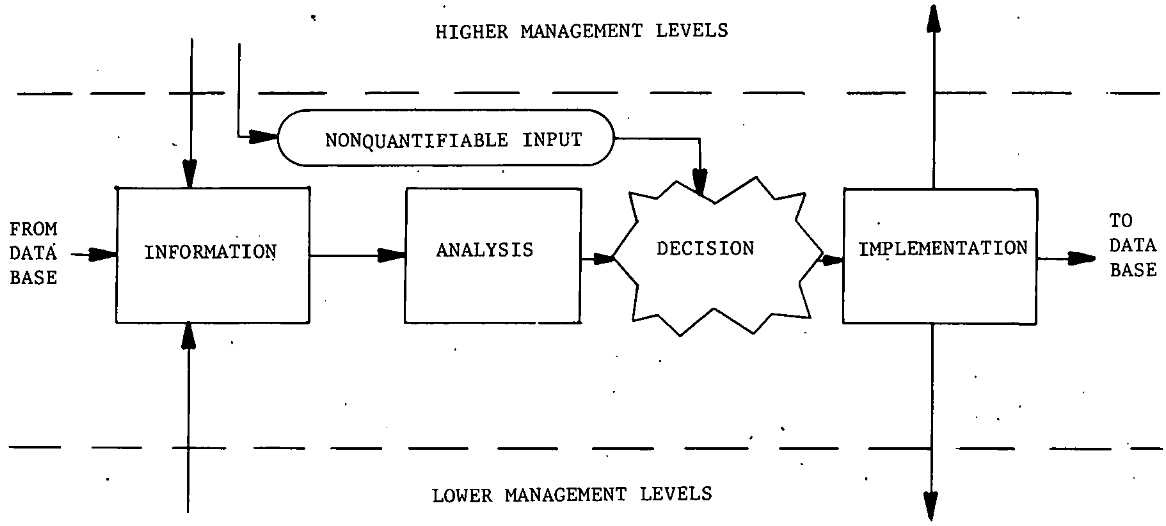

Figure 4. Flow of Information at a Typical Management Level Within a Total PMS

highway, airport, and/or transportation program (i.e., projects for capacity or geometric improvements, where pavement is part of the larger project).

10. Data from as-built projects and maintenance.

11. Data processing for input to network analysis subsystem and for transmittal to data file.

Periodic Update

Periodic updating of the information subsystem of Figure 5 is shown separately even though such updating may, to some extent, be conducted within the subsystem itself. In any case, what is important is the recognition of updating as a key activity and that it applies not only to periodic physical measurements but also to recording changes to the inventory as each project is completed (i.e., from the implementation subsystem shown at the Project Level of Fig. 5).

Network Analysis Subsystem

The essential function of the network analysis subsystem is to consider the pavement improvement and/or maintenance needs and to arrive at a program of rehabilitation, new construction, and maintenance. This is accomplished through the following activities:

1. Identification of needs and "candidates" for improvement, from the information subsystem.

2. Generation of alternatives for each candidate project or maintenance section (i.e., several types, thicknesses, and timings for new construction; several timings, types and thicknesses, or recycling alternatives for rehabilitation; several levels of maintenance for each section).

3. Selection of program analysis period, discount rate, minimum ride quality levels, etc., for technical and economic analysis; also, identification of what the basis will be for deciding on the final prioritized program (i.e., solely economic in terms of maximization of benefits or minimization of costs, or partially economic and partially nonquantitative, etc.).

4. Technical analysis of each alternative in terms of estimating performance, using models with acceptable computational time and input information requirements.

5. Economic analysis of each alternative in terms of calculating costs and benefits.

6. Development of initial program for new construction, rehabilitation and maintenance, optimized with respect to some measure of benefit or ranked by priority.

Decision Criteria and Budget Constraints Applied to Initial Program

The decision criteria and budget constraints applied to the initial program resulting from the network analysis subsystem may simply involve a selection of those projects and that maintenance program which can be done within some available budget. This budget may have been fixed at the higher management level, or several alternative budget levels may be considered.

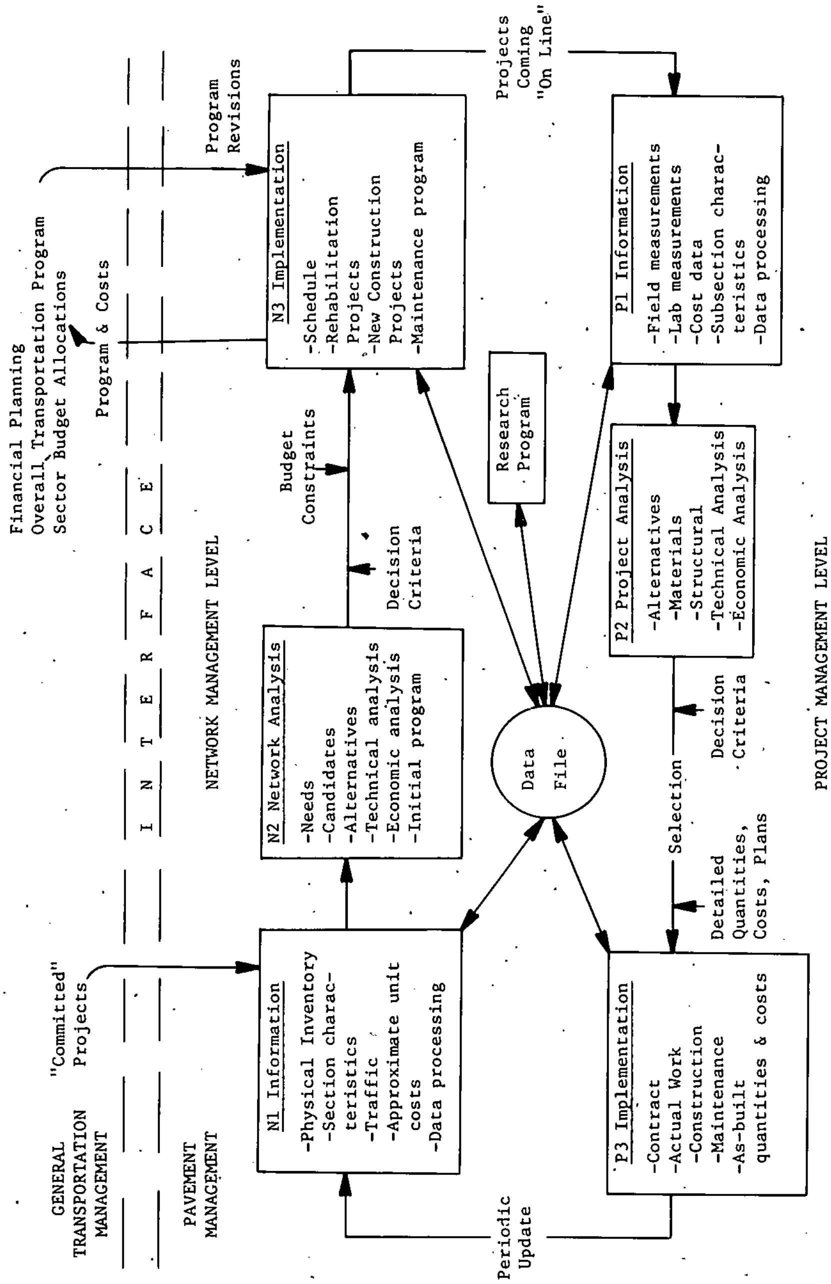

Figure 5. Framework and Major Subsystems for a Total Pavement Management System

The projects or parts of the maintenance program falling below the budget cutoff might then be put back on the candidate list for consideration the following year.

Some agencies designate separate budgets for new construction, rehabilitation and maintenance; while others, for example, have new construction projects "compete" with rehabilitation projects. As well, some transportation departments allocate budgets by region or district. Whatever the particular practice is, the framework of Figure 5 should be able to incorporate it.

The nonquantitative aspects of the decision criteria might involve, for example, an engineering judgment to move a project up in the priority list, or political decisions to include certain projects.

Implementation Subsystem

The implementation subsystem of the network management level of Figure 5 derives from the previously mentioned application of the decision criteria and budget constraints. It would list the final program and schedule for the new construction and rehabilitation projects, within the analysis period, plus the annual maintenance program. In some agencies, this program may be subject to final approval from the higher management level, which has been reflected in Figure 5 as a submission of program and costs to this higher level. Program revisions, as also shown in Figure 5, may or may not be required. An example of this type of activity is contained in Ref. 5, which provides a synthesis of current practice in priority programming at the general transportation management level.

Interface Between Network Management Level of Pavement Management and Over-all Transportation System Management

Since the major output at the network level is a prioritized or optimized program (subsystem N3 of Figure 5), the interface mechanism with the higher level of transportation management should primarily relate to priority programming at this higher level.

Reference 5 attempts to structure the priority programming process as it is practiced today. This structure is developed in terms of 15 basic steps, as listed in Table 2. The programming process illustrated in Table 2 is primarily based on network level information and analysis, but feedback from project level analysis is also included in this process. This is consistent with the general cyclical flow of information within a PMS, as illustrated in Figure 5. The development of a final program may thus involve one or more complete cycles through the pavement management process illustrated in Figure 5. Nevertheless, this process must be considered primarily a network level activity.

Project Level Subsystems and Management Activities

The project level subsystems and their components plus the other key management activities at this level are briefly described as follows.

Projects Coming "On Line" (From Network Implementation)

This has been separately identified in Figure 5 simply to recognize the importance of transforming a project from a network level program to action at the individual project level. Such individual projects would normally come "on line" one or more years before their scheduled construction. This lead time may only need to be one year for certain overlay projects and perhaps several years for a complex project with environmental and other approval requirements.

TABLE 2. 15 STEPS IN THE BASIC PROGRAMMING PROCESS (AFTER 5)

1. Project initiation
   - A. Technical sources
   - B. Nontechnical sources
2. Initial listing
   - A. Headquarters
   - B. District
   - C. County
   - D. MPO
3. Preliminary analysis
   - A. Available data and analyses
   - B. Planning report
4. Combined listing, first draft
5. Advanced analysis and prioritizing
   - A. Technical prioritizing
     - (1) Sufficiency ratings
     - (2) Priority ratings
     - (3) Option-evaluation techniques
     - (4) Input from other agencies
   - B. Nontechnical prioritizing
     - (1) Political commitments
     - (2) Legislative mandate
     - (3) Emergency
     - (4) Special emphasis
     - (5) Commitments to other agencies
     - (6) System continuity-connectivity
     - (7) Position in pipeline
   - C. Feedback from project planning and development
     - (1) Development of alternatives/joint development
     - (2) Environmental analysis (EIS-SEE)
     - (3) Community and technical interaction
     - (4) Input from other agencies
6. Combined listing, second draft
7. Financial analysis
   - A. Categorical grants
   - B. Geographical distribution
   - C. Fiscal-year fund projections
   - D. Manpower analysis
   - E. Financial modifications
8. Preliminary program (projects vs projected allocations)
9. Executive session
10. Short-range program, first draft
11. Executive and legislative review
12. Short-range program, final draft
13. Scheduling
14. Monitoring
15. Modifying

Information Subsystem

This subsystem involves the collection of more detailed data, appropriate to the size and type of project, so that the project analysis and subsequent implementation may proceed. The types of data and component activities may include the following:

1. Identification of homogeneous subsections within the project or section length (this may in some situations follow field measurements).

2. Field measurements for or estimates of:

   a. geometrics (lane widths, layer thicknesses, etc.)
   b. traffic volumes and loads
   c. structural capacity, ride quality, surface condition, skid resistance, etc., for existing pavements.

3. Laboratory measurements to determine material properties.

4. Acquisition or estimates of unit costs of materials, construction, etc.

5. Identification of criteria or standards for minimum ride quality, minimum skid resistance, etc.

6. Collection of climatic or environmental data.

7. Collection of available data on construction and maintenance variability.

8. Data processing for input to project analysis subsystem and for transmittal to data file.

Project Analysis Subsystem

The project analysis subsystem of Figure 5 might equally well be termed a design subsystem where new construction or rehabilitation projects are concerned. However, the terminology and concepts used in the Figure 5 project analysis subsystem are consistent with the network analysis subsystem; they also allow for such nondesign activities as maintenance to be analyzed. A list of activities for this subsystem would include the following:

1. Generation of alternative materials and layer thickness combinations, future rehabilitation and maintenance alternatives.

2. Selection of analysis period, discount rate, etc., for technical and economic analysis.

3. Technical analysis of alternatives in terms of

   a. predicting distress

   b. predicting performance

4. Economic analysis of alternatives to determine costs and benefits.

Decision Criteria and Selection

The decision criteria applied to the various alternatives from the project analysis subsystem, in order to select the best one, may involve both quantitative and nonquantitative factors. These factors should reflect the needs of the network as perceived by the decision-maker. A least cost or maximum benefit alternative may be selected, or previous experience, judgment, etc., may be combined with the economic-based criterion.

Detailed Quantities, Costs, and Plans

The documentation of detailed quantities, cost estimates, and plans of the project alternative selected has been separately identified in Figure 5. This is not only to show its importance in finalizing the output of the project analysis subsystem but also to stress its importance as input to the implementation subsystem.

Implementation Subsystem

This subsystem represents the achievement of a final physical reality from all preceding subsystems of both the network and project levels. Where new construction or rehabilitation is concerned, it includes contract bids and awards, actual work activities, construction control, and, finally, documentaton of as-built quantities, costs, and geometrics for updating the network information base and for transmittal to the data file subsystem.

Where maintenance is concerned, this subsystem would include the actual work performed, the quantities, the schedules, the costs, etc., comprising the application of what is usually termed maintenance management to individual section or project lengths. Maintenance management systems are usually, however, applied to regional or district networks.

Data File and Research Program Subsystems

The basic subdivision of pavement management into network management and project management levels is convenient from the point of representing the major levels of decision-making. However, there are two additional subsystems in pavement management; the data system or file and the research program, which can apply to both levels.

Data systems have been extensively discussed in Refs. 3 and 4. Properly designed, operated, and updated they are invaluable to efficiently carrying out the activities of both the network and project levels of pavement management.

Research programs, and individual projects within a research program, usually address both levels of pavement management. The elements of pavement research management have been discussed in Reference 3 and research implementation guidelines have been presented in Reference 4.

KEY CONSIDERATIONS IN APPLICATION OF A TOTAL PAVEMENT MANAGEMENT SYSTEM CONCEPT

There are several key considerations or issues in applying a total pavement management system concept, including the following:

1. The need for precise, understandable definitions in the pavement management field — but at the same time, not so restrictive that particular practices or methods are excluded.

2. The need for people within highway agencies with qualifications appropriate to the various activities of pavement management, such as economics, structural analysis, O-R methods, computer programming, statistics, field measurements, etc.

3. The need for properly defining and using functional, structural, and performance rating factors.

4. A well-developed interfacing mechanism between the policy level of transportation management and pavement management at the network level; also, properly coordinated interfacing between the network and project levels of pavement management.

5. A well-developed interfacing mechanism between maintenance management and other areas of pavement management.

CHAPTER THREE - ASSESSMENT OF EXISTING MANAGEMENT PRACTICE

INTRODUCTION

All highway departments utilize some form of management for planning, allocating budgets, assigning work schedules, and other required activities. In a small department, all of these functions may be adequately and efficiently coordinated by one good manager and a small staff, and many highway departments began with just such an arrangement. Over the years, however, transportation requirements have grown, and with them have grown the management responsibilities, problems, and the attendant managerial staff. Farsighted administrators realize that when several levels of administration are involved in making decisions it is useful to have standard procedures and criteria for making those decisions. Various agencies, therefore, began to develop rational procedures for evaluating pavements and for making decisions about current and future actions. This development, together with the advent of the modern computer and the growing realization of the need for objective data on which to base decisions, led naturally to the concept of a total pavement management system.

It is not surprising, therefore, that many agencies have codified pavement management programs. These may range from a loosely correlated series of interdepartmental memoranda to a comprehensive set of computer programs that are used in preparing and summarizing information for decision-makers. These practical working management programs were developed to fill specific needs within each agency. Hence no two are alike, but they share some common characteristics. It is instructive to ask what these common characteristics are and how the existing methods compare with the ideas discussed in Chapter Two.

A representative sample of the more advanced working management programs may be found among the agencies that participated in the November 1977 Pavement Management Workshop held in Tumwater (Olympia), Washington (1). Delegates from nine states and two Canadian provinces met to discuss and compare their respective current practices with emphasis on pavement monitoring and decision criteria. Each agency prepared a written report or reports (6 - 20) describing their management program and these reports were presented and examined in a series of panel discussions. The partici-

TABLE 3. SUMMARY OF PAVEMENT MANAGEMENT PRACTICES DISCUSSED AT TUMWATER '77

State or Agency	Major Activity Area	Major Measure of System Adequacy	Major Analysis Level	Major Use Level
Arizona	Maintenance	Combined	Project	Project
California	Rehabilitation	Multiple	Project	Project
Florida	Rehabilitation	Combined	Project	Network
Kentucky	Rehabilitation	Single	Project	Network
New York	Maintenance	Single	Project	Network
Ontario	Rehabilitation	Multiple	Project	Project
Pennsylvania	Maintenance	Multiple (Principally ride)	Project	Project
Saskatchewan	Maintenance	Multiple	Project	Project
Texas	Rehabilitation	Combined	Project	Network
Utah	Rehabilitation	Combined	Project	Network
Washington	Rehabilitation	Combined	Project	Project

pants also "voted" through a group dialogue machine on various statements concerning what should be included in pavement management systems. The existing practices detailed at the Tumwater Workshop are assesse next in relation to the total framework set forth in Chapter Two.

GENERAL FEATURES OF EXISTING MANAGEMENT PRACTICES

Some general features of the pavement management programs reported at the Tumwater Workshop are presented in Table 3. This table is based on our analysis of the written Tumwater reports, Refs. 6 through 20, as well as other documents concerning the Workshop (1, 21). It is evident that the major focus in each of these programs is maintenance and rehabilitation. Other activity areas such as design and construction are considered to some degree in a few of the systems, but the primary activity reported by each agency at the present time involves major maintenance or overlays.

Each state or province has developed a method for determining whether a pavement is serving adequately. These measures of system adequacy are categorized in Table 3 as "single," "multiple," or "combined." If evaluation and ranking are based primarily on a single attribute, such as PSI, the method is classified as "single." If rankings are made separately for a number of attributes and all are used individually in the evaluation or ranking process, the scheme is called "multiple." Finally, if several attributes are combined into a single number for ranking or evaluation purposes, the method is termed "combined." The latter approach generally involves utility theory, a convenient method for assigning a common value scale to diverse characteristics.

The management level, either project or network, at which each of these methods functions has been classified separately according to how the analysis is carried out and how the resulting information is used. The analysis is carried out at the "project" level if decision criteria or ranking criteria are applied within an individual project. If the criteria are applied to the system as a whole the analysis is termed "network" level. Note that all of the agencies currently employ "project" rather than "network" analysis. The use of information generated by the analysis, however, varies from state to state. Under this heading, those agencies that focus on how to repair individual sections are termed "project," while those that are concerned with selecting which sections should be rehabilitated for the good of the entire system are classified as "network". It should be mentioned that those states employing project level information to make programming decisions have generally found it necessary to establish fixed network service levels in advance rather than to seek an optimum solution using service level as a variable.

The Tumwater voting results, compiled through a group dialogue machine, show that a majority of the participants agree with the pavement management system requirements listed in Chapter Two, at least in concept. The participants strongly felt that an "idealized" long-term PMS should be based on feedback potential, should forecast consequences (based on costs) from the choice of (rehabilitation) alternatives, should have the capability for optimization on cost and, to a lesser degree, on utility, and should provide for considering the pavement from original design through construction, maintenance, and rehabilitation. In addition, it was felt that such a PMS should provide for the prediction of future needs, provide options for tailoring the (rehabilitation) program to fit expected revenue, provide a performance chart against which design, construction and maintenance practices can be evaluated, consider evaluation of user costs, and provide the capability for handling variable levels of service. Agreement on such broad questions is fortunate, but it should be pointed out that many of the more specific questions, such as "should structural capacity rating be based on deflections?", produced no consensus. This is to be expected, inasmuch as the pavement management system should reflect the attitudes and procedures of the implementing agency. Thus, the details will differ among various agencies, but all agencies should be able to agree on the general nature and role of a pavement management system.

SUBSYSTEMS AND COMPONENTS OF EXISTING PAVEMENT MANAGEMENT PRACTICES

Data Base and Research Systems

Data bases and research activities were not explicitly considered at Tumwater. However, each of the participating states and provinces reported having a data base, data file, or data system for use in conjunction with their current management process. A few of the participants mentioned the value of research to their management program, but none stressed the need for integrating the research program into the total management system. This lack of emphasis is probably due to the relatively small research budget in most highway departments as compared to maintenance, rehabilitation, and construction budgets, and to the fact that public interest is more likely to be focused on the latter activities. In implementing a PMS, those activities where the greatest benefit may be directly perceived and where the greatest potential for a short-term money savings exists are good candidates for early implementation. Coordinated research activities offer great potential benefits and savings, but are not likely to have a noticeable effect within the first few years.

Most of the participating agencies stated they were progressing toward a centralized data bank, although few claim to have one in operation. Typical current data collection practice involves several loosely coordinated data collections with each used for a particular management activity. This situation occurs quite naturally, because in most agencies the maintenance, construction, and monitoring activities are carried out independently. Actually, it is possible to implement a pavement management system without a centralized data base, relying instead on data sets for each management level or activity. In this case, it would be necessary to ensure that all data bases are conscientiously updated so that each contains current and consistent information. This could become a monumental task for a large agency, so a centralized source of data is generally to be desired.

Project Level Subsystems

The project and network level subsystems and components described in Chapter Two are intended to be specific enough to thoroughly outline a PMS, yet general enough to apply to any complete pavement management system. Because none of the participants at Tumwater '77 claimed to operate a total PMS at the present time, one would expect some components to be more fully developed than others in all of these existing management programs. Nevertheless, if a complete system is to be developed, all of these components must be included in some fashion. It is, therefore, instructive to examine which components have been reported by each agency at the Tumwater Workshop, and which components have yet to be developed.

The schemes described in the Tumwater report are categorized by their respective project level components in Table 4. This characterization is somewhat coarse because it is done subjectively and on the basis of written reports that are not directly addressed to all of these matters. For this reason, no attempt is made to evaluate the degree of sophistication or development of each component, but a simple yes-no classification is employed. A yes (✓) indicates that the component appears to be included on a fairly fundamental level in that agency's pavement management program. A no (-) means that the component in question is not included, is not discussed, or its status is not clear.

Table 4 shows that considerable development has occurred in all three major subsystems. Each agency has some sort of major data retrieval system and each utilizes some existing data for individual projects in order to generate some type of output. Most of the agencies carry out an analysis of the consequences of a given action or alternative actions, although very few choose an optimum strategy for an individual project after considering several alternatives. All of the pavement management programs reviewed include some method for monitoring projects in the field and keeping an updated data file on each project. Among the participants, Arizona and Washington stand out as having some development in almost all components. The undeveloped components in these cases are primarily those that contribute to the interface with the network level.

The systems employed by these states, along with those of the other agencies, are briefly discussed later in this chapter.

Network Level Subsystems

Table 5 indicates the state of development of network level subsystems and components among the Tumwater participants. It is immediately obvious that more development has occurred at the project level than at the network level, but again some development has occurred in each of the major subsystems. The area of least development falls right at the heart of a total network system — the analysis subsystem. None of the existing schemes generate alternative strategies for the network nor do they select an optimum strategy for the network as a whole. Several of the agencies compare priority listings indicating which pavements within the network require the most immediate attention. But these are evaluated with respect to fixed standard service levels, rather than chosen to ensure optimum network service levels. This lack of analysis is related to another missing element in Table 5 — the lack of development in the information subsystem. All of the agencies collect detailed project data, but very few collect averaged or thinly sampled engineering, traffic, and economic data to represent the total network. In order to undertake rational network analysis, however, the large volume of detailed project data must be reduced to a more usable form, or more approximate mass-inventory or sampling must be conducted. Program level analysis must consider the global picture and consequently requires a different type of information than project level analysis, as discussed in Chapter Two.

Of course, the agencies listed in Table 5 do have network level information, do carry out network level analysis, and do implement programs at a network level. These activities do not form a part of their codified pavement management practice as discussed at Tumwater. However, these activities do occur because they are necessary if the agency is to function on a continuing basis.

REVIEW OF INDIVIDUAL AGENCIES

Arizona

The system developed in Arizona is currently applied at the project level to flexible pavements only. Its focus is primarily maintenance, but some design applications are included. Each pavement is assigned a utility that is derived from combined skid, ride index, routine maintenance cost, and user inconvenience cost of major maintenance. These utilities were developed subjectively on the basis of pairwise comparison of attributes by department personnel. Subjective performance prediction models were also developed for use in forecasting future consequences of maintenance strategies. The system prepares a list of alternative strategies for each project ranked in order of the utility with the optimum strategy

TABLE 4. SUMMARY OF EXISTING MANAGEMENT PRACTICE, PROJECT LEVEL (TUMWATER WORKSHOP PARTICIPANTS)

PROJECT LEVEL SUBSYSTEMS AND COMPONENTS	INFORMATION										ANALYSIS									IMPLEMENTATION					
	DETAILED DATA FOR PROJECT						REQUIREMENTS FOR PROJECT				ALTERNATIVE STRATEGIES							REVIEW RESULTS		REPORT REQUIREMENTS AND ACCOMPLISHMENTS					
	ENGINEERING AND TRAFFIC			ECONOMIC			SERVICE LEVEL		BUDGET		GENERATE STRATEGIES	PREDICT CONSEQUENCES: ENGINEERING		PREDICT CONSEQUENCES: ECONOMIC		DERIVE SERVICE/COST	OPTIMIZE STRATEGY	EVALUATE WORK DONE	UPDATE MODELS	SERVICE LEVEL		BUDGET		PERFORM AND MONITOR WORK	UPDATE DATA BASE
STATE OR AGENCY	PAST	PRESENT	FUTURE	PAST	PRESENT	FUTURE	PRESENT	FUTURE	PRESENT	FUTURE		PRESENT	FUTURE	PRESENT	FUTURE					PRESENT	FUTURE	PRESENT	FUTURE		
ARIZONA	✓	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	✓	✓	✓	✓
CALIFORNIA	✓	✓	-	-	✓	-	✓		-	-	✓	✓	-	✓	-	✓	✓	-	-	✓	-	✓	-	✓	✓
FLORIDA	✓	✓	-	✓	✓	-	✓	-	-	-	-	✓	✓	✓	-	✓	-	-	-	✓	-	✓	-	✓	✓
KENTUCKY	✓	✓	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	✓	-	✓	-	✓	✓
NEW YORK	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	-	-	-	✓	✓
ONTARIO	✓	✓	-	-	-	-	-	-	-	-	✓	✓	✓	-	-	-	P	-	-	-	-	-	-	✓	✓
PENNSLYVANIA	✓	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓
SASKATCHEWAN	✓	✓	-	-	-	-	✓	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	✓	✓
TEXAS*	✓	✓	-	✓	✓	-	✓	-	✓	-	-	✓	✓	-	-	-	-	-	-	✓	✓	-	-	✓	✓
UTAH†	✓	✓	-	-	-	-	-	-	-	-	-	✓	✓	-	-	-	-	-	-	✓	-	-	-	✓	✓
WASHINGTON	✓	✓	✓	✓	✓	✓	✓	✓	-	-	✓	✓	✓	✓	✓	✓	✓	-	✓	✓	✓	-	-	✓	✓

✓ = included to some reasonable degree

– = not included or not discussed in references

P = generate priority listing

* = The TEXAS system is currently under development according to Brown's article from Tumwater

† = UTAH plans a comprehensive project level analysis subsystem which should fill virtually all of the boxes in the "analysis" section of this table

being at the top of the list. This list is used as a guide in developing a maintenance strategy for the project.

California

The California method considers rehabilitation strategies for both flexible and rigid pavements at the project level. These are short term or immediate repair strategies only. An alphanumeric rating system is used to evaluate the state of the pavement section, and deduct values are developed for each mode of distress monitored. This information is fed into a decision tree that selects the dominant strategy from a list of possible alternative strategies. The system is used on the network level to match program with available funds, but this must be done externally by adjusting preset standards.

Florida

Rehabilitation and reconstruction are the concerns of the Florida approach. An engineering rating, which is a combination of ride, defects, and ability to handle traffic, is calculated for each section of flexible pavement for a given rehabilitation strategy. A projected change in engineering rating is calculated as well as a cost effectiveness for the strategy. A program level priority list is prepared in which each project is ranked according to present engineering rating, expected change in engineering rating, and cost effectiveness. A network level of need is preset.

Skid number is not included in this scheme but is handled separately.

TABLE 5. SUMMARY OF EXISTING MANAGEMENT PRACTICE NETWORK LEVEL (TUMWATER WORKSHOP PARTICIPANTS)

NETWORK LEVEL SUBSYSTEMS AND COMPONENTS	INFORMATION									
	AVERAGE DATA FOR EACH LINK						REQUIREMENTS			
	ENGINEERING AND TRAFFIC			ECONOMIC			SERVICE LEVELS		BUDGET	
STATE OR AGENCY	PAST	PRESENT	FUTURE	PAST	PRESENT	FUTURE	PAST	PRESENT	PAST	PRESENT
ARIZONA†	-	-	-	-	-	-	-	✓	-	✓
CALIFORNIA	-	-	-	-	-	-	-	✓	-	✓
FLORIDA	-	-	-	-	-	-	-	✓		✓
KENTUCKY	-	-	-	-	-	-	-	✓	-	✓
NEW YORK	-	-	-	-	-	-	-	✓	-	-
ONTARIO	-	-	-	✓	✓	-	-	✓	-	-
PENNSYLVANIA	-	-	-	-	-	-	-	✓	-	-
SASKATCHEWAN	✓	✓	-	-	-	-	-	✓	-	-
TEXAS*	-	-	-	-	-	-	-	✓	-	-
UTAH	✓	✓	-	-	-	-	-	✓	-	-
WASHINGTON	✓	✓	-	-	-	-	-	✓	-	-

NETWORK LEVEL SUBSYSTEMS AND COMPONENTS	ANALYSIS									
	SET AND EVALUATE NETWORK REQUIREMENTS		ALTERNATIVE STRATEGIES						REVIEW RESULTS	
			GENERATE FOR ALL LINKS	PREDICT CONSEQUENCES: SERVICE LEVELS		PREDICT CONSEQUENCES: COST		OPTIMIZE OVER NETWORK	EVALUATE WORK DONE	UPDATE MODELS
STATE OR AGENCY	PRESENT	FUTURE		PRESENT	FUTURE	PRESENT	FUTURE			
ARIZONA†	-	-	-	-	-	-	-	-	-	-
CALIFORNIA	-	-	-	-	-	-	-	-	-	-
FLORIDA	-	-	-	-	-	-	-	P	-	-
KENTUCKY	-	-	-	-	-	-	-	P	-	-
NEW YORK	-	-	-	-	-	-	-	P	-	-
ONTARIO	-	-	-	-	-	-	-	-	-	-
PENNSYLVANIA	✓	-	-	-	-	-	-	-	-	-
SASKATCHEWAN	-	-	-	-	-	-	-	P	-	-
TEXAS*	-	-	-	-	-	-	-	P	-	-
UTAH	-	-	-	-	-	-	-	P	-	-
WASHINGTON	-	-	-	-	-	-	-	-	-	-

NETWORK LEVEL SUBSYSTEMS AND COMPONENTS	IMPLEMENTATION					
	REPORT REQUIREMENTS AND ACCOMPLISHMENTS				FUND AND MONITOR WORK	UPDATE DATA BASE
	SERVICE LEVELS		BUDGET			
STATE OR AGENCY	PRESENT	FUTURE	PRESENT	FUTURE		
ARIZONA†	-	-	-	-	-	-
CALIFORNIA	-	-	-	-	-	-
FLORIDA	✓	-	✓	-	-	-
KENTUCKY	-	-	-	-	-	-
NEW YORK	✓	-	-	-	-	-
ONTARIO	-	-	-	-	-	-
PENNSYLVANIA	-	-	-	-	-	-
SASKATCHEWAN	-	-	-	-	-	-
TEXAS*	✓	-	-	-	-	-
UTAH	✓	-	-	-	-	-
WASHINGTON	-	-	-	-	-	-

✓ = included to some reasonable degree

\- = not included or not discussed in references

P = generate priority listing

* = The TEXAS system is currently under development according to Brown's article from Tumwater

† = ARIZONA plans a comprehensive network level management system which should fill most of the boxes in this table

Kentucky

The Kentucky method was devised to determine overlay priorities, thicknesses, and financing schedules. It treats both flexible and rigid pavements, and the emphasis is on serviceability index. Distress is virtually ignored because the analysis is carried only for high quality "interstate type" pavements. Projections of future serviceability levels are made using an analysis of equivalent axle loads.

New York

The sole purpose of New York's scheme is to identify deficient pavement sections. The rather unique approach utilizes a modified riding comfort index, and subjective measurements of riding quality are made for each section in the network. Preset network values are used to identify "candidate" and "essential" projects. The system considers asphalt, PCC, and composite pavements separately, and both network and project data are made available to aid decision-making at all levels of management.

Ontario

The purpose of the Ontario management scheme is to schedule rehabilitation by asphalt overlay. Pavement sections are rated for riding comfort and pavement condition, and the riding comfort is projected for up to five years. At the network level, lists are prepared for 1-, 2-, and 5- year advance scheduling along with estimated project costs. At the project level, overlay alternatives are considered and overlay effectiveness factors are calculated for each alternative. A list of alternatives is prepared for each project scheduled for the coming year, and cost estimates are revised as projects move up on the lists.

Pennsylvania

Pennsylvania's program is geared to the determination of how to repair defective sections. Those sections considered defective are evaluated and classified by serviceability index, structural adequacy, and friction. Program level terminal serviceability values are set by maintenance functional class. This method is applied to flexible pavements only and it is not computer oriented; rather, it is a procedure whereby districts submit lists for testing, receive the tests results, and then submit proposed actions.

Saskatchewan

The over-all form of the Saskatchewan procedure is similar to that of Pennsylvania. Ride quality, deflections, and condition ratings are made for those pavements considered in need of repair. "Target" and "minimum acceptable" riding comfort terminal levels are set for the network, although priorities for repair are determined largely on the basis of condition survey data. This is due to the fact that the relatively thin pavements are subject to rapid changes in riding comfort index. Asphalt and oil treated sections are considered separately within the scheme.

Texas

Texas proposes a network and project level data management system to provide objective data for decision-makers. Deflections, serviceability index, and skid number are measured for those flexible, rigid, and composite pavement sections that are considered defective. Remaining service life is projected in terms of "relative design" based on equivalent axle load. Utilities are determined for skid, PSI, annual routine maintenance costs, relative design, and, for rigid pavements only, visual distress. These are combined in an over-all score for prioritizing, and individual scores are retained for determining the project repair strategy.

Utah

In Utah's approach, rehabilitation for flexible pavements may be triggered by a failure in PSI, distress, structural adequacy, or skid number. Pavements are selected for current evaluation on the basis of past values of these variables. Seven distress parameters are evaluated on a zero to five scale, and structural adequacy is determined in terms of remaining axle loads from Dynaflect deflections. An over-all priority ranking is made on the basis of distress, PSI, and structural adequacy values. Separate lists are also generated on the basis of each of the four individual variables.

Washington

The Washington system is designed to tabulate rehabilitation strategy alternatives by cost. Roughness and physical distress ratings are combined into a single pavement rating. The future condition of the pavement is projected in terms of this rating, using prediction models based primarily on subjective data. Rehabilitation alternatives are considered whenever this index falls below a present value, "UCLEV," and rehabilitation is considered mandatory when this over-all rating reaches a critical level "RCRI." The total expected cost for each strategy is calculated over an analysis period including user costs, routine maintenance costs, overlay costs, and salvage values. A list of alternative strategies is prepared, and the optimum strategy is chosen on the basis of minimum total expected costs.

SOME AVAILABLE WORKING SUBSYSTEMS

In addition to the management practices described at the Tumwater Workshop, several computer routines are currently available for use in pavement management programs. None of these computer programs represents a complete pavement management system, but several highly developed subsystems do exist. Some of these are discussed in the following.

Flexible Pavement Design System (FPS)

FPS was the first major working pavement subsystem. Its basic models were developed by Frank Scrivner and his associates at the Texas Transportation Institute (22, 23). This work was part of a major cooperative research project between the Texas Highway Department and TTI. These basic findings were further developed in Project 123, a joint effort by the Center for Highway Research at the University of Texas and TTI, under the support and leadership of the Texas Highway Department (24). With some modification, the computer program became FPS-1 and, following some additional changes, the first published version was presented as FPS-3 in Ref. 24.

The FPS computer program is not a self-contained pavement management system, but it was the development and use of FPS that led to verification of some of the broader management concepts. The utilization of FPS within a management system involves the following steps:

1. The application of FPS to generate a list of alternative strategies.

2. Selection of one of these alternatives by the decision-maker.

3. Preparation of plans, specifications, etc.

4. Construction of the pavement according to the strategy selected.

5. Maintenance of the facility as required.

6. Collection and analysis of feedback data regarding the consequences of the decision as implemented.

The details involved in carrying out these steps are discussed in several of the project reports (24, 25, 26).

FPS utilizes more than 50 input variables to specify the attributes, criteria, and constraints used in the analysis procedure. On the basis of these inputs, all possible initial design combinations are developed. The initial cost of each particular design is computed and compared against the available funds. If the costs are excessive, the design is discarded and FPS moves to the next design alternative. If the costs are feasible, the design is checked against the total thickness restraint and it is discarded if this criterion is not met. Those designs meeting both of these first two constraints are retained, and the expected design life is calculated using serviceability performance concepts, swelling clay parameters, and anticipated traffic. If the specified minimum time to first overlay exceeds the initially calculated design life, the design is discarded and the program continues with the next design alternative.

For each of the designs that has passed all of these tests, an optional overlay policy is selected to adequately maintain the pavement for the entire analysis period.

Provided that such a policy can be found, the design is termed "feasible," and the total cost over the analysis period is calculated. The program considers each design in turn and continues until all possible designs have been analyzed. The feasible designs are arranged by total cost, and a set of optimal designs is printed in order of increasing total cost.

System Analysis Method for Pavements (SAMP)

SAMP was developed by a research team of Fred N. Finn, B. F. McCullough, and W. R. Hudson, under contract to the National Cooperative Highway Research Program (27). The original SAMP program was developed in the late 60's and the first published version was SAMP-5 (27, 28). The NCHRP continued its work in the early 70's through a contract with TTI to conduct pilot implementaton tests in Kansas, Louisiana, and Florida, and to improve SAMP-5 based on the experience gained in this implementation. The principal outcome of this effort, as reported by Lytton and McFarland (29), was a somewhat improved version called SAMP-6. Their conclusion was that this type of system was readily implementable in other states, particularly in those using the AASHO Interim Design Guides.

The FPS and SAMP pavement systems are basically the same, inasmuch as the overall development in Texas has evolved through cooperative efforts. In fact, the original SAMP program is, to some degree, an extension of the work done by G. R. Carey and others in preparing FPS-1 and FPS-2. Also, important improvements in one system are generally applied to the other. The choice, for example, between FPS-14 and SAMP-6 would be primarily a choice between specific features of the particular programs. From an optimization point of view, there are no important differences.

In the SAMP program each initial construction design must satisfy the three constraints listed previously under FPS. It must cost no more than the funding that is available for initial construction, it must be no thicker than the total thickness constraint, and it must have a life at least as long as the minimum time to first overlay. The designs meeting these requirements are selected as feasible strategies, and the overlay design process continues as described earlier. The main differences between SAMP and FPS involve the model used for calculating routine maintenance cost, the performance models, and the use of seal coats. As before, total costs are calculated over an analysis period and each initial construction design, together with its optimal overlay policies, is output in order of increasing total costs.

Ontario Pavement Analysis of Costs (OPAC)

OPAC is an advanced pavement design and management subsystem developed for use in the Canadian province of Ontario (30, 31). It is a computer program that compares the performance and costs of hundreds of design alternatives for flexible pavements within a short time. It predicts the life of a pavement utilizing a model for the deterioration in Riding Comfort Index (RCI) as a function of repeated traffic loading and cyclic environmental changes. Total pavement costs are predicted throughout the life of the pavement including initial capital expenditure, resurfacing and maintenance expenditures, road user costs, and salvage value.

The OPAC computer program is designed to operate interactively so that the engineer can examine various design alternatives and modify the basic design criteria if desired. The engineer specifies the range of design alternatives to be analyzed, and OPAC generates each possible alternative providing a detailed cost analysis. A set of optimum designs is then presented, with optimization based on agency costs, or agency plus total user cost, or some other specified combination of agency and user costs.

Rigid Pavement Design System (RPS)

RPS is the only working pavement management program relating to rigid or portland cement concrete pavements (32 through 35). It was developed in 1969 and 1970 by Dr. Ramesh Kher, under the direction of Professors Hudson and McCullough, as part of the Texas Cooperative Pavement Research Program.

Over 100 parameter values must be input to the RPS routine for use in analysis and optimization. Optimal pavement strategies are selected primarily on the basis of minimum total over-all costs. However, several other factors are utilized as constraints, including availability of initial funds, minimum serviceability levels, and minimum safety provisions. Initial designs are developed to maintain specified serviceability levels. For those designs that reach the minimum level at times less than the analysis period, stage construction concepts are employed. Joints and reinforcement are designed as a part of each initial design. Subbase, concrete, and overlay thicknesses are computed for each strategy. All costs of initial and future construction are calculated. These include costs for overlays, maintenance, seal coats, and traffic delays during overlay operation, as well as initial construction costs.

The quantitative criteria included in RPS are not comprehensive enough to allow final judgments on total overlay costs, so the designer is presented with a set of alternative design strategies and other pertinent information.

U. S. Forest Service Project Optimization System

The U.S. Forest System has had under development since 1972 a program to provide systematic pavement management for design of Forest Service roads (Refs. 36, 37). This work has been under contract to the Council for Advanced Transportation Studies at The University of Texas at Austin and has resulted in the development of a project level pavement management system designated as LVR (Low Volume Roads). This project level design system is based on the SAMP 5 methodology that is described in this chapter. The AASHTO interim design guides provide the basic structural and performance models for the project level design system. In addition, the LVR procedure includes a model developed by the Corps of Engineers for the design of aggregate surfaced roads and airfields. The LVR program has the capability to design asphalt concrete pavements, surface treated pavements, and aggregate surfaced roads. The program has unusual constraints in that maintenance and rehabilitation funds are available only during timber sale periods; therefore, a constrained optimization procedure was developed that includes various intervals for the time between overlays. The traffic routine in LVR permits inputs for a traffic array that consists of piece-wise linear sections of 18 kip equivalencies with time to reflect the traffic variations occurring during the timber sale and non-timber sale periods.

The asphalt concrete pavement roads are designed on the basis of performance using the AASHTO equations. To design a surface treated road the engineer may proceed with initial design or may redesign an existing aggregate surfaced road. Therefore, there is a capability in LVR to consider existing in place materials that have strength but no cost that is considered in the optimization routine. In the design of aggregate surfaced roads, there are three ways in which failure may occur, and the design is selected on the basis of minimum thickness that will preclude failure by any of these mechanisms. The mechanisms are (1) failure by the PSI going below the terminal value (AASHTO Performance Equation), (2) failure in rutting (based on the Corps of Engineers procedure), and (3) failure due to excessive loss of surfacing material.

Implementation of LVR began in 1976 and continued through 1978. In March, 1979, the Division of Engineering for the Forest Service decided to implement LVR into the Forest Service Manual Series as a standard procedure for design of pavements Service-wide. The decision to implement LVR is the first instance of an agency-wide decision to implement a computerized pavement design procedure. The Division of Engineering recognizes that many of the models in the procedure are not of the quality that is desired; however, the program was developed in a modular fashion and as improvements occur in the models, modifications in the computer program will be made to reflect the state-of-the-art advances. Because of the need for improved models, the Forest Service intends to develop a data base of information to describe the performance of Forest Service roads. This information will include performance of forest roads under different conditions of traffic, load, climate, cost, materials, etc. These data should result in better input for the analysis of roadways and will be especially useful in evaluating the effects of design on pavement maintenance costs, vehicle operating costs, and pavement performance.

It is important to recognize that the system evaluates various alternatives for a particular project only. This means that there is no attempt to establish priorities between programs or to evaluate the demand for funds over a region or over a particular forest. The analysis is over a period of ten to twenty years for one project as specified by the user. The user obviously may consider the design, maintenance, and rehabilitation costs in developing design recommendations on initial pavement thicknesses. The recommendations developed by the designer are presented to the Forest Supervisor who is the decision-maker at the forest level.

OUTLOOK TOWARD A COMPLETE PAVEMENT MANAGEMENT SYSTEM

Some interesting technology is contained in the existing systems reviewed in the previous sections. Many of the ideas used by the various states in constructing their management schemes seem quite well suited for use within the total systems concept outlined in Chapter Two. In addition, some of the available computer programs are potentially useful as subsystems within a project level PMS. Either SAMP or FPS could be implemented immediately in conjunction with a project level system for flexible pavements, with RPS for rigid pavements. Such a system could hardly be called "simple," however, given the complexity and numbers of input parameters required by these programs. It is, nevertheless, possible that these codes may be utilized within a simplified PMS if most of the input parameters are assigned fixed "average" values in advance. These values would be tailored to the expected environmental and traffic conditions and material properties appropriate to the specific agency utilizing the PMS.

Of particular interest are the optimization techniques employed by those states currently seeking optimum solutions at the project level. Optimization is most efficiently carried out with respect to a single variable; however, most states consider several attributes to be important in determining project level strategies (e.g., skid number, riding quality, distress, and deflections). Several approaches to this dilemma were discussed at Tumwater. Arizona employs utility theory to combine the attributes of skid, ride, cost, and user inconvenience into a single index. The relative value of these attributes is determined subjectively according to the preferences of senior departmental staff. An optimum strategy in this approach can be chosen on the basis of a single number that takes into account the values of several different attributes. Texas recommends the use of such an approach for prioritizing projects over a network, while retaining the individual scores for each attribute for use in determining individual project repair strategies. In a slightly different approach, Washington optimizes over a single variable the present value of total expected costs over a long term analysis period. The actual repair strategies and the times at which they are applied are determined by other attributes, notably projections of over-all pavement rating.

Some additional ranking mechanisms are worthy of note. Utah uses an over-all ranking in which PSI, distress, and structural adequacy are weighted differently according to the values of certain additional attributes: average daily traffic, operational speed, and functional class. Each attribute is also monitored separately, and failure in any one mode is sufficient to trigger rehabilitation. Florida utilizes a form of benefit-cost analysis based on an engineering rating that specifically includes traffic flow data. The expected change in engineering rating and the cost effectiveness are used to evaluate rehabilitation strategies. Kentucky achieves a single index by limiting consideration to PSI for scheduling purposes. Additional engineering data, such as deflections, are used for design of the repair strategy.

New York, Texas, Kentucky, and, to some degree, several other states consider the user to be the final judge of a pavement. New York has developed this concept to a fine degree. They alone have successfully employed reproducible user ratings to prioritize over the network. Their success is built principally on use of relatively large (about 80 people) rating panels for calibration purposes, a separate consideration of rigid, flexible, and composite pavements, and rating of sections at the posted operating speed. They have achieved success at a relatively low cost (about $8 per mile) while rating each section in the entire network. If the user is to be the final judge, a variant of this approach may be quite useful within a total pavement management system.

Because most high-type pavements have a design life on the order of 20 years, and because all highway departments must plan their budgets several years in advance, a long-term consideration of network and project policy is mandatory to the total management concept. It is therefore necessary to be able to predict the values of those attributes to be used in a decision-making process over a reasonably long analysis period. Many of the agencies discussed here used some sort of prediction model within their current practices. Perhaps the most notable of these is the Markovian model employed by Washington to predict over-all pavement rating. The predictions are carried out over an analysis period on the order of 20 years, and predictions are made separately for individual maintenance strategies. The currently used model is developed from subjective data. This is highly advantageous because expert opinion concerning the future behavior of pavements is more readily available than objective data. Another advantage is that the model has a built-in method for updating and modifying predictions. As objective data become available, they may be incorporated into the model in a well-defined and preestablished manner. Such a self-modifying approach is almost mandatory for the stepwise implementation of a total PMS.

Clearly, none of the existing methods reviewed in this chapter represents a complete pavement management system as envisioned in Chapter Two. Many states have, however, taken a good first step in achieving such a system, and there are other systems in use or under development, not reviewed in this report, that may be equally as advanced. The development of a total management system must, in fact, proceed through many small steps so that each component may be tried and modified, new components may be properly interfaced, and a smooth transition may be effected in the operating procedures of the agency. The implementation of a pavement management system can begin at any level, from the highest administrative realm down to the most basic project level. Initial efforts may be concentrated in any subsystem that is perceived to promise the biggest payoff. Of course, an eye to the future is useful in planning and implementing these successive stages. Because modifications will undoubtedly be necessary, each piece of the system should be easily modifiable. Modular programming in each component is, therefore, a virtual necessity for efficient implementation.

CHAPTER FOUR - TOWARD A CURRENTLY APPLICABLE FRAMEWORK

LONG-TERM SYSTEM VS. SHORT-TERM REALITY

The total pavement management framework presented in Chapter Two represents an idealization of a management structure that could result from a long-term implementation phase. Nevertheless, this framework coupled with the assessment of current practice in Chapter Three can be used as a guide to determine what can realistically be accomplished in the short-term.

The key questions to be faced in defining what can realistically be accomplished in the short-term include the following:

1. How well and/or how completely does current practice cover the set of component activities in each subsystem of the total framework outlined in Chapter Two?

2. How can the varying size, type, and resources of different agencies who manage pavements (i.e., from large federal and/or state agencies to smaller, local jurisdictions) be considered in a single framework?

3. How can different sizes of projects and classes of roads (i.e., from spot repairs and tertiary roads to new pavement construction on a high-volume freeway) be considred in a single framework?

The answer to the first question, explicitly addressed in Chapter Three, is that methods and procedures currently exist within all the subsystems of the total framework. They have been developed in much more depth at the project management level, however, than at the network management level. Thus, the short-term reality is that considerable technology is available for the project level, and the major problem is one of selecting and interfacing compatible components in order to efficiently apply them to varying project sizes and types. Regarding the network level, the short-term reality is that the methodology for arriving at truly optimized programs is not well developed but that there is considerable current activity and interest in the subject area. Arizona, for example, is developing a network level system to complement its current project level system.

The answer to the second question is that the varying needs of different sizes and types of agencies can be considered in a single framework, but there must be provision for also varying the depth of analysis or models or data acquisition and physical measurements, etc., within the framework.

The answer to the third question is similar to the second in that different sizes of projects and different classes of roads can be considered in a single framework but that the depth and extent of information acquisition, analyses, modeling, etc., within the framework should be tailored to the specific application.

Thus, the answer to developing a currently applicable framework lies not in using only a part of the total framework of Chapter Two but in determining how current technology can best be applied within the total framework, considering the foregoing questions. The following section includes a discussion of a "game plan" for accomplishing this short-term development, with some consideration of long-term development needs. It thereby also attempts to set the stage for subsequent tasks in this project.

A 'GAME PLAN' FOR SHORT-TERM APPLICATION AND USE OF PAVEMENT MANAGEMENT PRACTICES

Figure 6 presents a general route to achieving short-term realization of pavement management at both the network and project management levels with currently available technology. The framework is consistent with the three major subsystems for each level as shown in Figure 5. Also shown in Figure 6 are some long-term possibilities for application of technology currently under active research and development.

Essentially, Figure 6 indicates that sufficient technology is available at the network management level to operate the three major subsystems contained in Figure 5, and to arrive at reasonably efficient, prioritized programs. True optimization procedures have not yet been developed at the program level, but efforts in this direction are currently underway in several agencies. At the project level, where a vast amount of technology is available, the short-term application should be one of.

better organizing and simplifying procedures to suit varying users and types and sizes of projects.

What remains to be specified, of course, is just exactly how a state agency can accomplish the various needs enumerated in Figure 6. Several questions immediately suggest themselves, particularly in the areas of data handling, prediction models and decision criteria. How does one determine what data need to be collected; how the data are to be collected; how frequently the values are to be measured; how they are to be stored, sorted, and retrieved? It will be extremely important for the optimization algorithm, and particularly the prediction models included therein, to have ready access to all the information necessary to make the system work. But how does one arrange this? How does one go about developing prediction models? How often are these prediction models to be updated? Are different models needed for different functional classes of road? How does one decide what decision criteria to employ? Should the primary decision criteria be riding quality, cost, structural adequacy, or preservation of investment? Is any of the required information already available within the resources of the state agency, and, if not, where is this information to be obtained?

Preliminary answers to some of these questions have been provided in this report. For example, several different optimization techniques and their associated prediction models are described in Chapter Three. Many of the Tumwater participants have dealt satisfactorily with most or all of these questions at the project level, and some of their solutions could be applied

NETWORK MANAGEMENT LEVEL	PROJECT MANAGEMENT LEVEL
Specifically identify the various user agencies and their decision making needs at both the network and project management levels. Focus on rehabilitation management.	
1. Adapt procedures for efficient information acquisition, use and updating on road networks.	1. Adapt procedures for information acquisition as related to various types and sizes of projects.
2. Adapt procedures for objectively identifying overall network needs and considering alternative programs and funding levels.	2. Adapt simple models for various classes of road and sizes of projects that produce alternative strategies.
3. Adapt efficient, simple procedures for arriving at programs. Consideration may initially be limited to analysis periods of one or two years.	3. Adapt procedures for efficient implementation and periodic monitoring of selected alternatives.
Short Term	
Incorporate additional management activity areas by repeating the above steps for new construction, routine maintenance, etc.	
1. Develop better interfacing transportation system management.	1. Develop better interfacing with network management level. including "upward" flow.
2. Develop models for true optimization at network management level, involving analysis periods on the order of a complete pavement life cycle.	2. Develop interfacing between subsystems, such as maintenance and design.
Long Term	

Figure 6. A General Plan for Application and Use of Pavement Management Practices, Using Currently Available Technology

with little modification by other agencies. Some of the most promising of these solutions are identified in Chapter Three.

IMPLEMENTATION OF PAVEMENT MANAGEMENT

Although this chapter has primarily concentrated on what sort of pavement management can be accomplished in the short-term, an equally important consideration is that of implementation.

Figure 7, from Ref. 4, provides a set of step-by-step guidelines for implementing a pavement management system. It is relatively self-explanatory, but there are two key features that should be especially noted:

1. The first step is a management decision for implementation, without which implementation is doomed from the start.

2. Implementation does not require that one grand, over-all, comprehensive system be established all at once. Rather, the implementation can be a step-by-step process that has been planned and executed within a well-defined over-all framework.

CONCLUSIONS

To date our research indicates that there has been significant progress in pavement management systems development, but that there are still many problems to be resolved before complete implementation can occur. Some of the more significant problems are as follows:

1. A search of the literature indicates that there are those who equate data management systems and pavement management systems. As this report shows, data management is an important part of pavement management, but is not the total PMS.

2. Some project level pavement management systems have evolved with too much attention to the development of complex models for predicting stress and strain. Such complexity has delayed implementation of the system and has delayed the over-all development of a total PMS.

3. In some situations, the development of a PMS has been halted by a lack of continuity in the research and implementation of the system. Because it may be necessary to change some attitudes and organizational relationships before the PMS activity can be a success, there is an important need for continuing the implementation for a period of several years before it can be fully operational.

Implementation of a total PMS can begin immediately, utilizing existing technology. Some states have already taken steps in this direction, with considerable development having occurred at the project level. The greatest current need is for comparable development at the network level.

Implementation should proceed in several steps, with the initial system including some working models or procedures in each of the major subsystems of the total framework. The implementation is most easily accomplished through such a stepwise procedure if the PMS is developed around a modular concept. The system may be initially applied to a single management area, such as rehabilitation programming, with additional areas to be added later. However, implementation will proceed most smoothly if the initial steps are taken with an eye toward future development.

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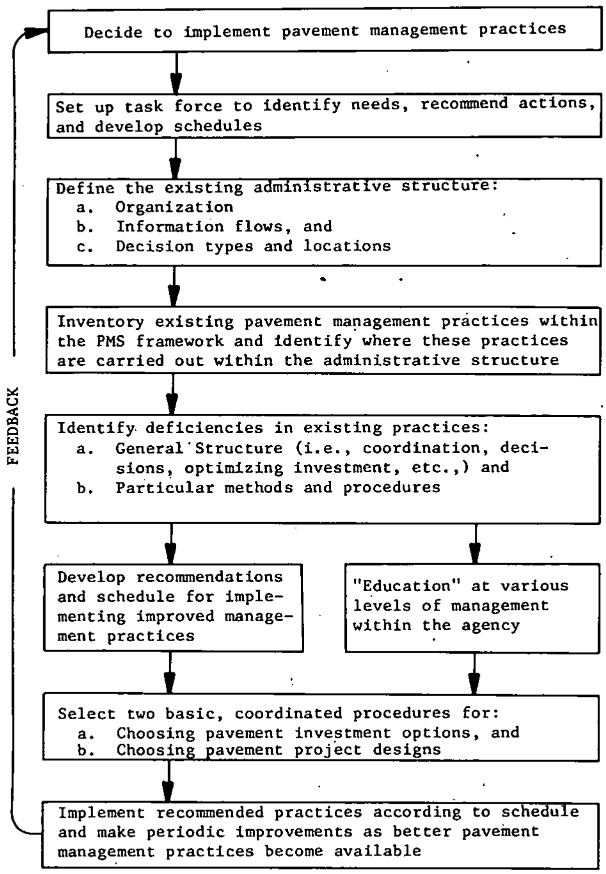

Figure 7. Major Steps in Implementing a Pavement Management System (After 4)

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