A final report

OKLAHOMA PAVEMENT MANAGEMENT SYSTEM

PHASE I : Development of Specifications

STATE STUDY NUMBER 87-09-2

ITEM # 2257

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Oklahoma Highway and Transportation Engineering Center
University of Oklahoma

for
The Research and Development Division
Oklahoma Department of Transportation

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December 1987

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EXECUTIVE SUMMARY

This report documents the first phase of the development of the Oklahoma Department of Transportation's (ODOT) pavement management system. Although much as been written on the pavement management process, little literature is available on the actual mechanics of developing a pavement management system. The purpose of this report is to lay a framework for the development of ODOT's pavement management system.

The report is divided into five chapters. The first chapter stresses the importance of the development process. The stages of development include system conceptualization, planning, and design. It is during these stages that a great deal of effort should be spent to ensure that the system's performance meets management's expectations. It is much easier to change the structure of the system during developmental stages than it is to make changes once the system is operational.

The second chapter covers fundamental aspects of the pavement management process. The chapter covers rudimentary pavement management concepts, pavement evaluations and performance, and uses of pavement performance information and condition data.

The third chapter covers a series of case studies of pavement management systems used by other state departments of transportation. The systems studied were those used by the Iowa, Arizona, and Pennsylvania Departments of Transportation. The primary purpose of these case studies is to provide ODOT engineers and managers with insight into the development process

used by other states. The three states studied took very different development paths. Thus, the case studies provide a rich information source for identifying the advantages and pit-falls of pursuing alternative development strategies.

The fourth chapter covers interviews with key ODOT staff. The purpose of the interviews was to determine the pavement management philosophies of key ODOT staff members. Individuals were interviewed from both ODOT's Headquarters and Field Divisions. In general, staff members were supportive of the development of a pavement management system. Once the system is operational, most of the individuals interviewed felt that Field Division personnel should initiate the pavement management planning process, with Headquarters personnel reviewing plans for consistency between Field Divisions and for accuracy.

The fifth chapter contains recommendations for the development of a pavement management system. A key recommendation is the implementation of training programs to improve staff skills in the use of computers for management functions in general, and specifically training on pavement management systems. Pavement management system training should be at two levels. The first level is to provide general training to ODOT engineers, planners, managers, and technicians through a series of short workshops (e.g., one-day workshops). The purpose of these workshops should be to provide a rudimentary level of understanding of the pavement management process. The second level of training should be provided to the middle management level engineers who will be responsible for the pavement management system's development. The second level should be highly technical and in depth.

Also recommended is the creation of a steering committee consisting of middle management level engineers and the establishment of a permanent pavement management staff. The purpose of the steering committee will be to develop a management plan and a system development plan. The permanent staff will carry out the steering committee's plans. The fifth chapter concludes with a list of target activities and dates for accomplishment of these activities.

ACKNOWLEDGEMENTS

"Oklahoma Pavement Management System Phase I: Development of Specifications," was funded by the Research and Development Division of the Oklahoma Department of Transportation. The assistance provided by the Assistant Division Manager, Jim Schmidt, and by the Research and Development Engineer, C. Dwight Hixon is gratefully acknowledged. T. H. Maze served as the Principal Investigator and Joakim G. Laguros served as a Faculty Associate. Leonard B. West, Jr. assisted in the final review and editing of the report. Two Civil Engineering students worked on the preparation of the report, Neal Hawkins and N. Devadoss.

Several individuals assisted in the case studies. The key individuals were: Mr. Bernard C. Brown, Materials Engineer, and Mr. Charles Potter, Special Investigations Engineer, both of the Iowa Department of Transportation; Mr. James Delton, Pavement Management Engineer, and Mr. Steven L. Tritsch, Senior Research Engineer, both of the Arizona Department of Transportation; and Mr. John Hunt, Pavement Management Engineer, and Mr. Wade L. Gramling, Director of Roadway Management Systems Division both of the Pennsylvania Department of Transportation. The efforts provided by these individuals were invaluable.

The report was ably word-processed by Betty Craig, a proficient technical text processor at the School of Civil Engineering and Environmental Science, The University of Oklahoma. Lori Austin of the University's Office of Grants and Contracts was responsible for the financial record-keeping.

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CHAPTER I

INTRODUCTION

This report is the first phase in the development of a pavement management system for the Oklahoma Department of Transportation (ODOT). Although much has been written on the pavement management process, little literature is available on the actual mechanics of conceptualizing, planning, designing and implementing a pavement management system for a state department of transportation. The purpose of this report is to lay the framework for the development of ODOT's pavement management system. This framework is built through: 1) the presentation of case studies covering the experiences of other state departments of transportation during their system development; 2) through interviews of key ODOT employees to obtain their pavement management philosophies, and 3) through a series of recommendations made to guide the development process.

Although the application of pavement management techniques to a state's highway network represents a structured, consistent, and analytical approach to management, there are a great many options in the way the system itself may be structured. For example, some states have a strong centralized system which uses the headquarters to schedule and plan major maintenance and pavement restoration activities in the present year and project programs in the future. Other states have systems which are used to develop programs one-year-at-a-time and the process is decentralized, starting in the field offices. Because of the broad variety of options, it is important that ODOT carefully designs the system which best suits its needs and reflects it management's philosophy.

THE IMPORTANCE OF SYSTEM DEVELOPMENT

In the last twenty years, the advent of inexpensive and highspeed computing has permitted the advancement of computerized management information systems. These systems provide information to improve efficiency and consistency of management system decision-making. Pavement management systems are a member of the family of newly develop management information systems.

The development of any computerized information system should go through five stages (1). They are:

1. Conceptualizing: What are the objectives? What is expected from the system? This is first determined through management-level brainstorming and decisions should be reached in light of current and desired practices.
2. Planning: This is the determination of information needs, system applications, system components, system relationships and other aspects not dealing with the actual system design of hardware, software, or specific procedures. Planning should result in a system performance specification.
3. Design: What hardware and software are required to meet performance specifications? How will the system be organized? How will Department procedures be changed and what new data collection procedures need to be implemented? How will the system be supported and implemented?

4. Implementation: During this step the new information system is installed. New procedures are implemented, staff members are trained, data are collected to calibrate pavement conditions which trigger maintenance and restoration treatment. Here the system is brought up to speed and procedures are modified to take into account the new capabilities provided by the system.

5. Maintenance: This stage covers the life of the system after the system builders complete their implementation.

The importance of proper conceptualization and planning at the beginning of the system's life is demonstrated in Figure 1-1. Figure 1-1 shows the relative cost of making changes in a computerized information system at each of the five stages of its development. For example, an error which is corrected at the conceptualizing stage will have a relative cost of 0.5 (say $100), while correcting an error at the maintenance stage may have a relative cost of 15.5 (31 times greater or $3,100). The cost data presented in Figure 1-1 represent actual costs experienced by developers of information systems for industrial applications (2). The graph includes only the costs of actually amending the system, but it does not include the costs incurred through the collection and entering of data into the system, and interpreting results of a system which does not meet the needs of the user. Therefore, it makes sense to accurately determine ODOT's pavement management information needs in the early stages of the system's development. Once a system is implemented, it may be too costly to change it to the way it should have been in the first place.

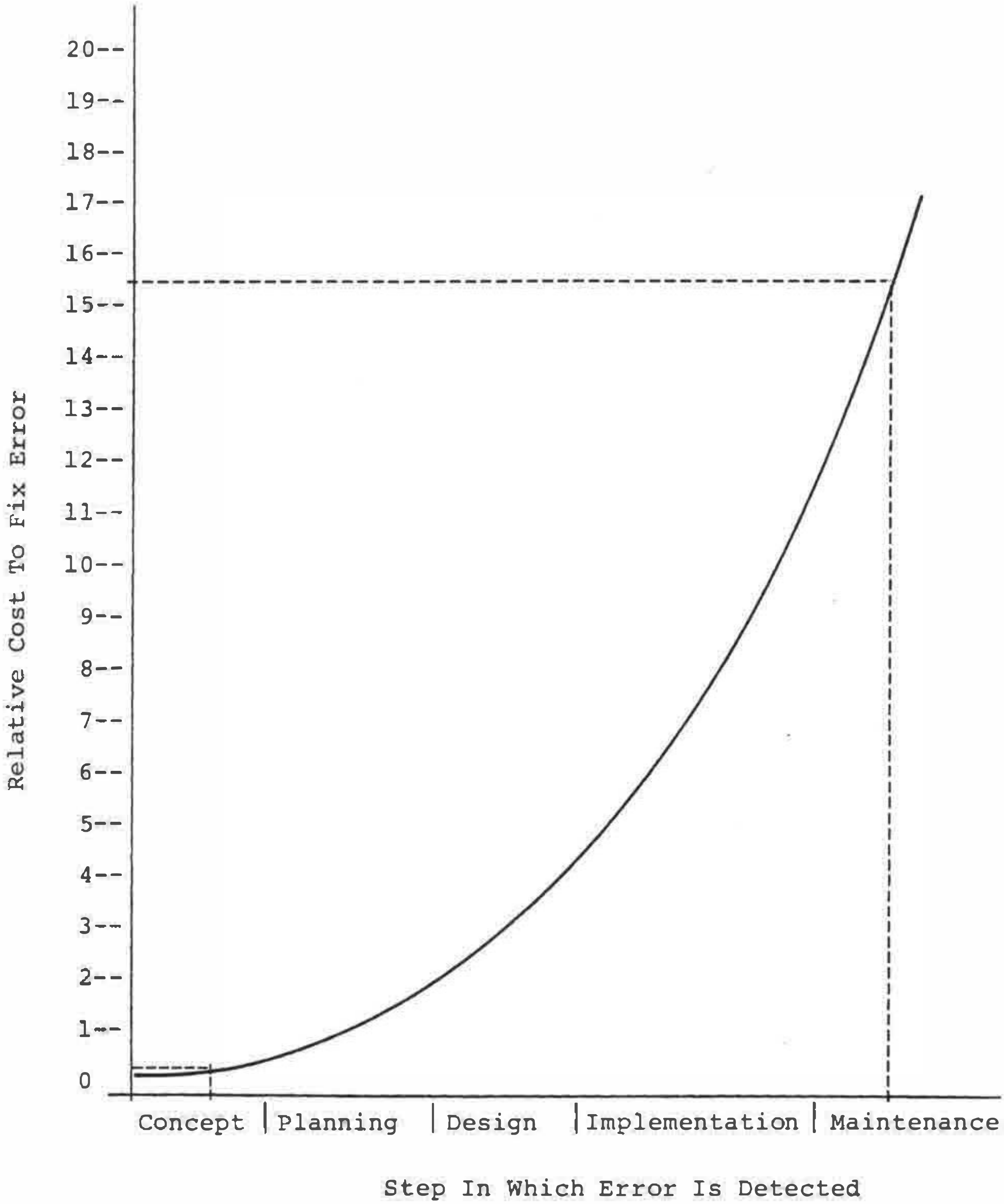

FIGURE 1-1

THE RELATIVE COST TO FIX AN ERROR AT EACH STAGE

ORGANIZATION OF THE REPORT

The remainder of the report is organized into four chapters. Chapter II covers "Pavement Management Fundamentals" and is meant to be only a brief overview of the pavement management process. Chapter II is divided into three sections covering: 1) Pavement Management Concepts, 2) Pavement Evaluation and Performance, and 3) Uses of Pavement Performance Information and Condition Data. Chapter III contains case studies of the pavement management systems operated by the Iowa, the Arizona, and the Pennsylvania Departments of Transportation. Chapter IV describes the results of interviews of key ODOT employees. All of the interviews summarized and the major points identified in each interview are listed. Chapter V contains recommendations for the process and steps ODOT should take in developing its own pavement management system. Chapter V is concluded with a list of critical activities on the path to the development of a pavement management system and target times for the completion of each activity.

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CHAPTER II

PAVEMENT MANAGEMENT FUNDAMENTALS

The purpose of this chapter is to review fundamental concepts of pavement management systems. Covered are the common measures of pavement condition data and performance information, and the equipment commonly used to measure pavement condition. Briefly discussed are the uses of pavement condition data and pavement performance information at the network level and the project level.

PAVEMENT MANAGEMENT CONCEPTS

The American Association of State Highway and Transportation Officials (AASHTO) has defined pavement management as, ".....the effective and efficient directing of the various activities involved in providing and sustaining pavements in a condition acceptable to the traveling public at the least life cycle cost (1)." Although AASHTO's definition sounds appealing, it does not clearly define the mechanics of a pavement management system. The lack of clarity in the specifics of pavement management is reflected by the broad variation in management methods used by different highway agencies.

Pavement management's definition is unclear. To further add to the confusion, the state of pavement management practice is constantly moving forward. Thus new aspects are always being added to the tasks considered part of the pavement management process. However, the state of practice is generally lagging behind the even quicker rate of new innovations that are being created by the research community. So a specific definition of pavement management is not only fussy, but it is constantly expanding.

Of course all highway agencies manage their pavements in some fashion. However, the property that makes pavement management special, is the use of an underlying and formal system to manage pavements. A system, as defined by Churchman, "is a set of parts coordinated to accomplish a set goal (2)." Coordination is executed by following a defined set of rules, procedures, policies, and programs that are established in advance. Hence, the formal plan used to manage pavements becomes the system.

Pavement Management Systems (PMS) generally have their logic coded into computer programs. The computer simply follows the steps defined by its developers to assist in deciding on actions (i.e., routine maintenance, restoration, or betterment activities) to be taken to hopefully minimize the life cycle costs of the pavement. However, a PMS does not require the use of a computer. A PMS can keep pavement condition records on paper, calculations can be made by hand, and plans may be written on paper. A computer only makes the normally numerous calculations feasible and routine.

Pavement Management Benefits

Most transportation related problems tend to be more complex than other fields because of the large number of interrelated variables. For example, even a small highway network can be divided into a large number of pavement sections. These sections will vary in their construction, maintenance history, environmental exposure, material quality, and traffic loading history. Further, because of their varying history, sections will vary in the timing and type of needed maintenance and restoration treatment they require, and all needed treatments compete simultaneously for funds from the same budget. The great number of variables involved makes it difficult for even the most experienced pavement manager to: 1) comprehensively consider and compare all competing projects; 2) prioritize; and 3) schedule pavement maintenance and restoration activities. On a state-wide basis, clearly simultaneous judgmental comparisons are impossible. A computerized pavement management system permits the simultaneous consideration of the maintenance and restoration needs of pavement sections using objective measures of pavement condition.

Other benefits of using a pavement management system include (the list is taken from (3) and modified):

1. Objectively based answers to:
   a. What level of funding is required to maintain the current status of pavement condition?
   b. Implication on pavement condition of greater or lesser budget levels.
2. The ability to back-up or justify restoration and maintenance programs to public decision makers (i.e., legislators and transportation commissioners).
3. Assurance that the maintenance and restoration program represents the best use of available funds.

4. Ability to assign priorities to projects on an objective, consistent, and comprehensive basis under limited funding.

5. Ability to objectively measure the performance of pavements over time to aid in the evaluation of design, construction and maintenance practices.

PAVEMENT EVALUATION AND PERFORMANCE

During the American Association of State Highway Officials (AASHO) road test, the concept of pavement "serviceability-performance" was developed by Carey and Irick (4). The development of serviceability was based on the premise that "highways are for the comfort and convenience of the motoring public." Therefore, the serviceability and performance of highways should be tied to the motorist's perception of the quality of the pavement.

To assess the road user's perception of the pavement, panels of pavement management professionals, truck drivers, and ordinary drivers were asked to rate pavements from very good to very poor on a scale of zero to five. The panels' scores are then correlated with measurements of the pavement's physical condition.

Conditions most noticed by highway users are those related to the longitudinal and transverse profile. To measure these conditions, roughness, faulting, cracking, spalling, pothole patching, and rutting were measured for each section. Roughness alone accounted for about 95 percent of the variation in the pavement section ratings. The remaining five percent is accounted for in the amount of patching, cracking, and rutting in the sections. Carey and Irick developed equations for the relationship between the ratings and condition measurements. These equations define the Present Serviceability Index (PSI) of a pavement. Although measures of surface distress (i.e., cracking, faulting, spalling, etc.) are included in the PSI equation, serviceability is not a measure of surface distress. PSI is a measure which is intended to model the users impression of the pavement. The rate of decline of a pavement PSI over time defines the serviceability performance of that pavement.

PSI, or just roughness, is widely used by highway agencies to define the performance of pavements. However, PSI generally provides little assistance in understanding why the pavement condition is deteriorating or what can be done to restore the pavement. Pavement condition measures other than PSI, are described individually in the following paragraphs.

Ride Comfort

Ride comfort is considered to be measured by pavement roughness. Roughness of the pavement is often a result of pavement distress (i.e., joint faulting, cracking, rutting, ravelling, etc.) and therefore, roughness is generally highly correlated with pavement deterioration.

A recent National Cooperative Highway Research Program (NCHRP) study found that half of the states that reported measuring roughness (37 states) use a Mays Ridemeter and about 20 percent reported using devices with mechanisms similar to a Mays Ridemeter (5). The Mays Ridemeter and similar devices measure roughness with a device that measures the number and magnitude of vertical deviation between the chassis of an automobile or its trailer and the center of a rear axle.

Most of the remaining states reported using profile measuring equipment; generally referred to as a profilometer or profilograph. Generally, these devices provide much more reliable and repeatable measurement of roughness than does a ridemeter. Further, the ridemeters usually require frequent calibration because measurements are dependent on the suspension of the vehicle in which the meter is mounted, while profilometers and profilographs are generally vehicle independent. However, most profilometers/profilographs are slow moving and costly to own and operate, although there have been recent improvements to the designs of available equipment.

<u>Distress</u>

Physical pavement distress is usually identified by the severity and extent of the various distress modes or types. Usually distress can be broadly related to one or more of the following factors:

1. Environmentally caused distress.
2. Traffic loading caused distress.
3. Material failure caused distress.

Distress data are most commonly collected by visual means. The detail of the distress data collected is generally a function of the extend that the distress data are used to trigger treatments. For example, if maintenance and restoration are triggered using Present Serviceability Index (PSI), then a less thorough distress survey is required. However, if distress data is used to select specific maintenance actions, then a more thorough distress survey is used. Further, in some pavement systems, severities of various types of distress (i.e., alligator cracking, bleeding, ravelling, patching, rutting, etc.) are combined, through a weighting scheme, to derive a single measure of the pavement's condition. In such systems it is not only important that detailed and accurate distress information is collected, but it is highly important that the data are consistent.

Aspects that are important in developing procedures for distress data include:

1. Collecting the data that are required to make the pavement management system effective at present and in the future.
2. Developing a pavement inventory and distress sampling system.
3. Determining a frequency of surveying which is both frequent enough to catch the pavement as its performance declines through critical stages in its life.
4. Productivity requirements for the teams conducting surveys.
5. Training of distress surveyors.
6. Development of a system to assure the quality of distress data collected (quality assurance of data collection).
7. Development of distress data coding, entry, and processing procedures.

8. Additional roadway features (i.e., roadway defects, hazards, condition of signs and pavement markings, etc.) that the surveyor collects while conducting the survey.

The more thorough the distress data collection system, the more costly the data collection is likely to be. However, this does not mean that a thorough collection system is not affordable. For example, the Pennsylvania Department of Transportation has an elaborate pavement evaluation, training, and quality assurance program where they visually survey 100 percent of the highway system every year. Conducting their surveys cost roughly $13 per mile (see the Pennsylvania case study).

Structural Capacity Measurement

The purpose of measuring structural capacity of a pavement is to understand the pavement structural response to loads placed on the pavement surface. The main uses of this information include (these uses are reported in (5)):

1. Determination of structural adequacy, which permits the estimation of when rehabilitation should be accomplished so as to maintain performance at a reasonable level.
2. Provision of information for use in the design of rehabilitation alternatives.

Structural capacity test methods may be first divided between non-destructive and destructive tests. Destructive tests involve the sampling of pavement, base and subgrade materials by disturbing the pavement. Although destructive techniques are a cost effective means for collecting structural information for a specific project, the costs associated with destructive testing make them infeasible for network wide, routine structural evaluation. Non-destructive tests involve the application of a load using one of three methods: 1) response to a slow moving wheel; 2) response to a repeated or dynamic load; or 3) response to an impulse load.

The information gathered from non-destructive testing is largely dependent on the type of pavement. For example, concrete pavements (rigid pavements) distribute loads due to their stiffness and strengths. An assessment of the structural capacity of a rigid pavement in response to applying a load consists of measuring both the tensile resistance of the slab and the support of the base. However, the strength of rigid pavements may be more a function of the joint condition, faulting, and cracking rather than the strength of the slab. As a result, tests for measuring the strength of asphalt pavements (flexible pavements) are more well defined than those for rigid pavements.

Flexible pavements achieve their structural capacity by spreading loads to weaker, underlying layers rather than by slab or beam action. As a result, the structural capacity of flexible pavement is directly a function of the pavement surface condition and the condition of the layers immediately below the non-destructive test. The methods for testing structural capacity are:

1. Slow moving wheel tests can be performed using several devices; however, the Benkelman beam is the most com-

monly used device. This method consists of either measuring the deflection of the pavement as a load approaches a probe, or the rebound of the pavement as a load moves away from a probe. The advantage that the Benkelman beam test has over other methods, is that the beam is relatively inexpensive (about $1,000) and the test does not require a highly skilled operator.

2. Steady-state vibratory load tests are performed by applying a sinusoidal force to the pavement and measuring deflections using inertial motion sensors. There are two types of devices that are most commonly used; the Dynaflect and the Road Rater. The Dynaflect applies forces to the pavement through two rigid wheels using counter rotating masses. The Road Rater is mounted in a vehicle or trailer and applies a vibrating force through two steel pads which are placed on the pavement.

3. Falling-weight (impulse) loading devices measure the deflection of the pavement when an impulse load is applied to the pavement. Loads are applied by dropping a weight from a specific height. Weights are dropped from varied heights to vary the force applied to the pavement.

One of the most crucial aspects of collecting structural capacity measurements is deciding on a data sampling scheme. For example, when a falling weight device is used, a decision must be made on how many samples are to be made per pavement section, and the frequency of sampling (e.g., once per year, once every other year, etc.). Some highway agencies vary sampling frequency by the functional classification of the roadway (e.g., freeways are sampled every year and primaries are sampled every other year) or by the strength recorded at the last test (e.g., weaker pavements are tested more frequently than stronger pavements).

Some states perform structural capacity measurements only when distress data indicates that there is a structural problem or when they are developing a restoration design for a specific project. Conducting structural tests only after a level of distress has triggered the need for a restoration treatment, assumes that all structural problems will be indicated through surface distress.

Friction Measurement

Pavement friction, or skid resistance, is measured for safety reasons. Although skid resistance is generally the major safety related factor considered by pavement management systems, other safety related factors that may be collected and included in pavement condition data are (as listed in (6)): 1) Rut depth (ruts can cause an accumulation of water and result in hydroplaning); 2) Light reflectivity of the pavement surface; 3) Lane demarcation; 4) Debris and foreign objects; and 5) Pavement to shoulder drop-offs.

Skid resistance data are most frequently measured using either a locked wheel trailer or a Mu-meter. The locked wheel trailer operates by locking a standard tire on the trailer while water is applied to the pavement ahead of the tire. The friction force generated by the locked tire is measured while the trailer is towed at a prescribed speed.

A Mu-meter is a yaw device. Friction is measured with a trailer that has two yawed wheels with smooth tires. Friction is measured through the resistance on the wheels in their yaw angle. Since both wheels are yawed at the same angle but in opposite directions, the force on each wheel counteracts the force on the other. Very few states use Mu-meters.

Deciding upon a sampling scheme for skid resistance data is very similar to the development of a sampling scheme for structural capacity measurement. For example, some states sample every section every year and others randomly sample sections. Some states vary their sampling frequency based on the pavement surface type, the functional classification of the highway, and the friction when the last skid test was conducted. However, some states only measure the skid resistance of when the pavement has experienced wet weather accidents.

USES OF PAVEMENT PERFORMANCE INFORMATION AND CONDITION DATA

Information describing the past performance of pavements and their present condition has three primary uses. These are:

1. Pavement performance information and condition data is used to make decisions which encompass the entire network. These include selection, prioritization, and scheduling of maintenance, restoration, and reconstruction activities within the agency's entire highway network. Network level decisions require the simulta-

neous consideration of all sections of the highway system so that resources are allocated objectively, efficiently, and equitably among all competing projects.

2. Pavement performance information and condition data is used to make decisions regarding the most efficient maintenance, restoration, or reconstruction design or treatment for a specific project. For example, structural capacity condition data should be a primary input in deciding upon the required thickness for a structural overlay. Usually, the efficiency of a design or treatment is determined by life-cycle costs. In other words, the most efficient strategy is one which minimizes the total of the initial costs plus the maintenance costs discounted over the relevant planning horizon (e.g., thirty years into the future).

3. Pavement performance information and condition data is used as feedback on the practices and materials used in the design, construction, use, and maintenance of pavements.

Network Level Pavement Management

Network level pavement management has varying levels of sophistications. At the very minimum, the network level should be a means to review the entire network and flag those pavements that require maintenance, restoration, or reconstruction. For example, in Figure 2-1, performance curves of pavement are shown with respect to four measures of condition; 1) structural capacity, 2) ride comfort, 3) distress, and 4) safety.

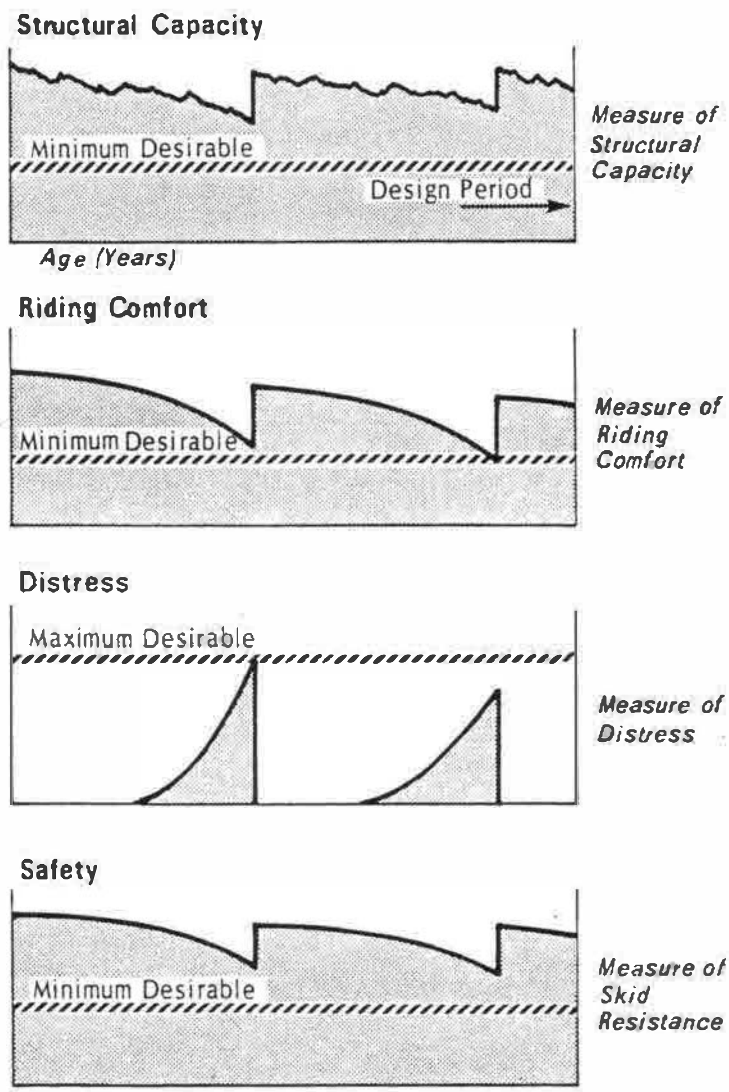

Figure 2-1 Pavement Performance Curves (7)

Each condition type changes with time until a predetermined condition level of one condition is met. At that point, an improvement treatment is applied to the pavement and all conditions are improved. In Figure 2-1, the first time the pavement is treated is when distress reaches its maximum limit. The second treatment is applied when ride comfort meets its minimum level.

In a simple network model, like the one shown in Figure 2-1, similar criteria are applied to all sections of the entire network simultaneously and funds are allocated based on needs. A more complicated network model may even select a specific treatment for each pavement segment and calculate the costs associated with the treatment. The costs of the pavement treatments can then be used in budgeting and priority programming. More sophisticated network models use optimization programs to allocate financial resources (up to budget limits) to individual projects within the network. The optimization programs may seek to maximize the benefits of pavement improvements or to minimize the cost of maintaining the pavement network; both are subject to the limits of available resources. Generally, the optimization programs consider the pavement performance over years into the future (performance forecasts) so that treatments are selected for application at the point in time when the life-cycle costs are minimized. Time dependent network level optimizations permit the analysis of the implication of future budget scenarios.

Project Level Pavement Management

Project level pavement management involves the evaluation of individual projects that were selected during the network level analysis. The project level cost analysis should involve the evaluation of initial cost and subsequent rehabilitations of various treatments which will lead to the selection of an alternative that has the minimum life-cycle cost.

In Figure 2-2 alternative pavement designs with varying restoration (overlays) cycles are shown. For example, design A achieves a 3.75 PSI. A PSI of 2.5 has been defined as the minimum level of serviceability permitted. Therefore, when a pavement falls to a PSI of 2.5, an overlay is applied to raise the PSI. Design A declines to a 2.5 PSI in eleven years and another overlay is applied resulting in a 3.5 PSI.

The other designs shown in Figure 2-2 have longer and shorter restoration cycles depending on the restoration design (thickness and materials used, and original pavement design). The performance curves for the candidate designs take into account the traffic loadings, environmental conditions, and routine maintenance. In project level evaluations, the design engineer will select the design with the minimum net present worth over the planning horizon (in the case of the scenario shown in Figure 2-2, a planning horizon is 30 years). The net present worth calculation should include initial construction costs, restoration costs, maintenance costs, and user costs (cost associated with the use of rough pavement and the costs associated with motorist delays during construction) over the entire planning horizon.

<u>Uses of Pavement Performance as Feedback</u>

A pavement management system provides a powerful medium for

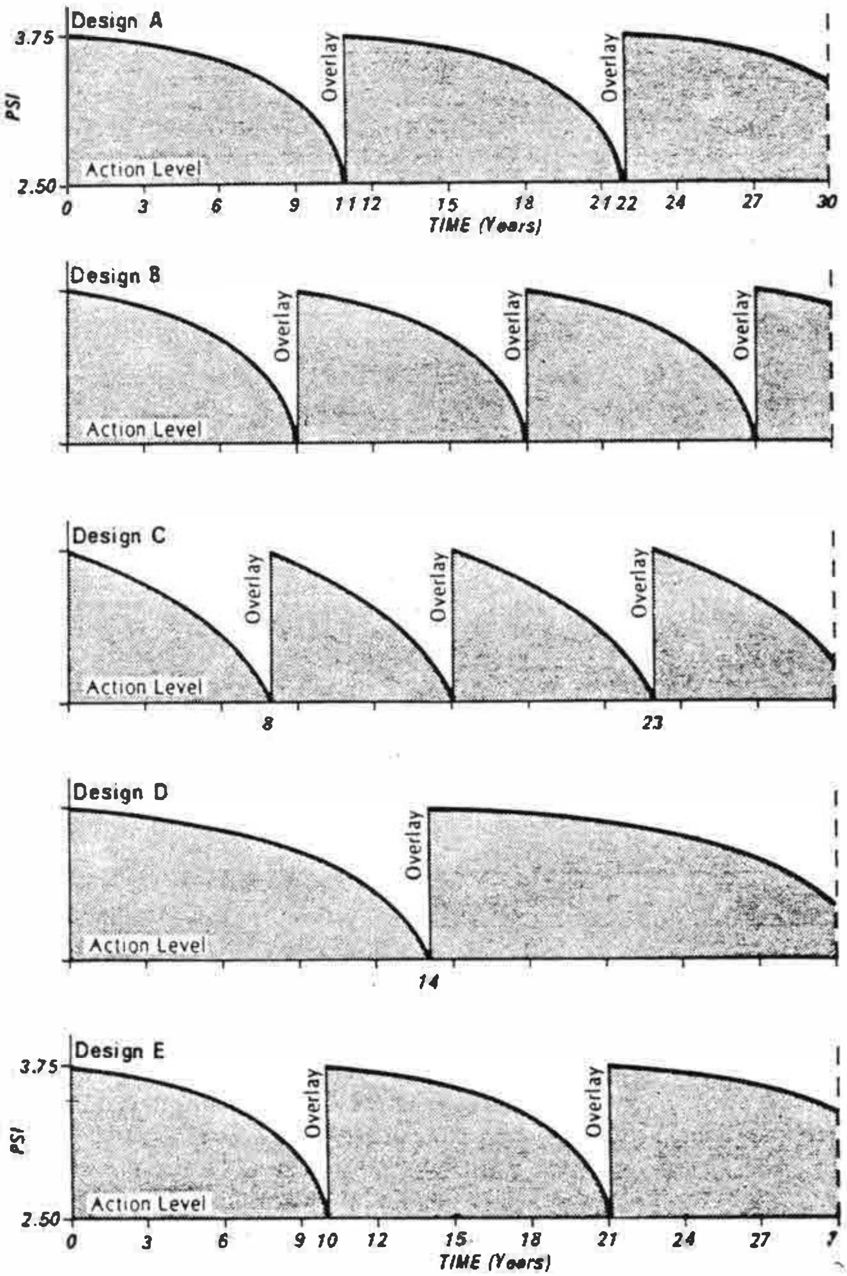

Figure 2-2 Pavement Performance Curves of Alternative Designs (6)

feedback information. If appropriate data are entered into the pavement management system data base as the pavement passes through design, construction, operation, maintenance, and reconstruction, the system can provide a rich history of valuable feedback information. Not including these vital data elements in the pavement management system data base diminishes the usefulness of pavement management. For example, when the Arizona Department of Transportation created its pavement management system, it failed to include a detailed description of the materials used in the consturction of the pavement and base. The lack of material properties data makes performance comparisons difficult.

Design and Material Feedback: These two areas are most directly benefitted by pavement performance feedback. Pavement performance serves as a yardstick for determining the performance of designs and materials. This information can then be used to improve designs and material specifications. However, to be able to accurately evaluate pavement designs and materials, data must be available that quantifies the actual traffic loadings and environmental stress that the pavement has received.

Construction Feedback: Pavement performance will provide information regarding the effectiveness of various construction methods, management techniques, and activities. For example, pavement performance will indicate the impact of a new quality assurance program or changes in existing quality assurance programs, or the importance of as built levels of pavement roughness on pavement roughness performance.

Maintenance Feedback: Maintenance policies and procedures should be designed to minimize the life-cycle costs of the pavement. Pavement performance can aid in the development of maintenance policies and procedures which minimize life-cycle costs. For example, the performance of pavements that have and have not been routinely sealed may be compared to determine the cost effectiveness of periodic crack sealing programs. Also, the performance and long-term cost of pavements that have receive thin overlays can be compared to thicker structural overlays. There are numerous other possible comparison that can be made.

All comparisons should be made with a goal to create standards for maintenance. When maintenance practices become routinized, they are more easily planned, scheduled, and budgeted. When maintenance can be planned and scheduled, resources are more efficiently used.

Planning Feedback: Pavement performance should be used to refine network level project programming and forecasting of future pavement conditions under varied budget scenarios. Since future predictions of pavement conditions are generated based on performance trends exhibited in the past, a sufficient quantity of past pavement performance data must be available to permit the modeling performance trends. As new condition data becomes available, the models should be recalibrated.

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CHAPTER III

CASE STUDIES

Case studies were performed on the development of pavement management systems in three states. The purpose of the case studies was to provide ODOT management with examples of the steps taken in the development of operational pavement management systems. The specific objectives of the case studies were to determine for each state department of transportation visited the following information:

1. The role of the system in research, design, planning, construction, the field divisions, and other divisions of each the state department of transportation.
2. The system operational procedures (i.e., which division or department within the state department of transportation has responsibility for the system, how is data entered, how is access to the system gained, etc.).
3. The inputs, outputs, and processes of each state system.
4. The data collection and pavement evaluation system used by each state (i.e., frequency of pavement evaluations, manpower required, equipment required, etc.).
5. The reasons for the placement of the system in a specific department within each state department of transportation.
6. The major users of the pavement management system information and their applications; including use by top management.
7. The cost and manpower requirements of operating the system in each state department of transportation.

The three states interviewed followed distinctly different paths in the development of their pavement management system. Each case study provided a different viewpoint on the pavement management process.

IOWA PAVEMENT MANAGEMENT INFORMATION SYSTEM (IPMIS)

The Iowa Pavement Management Information System (IPMIS) was, for the most part, built in-house (1). Even before the IPMIS was built, the Iowa Department of Transportation (IDOT) conducted field studies of pavement conditions (i.e., roughness, structural capacity, etc.). However, the individual field studies were not coordinated and the data from each survey were not integrated into a data base. In the late 1970s, IDOT decided to integrate the various pavement condition measurement surveys and automate the condition data processing. The joining of these independent efforts into a systematic data collection effort became the existing IPMIS.

The current computer software for the IPMIS resides on IDOT's mainframe computer and the individual pavement condition and pavement construction history files reside in individual flat files. Reading individual flat files tends to be clumsy and there are currently plans to merge the pavement condition and construction history data files within one relational data base system. The new data management system will integrate data storage and retrieval, and permit ad hoc data queries.

Pavement Condition Data Collection

The IPMIS contains pavement condition data collected covering five pavement condition attributes (2): 1) Skid resistance, 2) Structural adequacy, 3) Roughness, 4) Surface distress, and 5) Remaining pavement life, in 18 kip equivalent axle loads, until terminal pavement serviceability is reached.

Skid Resistance: Pavement friction data is collected every one to four years, depending on the current conditions observed on the roadway. The data are recorded by pulling a locked wheel skid trailer behind a modified pickup truck. IDOT recently procured a skid trailer and towing vehicle for $117,000, including an initial calibration.

Pavement Structural Adequacy: Structural capacity data are collected with the use of a Road Rater (manufactured by Foundation Mechanics, Inc.). The structural adequacy of the pavement is obtained by placing a load on the pavement, vibrating the load, and taking measurements from sensors placed at a set distance from the instrument. The Road Rater is mounted in a cargo van. The most recently purchased Road Rater cost roughly $80,000.

The Road Rater provides measures of an AASHTO defined structural rating, ranging from 1 to 7, with 7 the highest rating for extremely good pavements, 1 the lowest for extremely poor pavements. Thirty tests are taken within a section. Each section is nominally five miles in length and at least one test is taken every mile. The 30 tests are taken randomly within each section without regard to lane direction. Every year, 3,000 miles of pavement are tested in April and May. Four-man crews are used on the primary system with two persons to operate the Road Rater and two others to provide traffic control. On the interstate an additional warning vehicle and person is used.

Roughness Test: These tests are conducted with the use of an Iowa, Johannsen, and Kirk Ride Indicator (IJK Ride Meter). The IJK Ride Meter is mounted on the differential of a vehicle and measures undulations as the vehicle travels along the road. The IJK Ride Meter is calibrated by correlating its measurements with a CHLOE Profilometer. Iowa's CHLOE Profilometer dates back to the original AASHO Road Tests. Roughness tests are conducted on the primary highway system every other year and on the interstate every year.

Surface Distress Surveys (Crack and Patch): IDOT manually inspects pavements for a limited number of surface distresses. The inspections are conducted over a one-half mile subsection of roughly a five mile long test section. A survey crew of four to five persons from the central office inspects the interstate (800 miles in length) during the winter over a two to three month period. The district offices are responsible for inspection of the primary system. Training is provided for the inspectors once every other year.

The distress inspections collect information on: 1) cracking, the square feet of fatigue cracking per 1,000 square feet; 2) patching, the square feet of patching per 1,000 square feet; 3) the average rut depth; 4) average faulting, vertical displacement that occurs at pavement joints; and 5) D-cracking, deterioration that occurs due to the expansion of certain aggregates as a result of freezing and thawing.

Remaining Pavement Life: The remaining life of the pavement is calculated in remaining 18 kip Equivalent Single Axle Loads (ESAL) that the pavement may withstand before it reaches terminal serviceability. The accumulated 18 kip ESAL are based on traffic counts and the volume of trucks in the traffic flow.

Pavement Evaluation

The IDOT uses all the field generated condition data, except the skid resistance data, to evaluate pavement sections through a Pavement Management Matrix. The matrix contains values for eight measures of pavement condition divided into a score from one to seven. The eight factors currently used are: 1) percentage of remaining 18 kip ESAL life; 2) D-cracking occurrence; 3) structural rating (to be replaced by a ratio of the Road Rater's structural rating (SR) divided by the required structural number for AC pavements and SR divided by depth for PC pavements); 4) maintenance costs (a new factor replacing pavement width); 5) average rut depth; 6) PSI (a function of roughness, cracking and patching); 7) roughness (from the IJK Ride Meter); and 8) PSI decrease per year.

Each of the eight condition measurements are divided into seven individual categories ("factor scores"), where one is poor condition pavement and seven is good condition pavement. The matrix is shown in Figure 3-1. Along the left side of the matrix is a list of pavement condition factors and along the top of the matrix are the factor scores. In each of the cells are listed

Factor Value

	1	2	3	4	5	6	7
Percent Remaining 18 Kips	<-19	-19	0	10	25	45	>70
P.C.C. D-Crack Occurrence Factor	> 4	4	3	2	1		0
Relative Structural Ratio	0.40	0.50	0.60	0.70	0.80	0.90	1.00
Maintenance Costs							
Rut Depth	> .50	.40	.30	.20	.10	.05	< .05
PSI Deduction	> .80	.60	.40	.25	.15	.05	< .05
Longitudinal Profile Value (I.J.K. Ride)	< 3.00	3.20	3.40	3.55	3.65	3.75	> 3.75
P.S.I. Decrease/Year 6 year basis	> .20	.20	.17	.14	.11	.08	< .05

Add factors and compute to a 7 point scale.

If PSI<2.0, the Δ_6 in PSI will reflect a factor value of 0

Figure 3-1 Iowa Pavement Management Matrix the values of the condition measurement required to fall in each of the pavement condition factor scores. For example, the first row deals with the percentage of the 18 kip ESAL remaining in the life of the pavement. If the pavement has received loadings equal to its design life (zero percent remaining), then the pavement receives a factor score of three for the remaining pavement life. To obtain an overall measure of the pavement condition, the factor scores of all pavement condition measures are added together and the sum is recomputed into a score on a scale from one to seven.

IDOT plans to develop a Pavement Condition Rating (PCR) system from the condition measurements included in the Pavement Management Matrix. The PCR would be a composite score from zero to 100, where zero is the poorest condition pavement and 100 is the best condition pavement. The rating system to be developed will be dependent on the pavement type; AC pavement, PC pavement, continuously reinforced concrete pavement, and composite pavement. In the past, scores from different pavement types were not found to be comparable for all pavement types. By independently factoring the condition scores to a 100 point scale for each pavement type, the composite rating is customized for each pavement type and the PCR composite ratings become comparable. The purpose of the new 100 point rating system is to permit prediction and prioritization of pavement for rehabilitation. Further, a 100 point scale PCR will be compatible with IDOT's 100 point scale sufficiency rating.

The Role of IPMIS in Divisions of IDOT

The IPMIS is currently managed by the Office of Materials which is within the Highway Division. Other divisions within IDOT include the Administration Division, the General Council Division, the Planning and Research Division, the Rail and Water Division, the Air and Transit Division, and the Motor Vehicle Division. The reason for the placement of pavement management in the Office of Materials is because of their historical role in the collection of pavement condition data. Eventually, when IPMIS becomes completely operational, the Planning and Research Division will manage the IPMIS.

Because IPMIS is still being improved, the role of other departments has been primarily to assist in the development of the system functions, and to help make the system fit their needs. For example, the Office of Road Design is currently developing a system to analyze the life-cycle cost implications of different design options. During interviews with top level managers, they often commented that they saw the greatest use of the IPMIS would be in major pavement rehabilitation programming. Once the IPMIS 100 scale PCR system is ready, then the PCR would compliment the sufficiency rating in the development of the highway improvement program.

There are two levels of steering committees for the IPMIS. The Pavement Management Committee is made-up of largely top management staff. The Pavement Management Task Force consists of middle managers. The Task Force operates at the operational level while the Committee operates at the policy level. For example, while making the visitation to IDOT, the Task Force developed a list of short and mid-term goals and products which will be presented to the Pavement Management Committee for revisions and approval.

System Inputs, Outputs, and Processes

Figure 3-2 is a data flow diagram of the IPMIS. The current IPMIS is a relatively simple system. However, a senior systems analyst that has had primary responsibility for the IPMIS estimated that the development of the current computing system took roughly 5 man-years and that an estimated 2 man-years will be required to have the IPMIS running on a relational data base management system.

One of the largest difficulties in the development of the IPMIS has been in the coordination of a non-standard pavement location coordinate system. The pavement management system works on a milepost location system which originates at each county line. Other data were available on other non-standard location systems. For example, limits of construction projects are based on milepoints. IDOT staff recommend the use of a state plain coordinate system instead of other location identification schemes.

Costs

IDOT provided extensive data on the cost of collecting pavement condition data, the total cost of operating/administering their system, and the cost of purchasing the equipment that they use to evaluate pavement conditions.

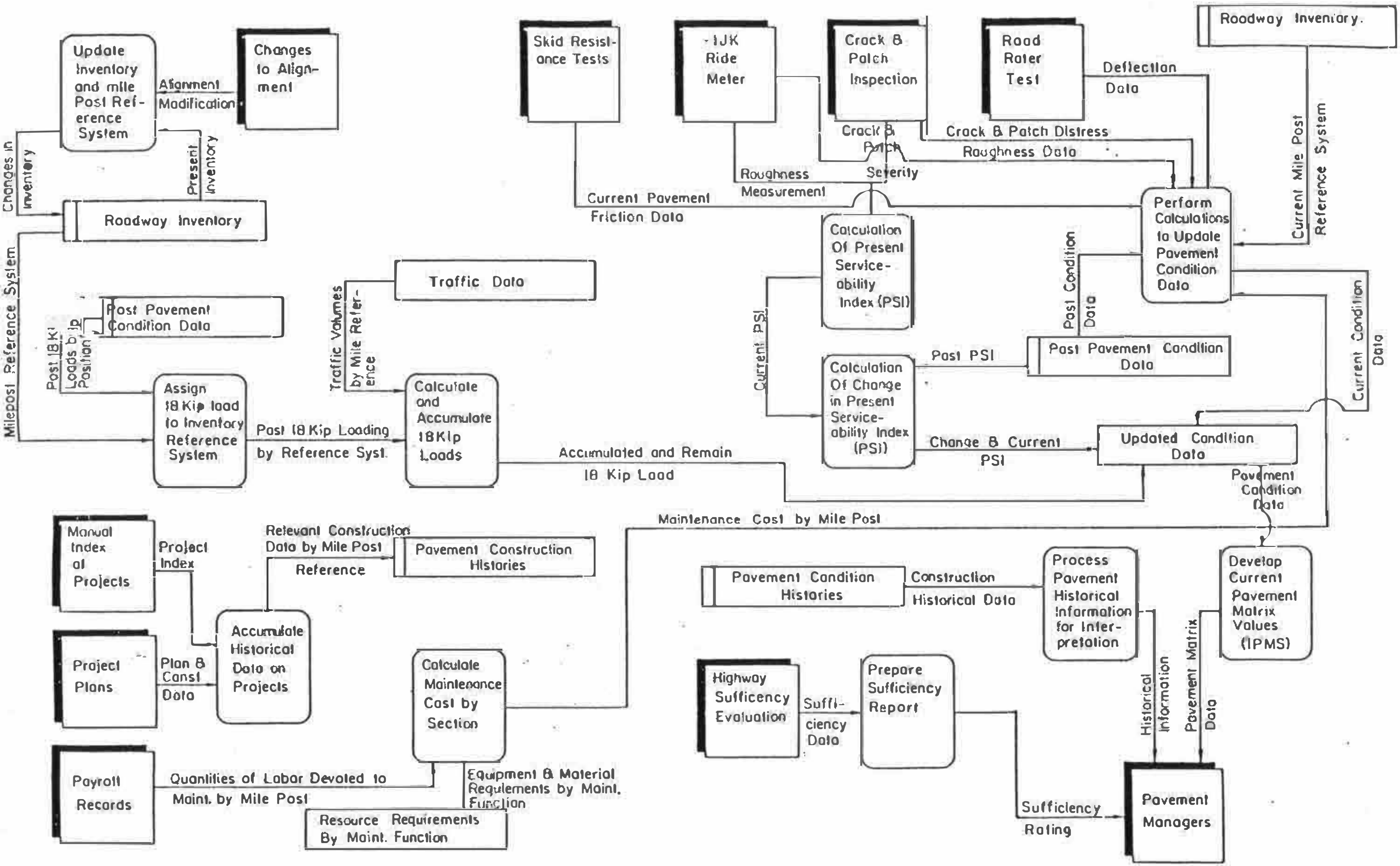

Figure 3-2. Data Flow Diagram of the Iowa Pavement Management System.

The costs of performing pavement condition tests per mile are listed in Table 3-1. The cost figures include labor cost, depreciation on test equipment, and the cost of equipment maintenance and operation. When reviewing the figures, one should note that although the entire state highway system condition is measured, measurements are done only on random samples. For example, the crack and patch survey is conducted on one-half mile subsections within each five mile section. Therefore, the cost per mile of a crack and patch survey is really the cost of evaluating two five mile sections.

The costs of operating/administering the IDOT pavement management system are listed in Table 3-2. The operation/-administration costs have increased dramatically in the last few years because of increased pavement management activity. Currently it costs IDOT roughly $500,000 to operate/administer their system and in 1985 IDOT was spending only $225,000.

Listed in Table 3-3 are the initial costs of the pavement condition survey equipment used by the IDOT.

TABLE 3-1

THE IOWA PAVEMENT CONDITIONS COST

Evaluation Test	Cost per 2 Lane Mile
IJK Ride Meter	$ 9.41
Skid Resistance Test	$ 15.06
Pavement Deflection	$ 34.92
Pavement Texture Test	$ 86.16
Crack and Patch Survey	$101.71

TABLE 3-2

THE IOWA ANNUAL OPERATING AND ADMINISTRATION COSTS OF PMS

Data Collection	Two-Lane Miles		Cost/Mile		Total
IJK Roadmeter	5,050	X	$ 9.41	=	$ 47,521
Friction (not in Matrix)	5,000	X	15.06	=	75,300
Road Rater	3,000	X	34.92	=	104,760
Crack & Patch Survey	800	X	101.71	=	81,368
Administration (2 P.E.s, 1 E.I.T., 1 Tech-4, 1 Tech Supervisor-2, and 2 Temp. Eng. Students)					50,000
Traffic, truck weight and class, 18 kip ESALs			Est.	=	50,000
Equipment Maintenance Costs			Est.	=	30,000
Computer Program Development			Est.	=	35,000
Pavement Management Task Force (5 people x 2 hours/week x 52 weeks/year x $20/hour)					10,400
Pavement Management Committee (8 people x 2 hours/month x 12 month/year x $30/hour)					5,760
					$490,109

(roughly $500,000 per year)

TABLE 3-3

THE IOWA COST OF PAVEMENT CONDITION SURVEY EQUIPMENT

Equipment Type		Cost
Two K.J. Law Friction Trails at $117,000 each	=	$234,000
Friction tires, parts, etc.	=	5,000
Two Model 400 Road Raters at $80,000 each	=	$160,000
Two Flashing Arrows	=	3,000
Five Safety Vehicles with Sign Racks	=	45,000
Two Infra-red Temperature Guns	=	3,700
Two IJK Road Meters and Vehicles at $15,000 each	=	$ 30,000
Equipment for Crack and Patch Survey: Four Rut Depth Gauges, Punch Counters, Tapes, etc.	=	$ 1,000
		$481,700

ARIZONA PAVEMENT MANAGEMENT SYSTEM

The Arizona Department of Transportation (ADOT) began investigating the development of a pavement management system in the mid and late 1970s (3). At that time there were two main issues that ADOT hoped to address through the use of a pavement management system (4). The issues were: 1) Estimates of preservation needs and maintenance decisions were for the most part based on the judgement of District Engineers. The concern was that judgmental decision making might lead to non-uniform pavement conditions across the state. Also, the state government was aware of the subjective nature of these decisions and was reluctant to appropriate additional funds when resource allocation decisions were made in a judgmental manner. 2) There needed to be some way of predicting the long and short-term effects of funding shortages on road conditions and a systematic procedure to cope with budget cuts.

ADOT contracted with Woodward-Clyde Consultants in 1978 to develop a pavement management decision making tool for Arizona. The focus of the pavement management system created by the consultant is at the network level and the program is called the Network Optimization System (NOS). NOS forms the focal point of the current pavement management system. However, ADOT has developed a program to augment NOS and they collect data in their evaluation of pavement which are not used in NOS.

NOS Description

NOS is an optimization model which is based on pavement sections being categorized by condition states. For example, assume roughness and cracking are the only relevant variables for categorizing a pavement condition state. Using roughness and cracking, a pavement section may be categorized by less than 125 inches per mile of roughness and less than 10 percent cracked. Other categories would include other intervals of roughness and cracking. Pavement sections can then be placed into condition states based on their observations (categories of a combine level of roughness and cracking). All the condition states together would represent a matrix with each cell representing the condition state of pavement sections.

Once the relevant categorization of variables and their intervals have been identified, the probability of moving from one condition state to another in one year is estimated. For example, the probability of moving from 125 inches per mile of roughness and less than 10 percent cracking to 125-175 inches per mile of roughness and 10 percent cracking during one year may be 10 percent.

The probability of moving from one condition state to another is a transition probability, and the probabilities of moving from every condition state to every other condition state form a transition matrix. The model uses the transition matrix to forecast the percentage of the pavement sections that will move from one state to another during one year. The same process may be repeated to estimate the change during two years. The transition matrix is applied recursively to predict the portion of the pavement sections in each condition state during future years.

As the predicted condition of the pavement sections deteriorate through recursive applications of the transition matrix, the model will apply a necessary restoration policy to the pavement. The model then automatically improves the condition of the pavement. The selection of the timing of the pavement restoration is based on an optimization (a linear program) with the objective of minimizing the long-term cost of restoration. The optimization is constrained by pavement condition standards. For example, a constraint may be that only five percent of the pavement with an average daily traffic of more than 10,000 vehicles will be allowed to have more than 256 inches per mile of roughness.

The variables that ADOT uses to categorize the condition state of pavements are: roughness (3 levels), percentage of cracking (3 levels), change in the percentage of cracking (3 levels), and an index which identifies the number of years following a preservation strategy in which the first cracking appeared (5 levels). This means that there are a total of 135 cells in the matrix used to identify the condition state of each pavement (3 x 3 x 3 x 5 = 135). However, 15 of the states were felt to be highly unlikely (i.e., highly cracked and little roughness) and therefore, only 120 condition states are considered.

The state highway network is further divided into thirteen road categories which are defined by a combination of average traffic categories (ADTs of 0-2,000, 2,001-10,000, and greater than 10,000 vehicles) and a regional/environmental factor. The regional/environmental factor is based on rainfall and elevation on a scale of zero to five. The division of the network by traffic and regional/environment factors has the effect of dividing the highway network into 13 individual networks, each with their own probability transition matrix and each matrix containing 120 condition states.

The optimization program is applied to all 13 network simultaneously to globally optimize the allocation of restoration funds. The optimization has a total of 17 pavement preservation alternatives from which to select. The actions range from routine maintenance to substantial restoration.

NOS is largely used to forecast the likely condition of the pavement under varied funding conditions and under changed pavement condition standards. However, the primary problem with NOS is that it does not associate specific restoration actions with a specific section of pavement. The condition of the pavement network is forecasted in portions of the total pavement network at each condition state. The program cannot track the condition of a specific section; it is only concerned with the proportion of the entire network in each condition state.

To overcome the inability to track the condition state of individual pavement sections over time, ADOT has built a program which uses the probability transition matrix to forecast the future condition of each section. A heuristic algorithm is used to select the preservation alternative. In comparison, the ADOT model tends to generate future cost predictions which nearly coincide with the NOS future cost prediction.

Pavement Condition Data Collection

ADOT collects and maintains date files for several types of pavement condition data on its 2,200 miles of interstate (actual interstate miles have been doubled) and 5,200 miles of non-interstate highway. The condition data collected includes; 1) Surface distress, 2) Skid resistance, 3) Roughness, and 4) Structural Adequacy.

Surface Distress: Surface distress is measured by visual inspection of the pavement. A sample of each mile of pavement in the entire 7,400 miles network is inspected annually using two-man survey crews from the central office. During the visual inspection, the pavement is checked for cracking, flushing, patching, rut depth, and faulting. Cracking is recorded by the percentage of the roadway cracked and the type of crack (random, transverse, longitudinal, block, or alligator cracking). Thirty percent or greater of the roadway cracked is considered a bad condition pavement. Flushing is where oil is bleeding through the pavement surface. Flushing is rated on a scale of one to five, where one indicates severe and five indicates none. Patch is the percentage of the pavement surface that is patched. Rut depth is the average rut depth in the wheelpath as measured by a four-foot long rut depth indicator and measured in inches. Faulting is the difference in the vertical displacement between the joints on concrete pavements.

The visual surveyors inspect 1,000 square feet of the right travel lane at the milepost. Since traffic lanes are normally 12 feet wide, a distance of 83 feet at the mile post is inspected.

Skid Resistance: ADOT uses a Mu-Meter to determine skid resistance. The Mu-Meter is a yaw mode device where two wheels are both turned inward at a 7.5 degree yaw angle to the direction of motion to provide balance. The side or cornering force is measured and peaks at the yaw angle. The Mu-Meter is a trailer method originally developed and tested in Britain (5).

ADOT tows the trailer behind a 2.5 ton truck with a 500 gallon water supply. The first 500 feet of travel lane at the beginning of each mile post are measured for skid resistance. All roadway miles are inventoried annually. Further, the skid resistance trailer is often used to check pavement friction at accident sites.

Roughness: Roughness is measured using a Mays Ride Meter. The Mays Ride Meter is attached to the rear axle of an automobile equipped with a heavy duty suspension and shocks. The Mays Ride Meter measures roughness in terms of deflection inches per mile. Forty inches per mile is considered very good (typically new construction) and 250 inches per mile is considered very poor. The readings are recorded on either a strip chart or an automated processing unit. All roadway miles are inventoried for roughness annually during a four month period in the summer.

Structural Adequacy: Structural strength tests are performed on special request of the Pavement Design Branch. Tests are primarily requested to provide detailed structural adequacy information for overlay design projects. Tests are conducted with either a Dynaflect or a Falling Weight Deflectometer.

The Dynaflect is a trailer mounted device which applies a static weight of 2,000 to 2,100 pounds to the pavement through a pair of rigid steel wheels (6). A dynamic force generator uses a pair of unbalanced fly-wheels, rotating in opposite directions, at eight cycles per second to produce a 1,000 pound peak-to-peak force. The deflection is measured using five velocity transducers which are suspended from a placing bar in the center of the loaded area and at one-foot intervals.

The Falling Weight Deflectometer is also trailer mounted. A single weight is dropped from different heights to develop impact loads. The load is transferred to the pavement through a 11.8 inch diameter plate (6). The deflection is measured using three deflection sensors. Generally 10 tests are made per mile.

The Role of the Pavement Management System at ADOT

The pavement management system is currently managed within the Materials Section. The Materials Section is in the Highway Division which is one of five divisions in ADOT. The other divisions are Motor Vehicle Division, Aeronautics Division, Administrative Services Division, and Transportation Planning Division. Within the Highway Division there are the Highway Development Group and the Highway Operations Group. The Materials Section is part of the Highway Operations Group and the Materials Section contains three areas: Geotechnical Services, Testing Services, and Pavement Services. The Pavement Management Branch is a function of Pavement Services, along with the Pavement Design Branch.

The Pavement Management Branch has 11 employees and is managed by a pavement management engineer. The pavement management branch is responsible for the collection of pavement condition data, management of the pavement management data base, and the pavement management programs. The primary management responsibility of the Pavement Management Branch is the identification of pavement preservation projects. In 1987, ADOT's pavement preservation budget was roughly $62,000,000. It is the responsibility of the pavement management engineer to develop a preservation program in consultation with the district engineers. The preservation program is developed annually and presented to the priority planning subcommittee and, once approved, becomes the preservation portion of the five year construction program.

The preservation program starts at the beginning of the fiscal year (July 1) with meetings between the districts. In the meetings, pavement projects and priorities within the districts are discussed. In the next few months, a draft preservation program is developed and the pavement management data base is updated with condition data collected during the summer. After the data base is updated, the network level models are run and the pavement management engineer refines the preservation projects programmed based on the most current data. The next step is to meet with the districts again and to compromise on a final preservation program. The preservation program then goes to the priority planning subcommittee at the first of the year, to be included in the five year construction program which is then forwarded to ADOT's board for final approval.

Through experience with the pavement management process, the past pavement management engineer estimated that between 70% and 80% of the time, the projects selected through the pavement management system and those selected by the districts agreed. The agreement between the districts and pavement management system tends to be closer in terms of dollars programmed for preservation and tends to agree less in terms of identifying the specific miles for restoration. This is because more expensive projects (i.e., interstate restoration) are more easily identified. In a conversation with a Deputy District Engineer, he noted that in advance of the annual meetings with the pavement management engineer he obtains copies of roughness and distress data on magnetic media for his district. He then sorts through the data with a microcomputer program to develop the priorities for pavement preservation projects within his district.

The pavement management system was placed in the Material Section because they has always performed pavement testing. Pavement management was simply an extension of their historically defined role of pavement testing. The interesting aspect of pavement management's location at ADOT is that pavement management has largely been used as a network level pavement restoration planning tool. Even though this planning function is based outside of the planning division, none of the staff interviewed (including planning staff members) saw a need to transfer pavement management to planning.

System Inputs, Outputs and Processes

In Figure 3-3 is a data flow diagram of the ADOT pavement system. NOS is a sophisticated program that involves the use of

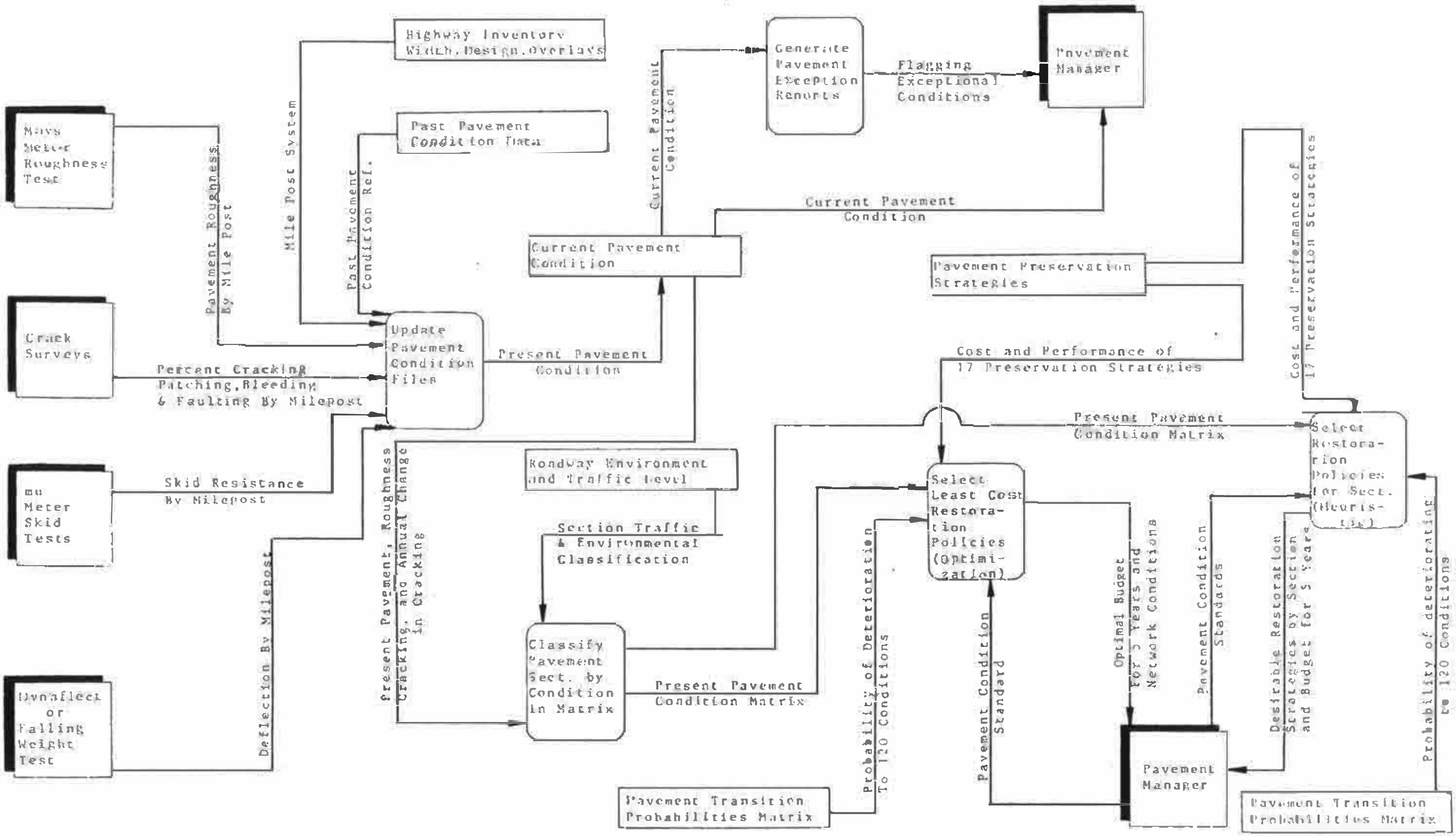

Figure 3-3. Data Flow Diagram of the Arizona Pavement Management System.

Markov Chains (the recursive model described in the beginning of this report). When asked for the cost and effort involved in developing NOS, ADOT spent roughly $300,000 in 1979 on consulting services and hired temporary staff for a total of roughly 13 man-years to work on the pavement management system during its development.

The costs of performing pavement condition tests per mile are listed in Table 3-4. The cost figures include labor cost, vehicle rental rates, and employee per diem. The figures do not reflect the cost of survey equipment depreciation. The cost of visual crack and distress tests are low because ADOT inspects only the first 83 feet of each mile.

The annual labor costs of operating the ADOT pavement management system is roughly $275,000 (11 staff members). The replacement costs of the ADOT pavement condition survey equipment is listed in Table 3-5.

TABLE 3-4

THE ARIZONA COST OF PAVEMENT CONDITION TESTS

Evaluation Test	Cost per 2 Lane Mile
Mays Meter Roughness Test	$ 3.48
Cracking and Distress Visual Inspection	$ 4.85
Mu-Meter Skid Resistance Test	$ 5.77
Dynaflect Deflection Test	$21.78
Falling Weight Deflectometer Test	$53.22

TABLE 3-5

THE ARIZONA REPLACEMENT COST OF PAVEMENT CONDITION TESTING EQUIPMENT

Equipment	Replacement Cost
3 Mays Meters	$ 19,000
3 Mu-Meters	$120,000
2 Dynaflects	$ 70,000
1 Falling Weight Deflectometer	$ 90,000
2 Profilographs	$ 20,000
Stopping Distance Equipment	$ 5,000
Trucks and Cars	$100,000
Spare Parts and Miscellaneous Equipment	$ 10,000
	$434,000

PENNSYLVANIA SYSTEMATIC TECHNIQUE TO ANALYZE AND MANAGE PAVEMENTS

Prior to 1983, the Pennsylvania Department of Transportation (PennDOT) had made several overtures toward the development of a pavement management system (7). On various occasions committees were appointed to investigate pavement management, however, little progress was made. In 1983 the Pennsylvania Secretary of Transportation named an eight person Task Force to investigate the possibility of developing a pavement management system for PennDOT.

The members of the Task Force were hand picked by the Secretary. Before the first meeting of the Task Force, none of the members had knowledge of the identity of the other members. The Secretary gave the Task Force the charge of first determining whether it was possible for PennDOT to develop a pavement management system, and second, if it was possible to develop a system, then the Task Force should assume responsibility for the development.

The Task Force included the Director of Operations, a District Engineer, an Assistant District Maintenance Engineer, a District Pavement Management Engineer, an Assistant District Maintenance Engineer, a District Pavement Management Engineer, the Bureau of Design Pavement Management Engineer, the Division Manager of the Bureau of Strategic Planning, the Manager of the Office of Research, and the Division Chief of the Bureau of Management Information Systems (8). Once the Task Force had decided that it was feasible to develop a pavement management system, the members were relieved of their normal duties and sequestered for the duration of the project. The project was completed after nine months of work by the Task Force.

The objectives developed by the Task Force for the pavement management system included:

1. To provide a uniform statewide condition evaluation which would improve decision making.
2. To provide management with the information and tools to monitor the condition of the network, assess future needs, establish county condition rankings and optimize investments.
3. To provide condition information to fulfill the requirements of Act 68 (1980), which requires the allocating of maintenance funds to the individual counties based on needs.
4. To provide information for monitoring the performance of various pavement designs, rehabilitation, and maintenance techniques.
5. To provide information for identifying candidate projects for maintenance and betterment programs.

The original pavement management system was designed by the Task Force and given the name "Systematic Technique to Analyze and Manage Pennsylvania's Pavement" (STAMPP). The original computer program developed to automate STAMPP was developed in the Basic language and was run on a microcomputer (9). During its development, a demonstration of STAMPP was conducted by applying the system to a single county. Once STAMPP was burnt-in through a county demonstration, it was ready for application to the remaining highway system.

The PennDOT philosophy on pavement management is one that works from the bottom up. The pavement management system is used at the county level by the county manager to set pavement maintenance and betterment priorities within the county. Then an assistant district engineer takes the recommendations from the county manager into account in making project selections within the district. The project level pavement management analysis is all done at the district level and the network level pavement management analysis is all done at the PennDOT headquarters. The involvement of headquarters in the pavement management process is one of insuring consistency between divisions. Also, if a division recommendation deviates from the STAMPP recommended treatment, then there is ample justification for not following the program recommendation. Because STAMPP has only been in operation for a short period, PennDOT has not begun developing performance curves that forecast the future performance of the pavement system.

Pavement Conditions Data Collected

PennDOT has divided the state highway system into inventory segments of roughly one-half mile in length. The segment divisions are located at either the end of the one-half mile segment or they are located at a physical change in the pavement or a change in the characteristics of the traffic loading (i.e., at an intersection). There are roughly 90,000 segments in PennDOT's highway network. The beginning and the ending of segments are physically marked by inventory posts and the inventory segments are used to identify the highway system for all other inventories (i.e., accident location, traffic control device location, etc.)

PennDOT uses and collects several types of pavement condition data. Included are: 1) A visual pavement condition inspection; 2) Roughness; 3) Skid resistance; and 4) Structural adequacy (10).

Visual Pavement Condition Inspection: One hundred percent of the Pennsylvania state highway system is visually inspected every year. The pavement inspection is collected by about 90 temporary engineering technicians (generally college students) between June and November. The inspections are coordinated through each division, although inspection training and quality assurance are centralized through PennDOT headquarters. The quality assurance program resamples roughly five percent of the sections. The cost of conducting the visual inspection is slightly less than $13 per mile.

The evaluation is quite elaborate, although it does not require a great deal of time to complete an evaluation. An evaluation team tends to average between 15 and 20 miles per day. There are separate evaluation forms for rigid, flexible and unpaved roads. The evaluation forms for rigid and flexible pavement are shown in Figures 3-4 and 3-5, respectively. Each includes several types of distress and the evaluator is asked to rate the travel lanes and shoulders for each type of distress on a scale from one to nine. Each number in the scale corresponds to a combined category of severity and extent for each distress type rated. The score increases with the severity and extent.

CONDITION SURVEY INPUT FORM - RIGID PAVEMENT

DIST. CTY. P/S APPL LEG.RTE. SPUR EQ. BEGIN STATION BEG. MILEPOST BEGIN DESCRIPTION

TYPE SURF. 30/40/50 FLEXIBLE 60/80/90 RIG.BASE 70 RIGID

DATE (M M D D Y Y)

ADT U/R TRAF.RTE. MFC LENGTH END STATION END MILEPOST END DESCRIPTION WIDTH DIR. OBS1 OBS2 OBS3

CONDITION		EXTENT			SEVERITY
		<10%	10-30%	>30%	# JOINTS
JOINT SEAL FAILURE		7	8	9	> 50% MISSING
	NONE	4	5	6	> 1' SEALANT MISSING
	0	1	2	3	BOND LOSS >2'/JOINT
		<10%	10-30%	>30%	LENGTH
LONG. JOINT SPALLING		7	8	9	> 6"
	NONE	4	5	6	1"-6"
	0	1	2	3	< 1"
		<10%	10-30%	>30%	SLABS
TRANSVERSE CRACKING		7	8	9	> 1"
	NONE	4	5	6	1/4"-1"
	0	1	2	3	< 1/4"
		<10%	10-30%	>30%	# JOINTS
TRANS. JOINT SPALLING		7	8	9	CRUSHED JOINT
	NONE	4	5	6	ISOLATED SPALL >2"
	0	1	2	3	MINOR SPALL <2"
		<10%	10-30%	>30%	# JOINTS
FAULTING		7	8	9	> 1/2"
	NONE	4	5	6	1/4"-1/2"
	0	1	2	3	< 1/4"
		<5%	5-15%	>15%	SLABS
BROKEN SLAB		7	8	9	LOOSE PIECES
	NONE	4	5	6	INTERLOCKING PIECES
	0	1	2	3	HAIRLINE CRACKS
		<5%	5-15%	>15%	SLABS
BITUMINOUS PATCHING		7	8	9	POOR CONDITION
	NONE	4	5	6	FAIR CONDITION
	0	1	2	3	GOOD CONDITION
		<5%	5-15%	>15%	SLABS
SURFACE DEFECTS	NONE	4	5	6	5 OR MORE PER SLAB
	0	1	2	3	< 5 PER SLAB

RUTTING >1/2" OVER 50% SECTION LENGTH

NO	YES
0	1

SHOULDERS

LEFT AVERAGE TOTAL WIDTH	LEFT AVERAGE PAVED WIDTH	PAVED AND UNPAVED	RIGHT AVERAGE TOTAL WIDTH	RIGHT AVERAGE PAVED WIDTH
0-CURB	0-CURB	UNPAVED	0-CURB	0-CURB
2'	2'		2'	2'
4'	4'		4'	4'
6'	6'		6'	6'
8'	8'		8'	8'
10'	10'		10'	10'

PAVED PORTION ONLY

CONDITION		LEFT EXTENT			SEVERITY		RIGHT EXTENT		
		<10%	10-30%	>30%	LENGTH		<10%	10-30%	>30%
LANE/SHOULDER		7	8	9	> 1"		7	8	9
SEPARATION	NONE	4	5	6	1/4"-1"	NONE	4	5	6
	0	1	2	3	< 1/4"	0	1	2	3
		<10%	10-30%	>30%	LENGTH		<10%	10-30%	>30%
DETERIORATION		7	8	9	HOLES/SEV.CRKING		7	8	9
	NONE	4	5	6	ENTIRE WDTH	NONE	4	5	6
	0	1	2	3	MINOR CRKING	0	1	2	3

PAVED AND UNPAVED

	DRAINS	<10%	10-30%	>30%	LENGTH	DRAINS	<10%	10-30%	>30%
SLOPE	0	1	2	3	DOES NOT DRN	0	1	2	3
	DRAINS	<10%	10-30%	>30%	LENGTH	DRAINS	<10%	10-30%	>30%
BUILDUP	0	1	2	3	DOES NOT DRN	0	1	2	3
		<10%	10-30%	>30%	LENGTH		<10%	10-30%	>30%
DROPOFF		7	8	9	> 4"		7	8	9
	NONE	4	5	6	>2"-4"	NONE	4	5	6
	0	1	2	3	1"-2"	0	1	2	3

REMARKS:

Figure 3-4 Pennsylvania Evaluation Form For Rigid Pavements

CONDITION SURVEY INPUT FORM - BITUMINOUS SURFACE PAVEMENT

DIST. | CTY. | R/S | APPL | LEG.RTE. | SPUR | EQ. | BEGIN STATION | BEG. MILEPOST | BEGIN DESCRIPTION

TYPE SURF. — 30/40/50 FLEXIBLE; 60/80/90 RIG.BASE; 70 RIGID

DATE — M M D D Y Y

ADT | U/R | TRAF.RTE. | MFC | LENGTH | END STATION | END MILEPOST | END DESCRIPTION | WIDTH | DIR. | OBS1 | OBS2 | OBS3

CONDITION		EXTENT			SEVERITY
		<10%	10-30%	>30%	LENGTH
EXCESS ASPHALT		7	8	9	LITTLE VISIBLE AGGR.
	NONE	4	5	6	WHEEL TRACK SMOOTH
	0	1	2	3	OCCAS. SMALL PATCHES
		<10%	10-30%	>30%	AREA
RAVELING/WEATHERING		7	8	9	HIGHLY PITTED/ROUGH
	NONE	4	5	6	SOME SMALL HOLE/PITS
	0	1	2	3	MINOR LOSS
		<10%	10-30%	>30%	LENGTH
BLOCK CRACKING		7	8	9	> 1/2" SPALLED
	NONE	4	5	6	1/4"-1/2" SPALLED
	0	1	2	3	< 1/4" OR SEALED
		<101	101-200	>200	LF IN 100'
TRAN.& LONG. CRACKING		7	8	9	> 1" & SPALLED
	NONE	4	5	6	1/4"-1"
	0	1	2	3	< 1/4" OR SEALED
		<10%	10-30%	>30%	LENGTH
ALLIGATOR CRACKING		7	8	9	SPALLED & LOOSE
	NONE	4	5	6	SPALLED & TIGHT
	0	1	2	3	HAIRLINE
		<10%	10-30%	>30%	LENGTH
EDGE DETERIORATION		7	8	9	EDGE LOOSE/MISSING
	NONE	4	5	6	CRACKED EDGE JAGGED
	0	1	2	3	CRACKED EDGE INTACT
		<5%	5-15%	>15%	AREA
BITUMINOUS PATCHING		7	8	9	POOR CONDITION
	NONE	4	5	6	FAIR CONDITION
	0	1	2	3	GOOD CONDITION
		1-2	3-6	>6	COUNTS
POTHOLES		7	8	9	> 3" DEPTH
	NONE	4	5	6	1"-3" DEPTH
	0	1	2	3	< 1" DEPTH
		<10%	10-30%	>30%	LENGTH
WIDENING DROPOFF		7	8	9	> 1"
	NONE	4	5	6	1/2"-1"
	0	1	2	3	< 1/2"

PROFILE DISTORTION	NONE	1-2	3-6	>6	COUNTS
	0	1	2	3	

RUTTING OVER 50% SECTION LENGTH	NO	1/2"-1"	>1"
	0	1	2

SHOULDERS

LEFT AVERAGE TOTAL WIDTH	LEFT AVERAGE PAVED WIDTH	PAVED AND UNPAVED	RIGHT AVERAGE TOTAL WIDTH	RIGHT AVERAGE PAVED WIDTH
0-CURB	0-CURB		0-CURB	0-CURB
2'	2'		2'	2'
4'	4'		4'	4'
6'	6'		6'	6'
8'	8'		8'	8'
10'	10'		10'	10'

PAVED PORTION ONLY

CONDITION		LEFT EXTENT			SEVERITY		RIGHT EXTENT		
		<10%	10-30%	>30%	LENGTH		<10%	10-30%	>30%
LANE/SHOULDER SEPARATION		7	8	9	> 1"		7	8	9
	NONE	4	5	6	1/4"-1"	NONE	4	5	6
	0	1	2	3	< 1/4"	0	1	2	3
		<10%	10-30%	>30%	LENGTH		<10%	10-30%	>30%
DETERIORATION		7	8	9	HOLES/SEV.CRKING		7	8	9
	NONE	4	5	6	ENTIRE WITH	NONE	4	5	6
	0	1	2	3	MINOR CRKING	0	1	2	3

PAVED AND UNPAVED

	DRAINS	<10%	10-30%	>30%	LENGTH	DRAINS	<10%	10-30%	>30%
SLOPE	0	1	2	3	DOES NOT DRN	0	1	2	3
	DRAINS	<10%	10-30%	>30%	LENGTH	DRAINS	<10%	10-30%	>30%
BUILDUP	0	1	2	3	DOES NOT DRN	0	1	2	3
		<10%	10-30%	>30%	LENGTH		<10%	10-30%	>30%
DROPOFF		7	8	9	> 4"		7	8	9
	NONE	4	5	6	>2"-4"	NONE	4	5	6
	0	1	2	3	1"-2"	0	1	2	3

REMARKS:

Figure 3-5 Pennsylvania Evaluation Form For Flexible Pavements

The evaluation is made from a moving vehicle. In the vehicle are a driver and evaluator. The evaluator makes his evaluation in the seat behind the driver while the vehicle is moving at 5 to 10 miles per hour. The driver stops the vehicle at the end of the section while the evaluator fills out the pavement condition survey. The evaluator also has a straight line diagram that can be used to note features and roadway hazards within the right-of-way.

Roughness Test: Roughness is measured with a Mays Ride Meter. PennDOT operates four Mays Ride Meters and samples the entire network. However, roughness data is not used by STAMPP in the selection of maintenance strategies. Roughness data is kept in the Pennsylvania Automated Roadway Information System (PARIS). Roughness is only used to supplement pavement condition data for program development and project selection.

Skid Data: Friction measurements are made with three locked wheel skid trailers operated by PennDOT. Skid measurement tests are performed on special requests and when there is a high frequency of wet weather accidents at a particular location.

Structural Adequacy: PennDOT operates one Falling Weight Deflectometer (FWD) and a Road Rater. The FWD is used to test concrete pavements and the Road Rater is used on asphalt pavements. Structural adequacy tests are only performed at locations where structural strength information is needed for design.

When testing concrete pavement , the number of test points taken per unit of distance is a function of the purpose of the tests. For example, if the purpose for testing is to locate voids under P.C. slabs, then more test points will be taken than if the purpose is to simply define the structural adequacy of the existing pavement for an overlay design. Generally three drops of the FWD are made per test point, with an average cost per point of roughly $8.00 per test point. The $8.00 includes the cost of traffic control at the test location. When tests are made on asphalt pavements with the Road Rater, normally 11 tests are made per mile at a cost of roughly $88.00, which includes traffic control along the mile being tested.

Pavement Evaluation

The STAMPP system computer program uses the visual distress data, average daily traffic, average daily truck traffic, and whether the roadway is in an urban or a rural area to identify suggested maintenance treatments. Pavement roughness and the percentage of truck traffic are included in the STAMPP data files and can be accesses through STAMPP; however, the program does not use them in the calculation of the treatment.

The program uses the severity score of the distress (a value from one to nine) to select a treatment strategy. A treatment matrix for rigid pavements is shown in Figure 3-6. For example, suppose that a concrete pavement has transverse cracks that are greater than an inch in width (high severity) over ten to thirty percent of the slabs in a section (see Figure 3-4). Thus, the severity score for transverse cracks in this section is eight. The severity score is then used in the treatment matrix in Figure 3-6. The cell of the matrix in the row marked transverse cracking and under column eight contains a nine. Nine corres-

RIGID PAVEMENT TREATMENT STRATEGIES

		LOW			MEDIUM			HIGH		
		1	2	3	4	5	6	7	8	9
A	JOINT SEAL FAILURE	X	1	2	1	2	2	1	2	2
B	LONGITUDINAL JOINT SPALLING	1	2	3	4	4	4	4	4	4
C	TRANSVERSE CRACKING	X	X	X	2	3	3	9	(9)	9
D	TRANSVERSE JOINT SPALLING	X	1	3	4	4	4	5	5	5
E	FAULTING	X	6	6	7	8	8	9	9	10
F	BROKEN SLAB	6	6	6	9	9	9	9	9	9
G	BITUMINOUS PATCHING	9	9	9	9	9	9	9	9	9
H	SURFACE DEFECTS	4	4	4	9	9	9			
K	RUTTING	10								

(X) ROUTINE MAINTENANCE
(1) SPOT JOINT SEAL
(2) JOINT SEAL
(3) JOINT REHABILITATION
(4) JOINT SPALL REPAIR
(5) JOINT REPLACE
(6) SUBSEAL
(7) SUBSEAL & SLABJACK
(8) SUBSEAL & SLABJACK & GRIND
(9) SLAB REPLACE
(10) OVERLAY

COMBINATIONS FOR OVERLAY:

>30% PATCHING

OVERLAY REPAIR RECOMMENDATIONS:

ADTT	REPAIR
0 - 1000	3-1/2" BITUMINOUS
1001 - 2000	6" BITUMINOUS
2001 - 3000	CONCRETE OVERLAY
ABOVE 3000	RECONSTRUCT

Figure 3-6 Pennsylania Treatment Matrix For Rigid Pavement

ponds to a suggested treatment. The suggested treatments are listed beneath the matrix and nine corresponds to slab replacement. Similar treatment strategy matrices are included in the program for flexible pavement, and for paved and unpaved shoulders and for unpaved roads.

Rigid Pavement Treatment Strategies: PennDOT attempts to maintain rigid pavements as rigid pavement as long as it is economically justified. Therefore, the treatment strategies focus on prolonging the life of the pavement through preventive maintenance. There are ten concrete pavement preventive and corrective treatment strategies and they include: 1) Spot joint sealing; 2) Joint sealing; 3) Joint rehabilitation; 4) Joint spall repair; 5) Joint replacement; 6) Subsealing; 7) Subsealing, and slabjacking; 8) Subsealing, slabjacking, and grinding; 9) Slab replacement; and 10) Overlays (bituminous or concrete).

The overlay category is only triggered when there is high severity faulting (see Figure 3-6) or when a combination of distresses occur on the same section and thus warranting a more intensive corrective action. For example, when more than 30 percent of the slabs of a section are broken and more than 10 of the section's joints are spalling, then the recommended strategy would be to overlay. The type of overlay is then dictated by the average daily truck traffic on the roadway following the criteria listed below:

ADTT	REPAIR STRATEGY
0 - 1,000	3-1/2 inch Bituminous Overlay
1,001 - 2,000	6 inch Bituminous Overlay
2,001 - 3,000	Overlay (Type of overlay determined by economic analysis
Above - 3,000	Reconstruct

Flexible/Rigid Base Pavement (Composite Pavement) Treatment Strategies: Fifteen treatment strategies are considered for flexible pavements. The treatment matrix for flexible pavements is shown in Figure 3-7. All treatments assume that drainage and base repairs are performed before surface improvements are applied. The fifteen strategies include: 1) Crack sealing; 2) Skin patching; 3) Manual patching; 4) Seal coat; 5) Mechanized patching; 6) Base repairs; 7) Surface treatment/one inch plant mix; 8) Leveling and seal coat; 9) Joint repair; 10) Mill, leveling and seal coat; 11) Widening, leveling, and seal coat; 12) Leveling and resurfacing; 13) Mill (recycle), leveling, and resurface; 14) Widen, leveling, and resurface; and 15) Reconstruction.

The computer program not only selects treatments based on the matrix in Figure 3-7, but the selection is also based on the average daily traffic and whether the roadway is urban or rural. For example, certain treatments, such as seal coats, do not lend themselves to use in urban areas, thus the triggering of mechanized patching or plant mix surface treatment are substituted for seal coats in urban areas. Further, various combinations of distress, trigger more extensive treatments.

BITUMINOUS SURFACE PAVEMENT TREATMENT STRATEGIES

		LOW			MEDIUM			HIGH		
		1	2	3	4	5	6	7	8	9
A	EXCESS ASPHALT	X	X	X	X	X	X	X	X	X
B	RAVELING/ WEATHERING	2	2	4 (7)	2	4 (5)	4 (7)	5	8 (5)	8 (12)
C	BLOCK CRACKING	2	2	4 (7)	1	1+8 (5)	1+8 (7)	1+5	1+8 (1+5)	10 (13)
D	TRANSVERSE AND LONGITUD.CRACKING	X	X	X	1	1	1	1+2	1+2	10 (13)
E	ALLIGATOR CRACKING	2	2	2	2+3	2+3 (5)	3+8 (3+12)	6	6	6+8 (6+12)
F	EDGE DETERIORATION	X	2	2	3	2+3	2+3	3	5	11
G	BITUMINOUS PATCHING	X	X	X	3	5	5	3	3+5	10 (13)
H	POTHOLES	3	3	3	3	3	3	3	3	6
I	WIDENING DROPOFF	X	2	2	X	5*	5*	3	10* (13)*	10* (13)*
J	PROFILE DISTORTION	6 OR 9*	6 OR 9*	6 OR 9*						
K	RUTTING	X	8 (13)							

* ASSUME 6' WIDTH FOR COST

( ) URBAN AREA

(X) ROUTINE MAINTENANCE
(1) CRACK SEAL
(2) SKIN PATCH
(3) MANUAL PATCH
(4) SEAL COAT
(5) MECHANIZED PATCH
(6) BASE REPAIR
(7) SURFACE TREATMENT - 1" PLANT MIX
(8) LEVEL & SEAL COAT
(9) JOINT REPAIR
(10) MILL & LEVEL & SEAL COAT
(11) WIDEN
(12) LEVEL & RESURFACE
(13) MILL (RECYCLE) & LEVEL & RESURFACE
(14) RECONSTRUCTION

Figure 3-7 Pennsylvania Treatment Matrix For Flexible Pavement

Shoulder Treatment Strategies: There are separate treatment strategy matrices for paved and unpaved shoulders. The shoulder strategy matrices are shown in Figure 3-8.

STAMPP Computer Program

The STAMPP program starts by accessing a physical description of roadway sections (e.g., location, county, route, pavement width, etc.) from the PARIS. PARIS contains the history of the latest construction on all state owned highways, functional classification of roadways, base material types and depths, widths, the dates of resurfacing, and other characteristics describing the highway system. The most recent visual distress data are input for the program for the sections described in PARIS and the program generates treatments using the treatment strategy matrices.

Once a treatment for each section is identified, the program allows the user to review the proposed treatments for each section in a number of formats (i.e., graphical displays of treatments versus section, total lane miles by treatment, and treatments by route). Lastly, the program allows the user to estimate the costs and material quantities for the proposed strategies.

A microcomputer version of the program is available to the county manager to develop a county-wide plan for maintenance and betterment work. The county plans are then aggregated at the district level. District engineers review and revise the county plans and then a district-wide plan is developed.

When the system was first introduced, it was implemented on the 10,000 mile Priority Commercial Network (11). The

SHOULDER TREATMENT STRATEGIES
****

** PAVED **		LOW			MEDIUM			HIGH		
		1	2	3	4	5	6	7	8	9
Q R	LANE/SHOULDER SEPARATION	X	X	X	1	1	1	1	1	1
S T	DETERIORATION	X	2	2	2	3	3	7	7	7
U V	SLOPE	X	7	7						
W X	BUILDUP	X	4	4						
Y Z	DROPOFF	X	X	5	X	6	6	6	7	7

(X) ROUTINE MAINTENANCE
(1) JOINT SEAL
(2) SKIN PATCH
(3) SEAL COAT
(4) SHOULDER CUTTING
(5) SURFACE TREATMENT
(6) WEDGE & SEAL
(7) CUT OUT & SEAL
(8) RECONSTRUCT

Figure 3-8 Pennsylvania Treatment Matrix For Shoulders

Priority Commercial Network is defined by those roads that carry 500 or more trucks per day or roads that are of significant importance to regional industries. In the first application of STAMPP in 1984, only about 25 percent of the surface improvement projects (i.e., resurfacing, resurfacing and widening, reconstruction and concrete patching) agreed with those proposed by the districts for the 1985-86 budget cycle. The major cause of the discrepancies were factors unrelated to parameters considered by the STAMPP. For example, projects were justified based on the completion of safety improvements, to support local economic development, and to improve rideability. As a result of the discrepancies found, minor modifications have been made to the computer program to allow it to consider more factors.

On the 1,200 mile interstate network in Pennsylvania, the program selection of projects conformed to a greater degree to those proposed by the districts. For example, while analyzing the interstate for 4-R work for a three year period from 1985-1988, about 75 percent of the total district submissions and 80 percent of the submission items related to pavements and shoulders conformed to the projects selected by STAMPP.

The Role of Pavement Management in the Divisions of PennDOT

In 1983 the Pennsylvania Department of Transportation was reorganized. In the reorganization, the Bureau of Bridge and Roadway Technology was created. The objective of the reorganization was to organize the Department by function and the management functions of the highway system were placed in one bureau (12).

Within the Bureau of Bridge and Roadway Technology are three divisions. The Engineering Technology Division is responsible for electronic data processing, value engineering coordination, new product evaluations, HPR experimental and evaluation projects, and technology transfer. The Bridge Management Systems Division is responsible for bridge system evaluation and bridge experimentation projects. The Roadway Management Division is responsible for pavement management, pavement design practice, and pavement experimental projects. Although the three management divisions have control over the development of roadway and bridge design and maintenance practices, actual design and maintenance are conducted by the Bureaus of Design and of Maintenance and Operations.

By reorganizing, PennDOT has avoided orienting the pavement management system toward the objectives of a functional area (i.e., maintenance, materials, design, or planning). The pavement management system is a management tool available for use by managers in each of the functional areas.

System Inputs, Outputs, and Processes

In Figure 3-9 is a data flow diagram of STAMPP. Although STAMPP was originally designed as a stand along system, it is currently a module of the PennDOT Roadway Management System (RMS). RMS is a computerized information system which integrates Pavement Management, Roadway Information (data covering descriptions of the roadway and construction history), special processes (traffic data, accident data, and others), computer generated Straight Line Diagrams, and other management functions.

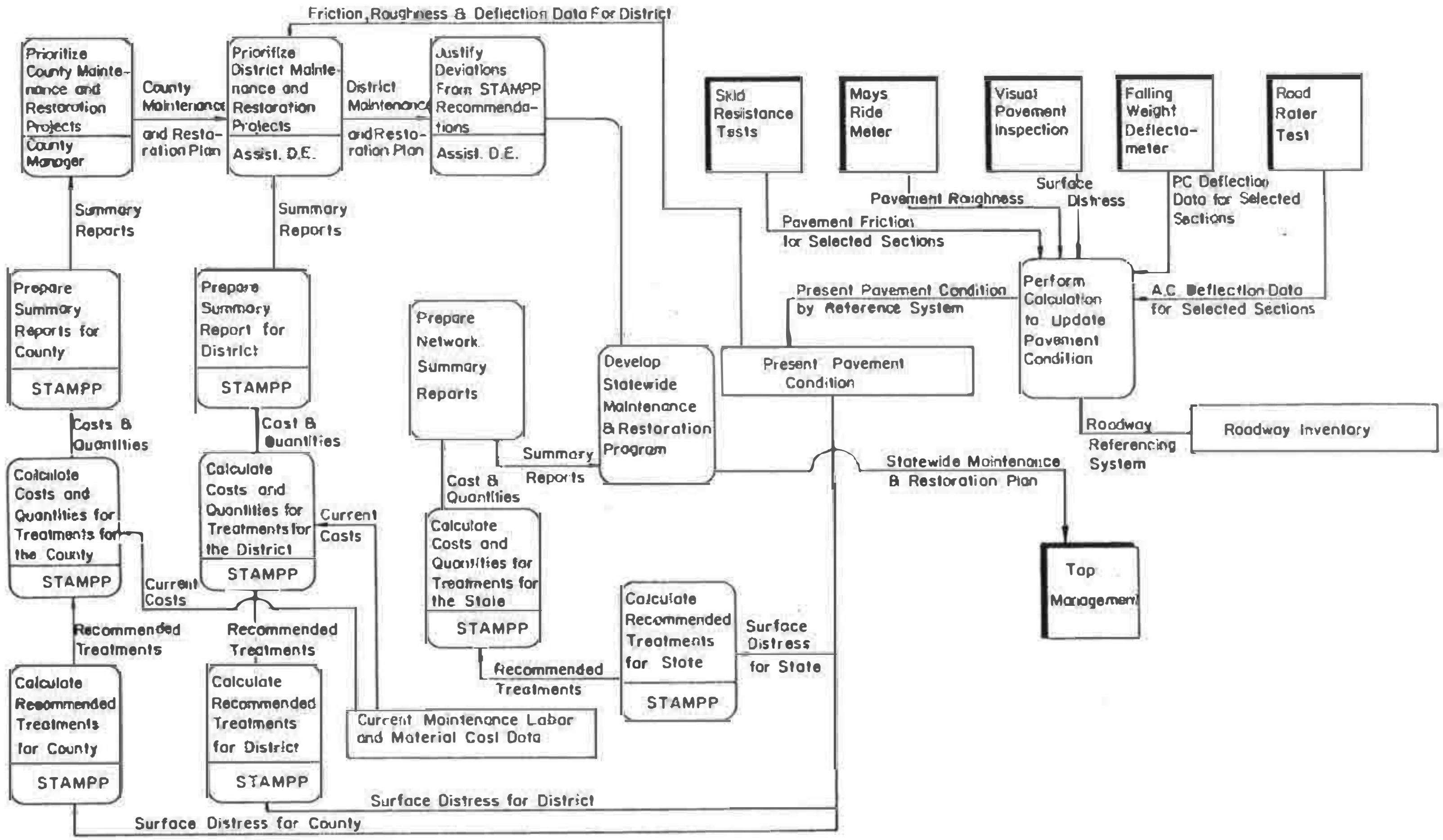

Figure 3-9. Data Flow Diagram of the Pennsylvania Pavement Management System.

The development and testing of the RMS is expected to cost roughly $20,000,000.

CONCLUSIONS

Each of the three states visited provides a distinctly different approach to the development of a pavement management system. The Iowa system was and is being developed in-house. The Iowa system has been slow to evolve over its eight year history; however, current progress seems to be more quickly paced. The Arizona system was first developed by a consultant and has been later modified in-house. The Arizona system is highly centralized and their pavement preservation program is initiated within the headquarters while the field districts review and critique the plan. The Arizona system only examines pavement management process at the network level and is principally used in project planning and programming. The Pennsylvania system was developed in-house through the concentrated efforts of a committee of mid-level managers. The Pennsylvania system is very decentralized and the process starts at the county level. The Pennsylvania system focuses primarily on the selection of individual projects and does not currently have the capability to project pavement conditions in the future for planning purposes.

From the case studies, it is clear that successful and speedy implementation of a pavement management system is dependent upon: 1) A strong commitment by top management; 2) The dedication of the services of mid-level managers to direct the development of the system; and 3) Significant financial resources are required to operate a system (i.e., $500,000 per year is spent to operate Iowa's system).

REFERENCES

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2. Klopping, R.R., "Pavement Management at the Iowa Department of Transportation: Iowa's Pavement Management Information System (IPMIS)," presented at the 28th International Meeting of the Highway Engineering Exchange Program, Phoenix, Arizona, October 1986.

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6. ERES Consultants, Inc., "Techniques for Pavement Rehabilitation: Training Course Notebook," prepared for the Federal Highway Administration, Washington, D.C., Contract No. DOT-FH-11-9580, 1984.

7. The report on Pennsylvania's Pavement Management System was largely generated through interviews with Pennsylvania Department of Transportation Staff on July 1 and 2, 1987.

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9. "STAMPPCS.1, STAMPPCS.2, and STAMPPCS.3 - General Computer Instruction for IBM Personal Computer," - Internal Task Force Report, Pennsylvania Department of Transportation, 1983.

10. "Pavement Condition Survey Field Manual," Pennsylvania Department of Transportation, 1985.

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CHAPTER IV

INTERVIEWS

During the summer of 1987, key ODOT staff members were interviewed to determine their concerns and philosophies regarding a pavement management system. The interviews were informal and started from a discussion of pavement management in general. As the discussions progressed, each ODOT staff member was asked questions regarding the location within the department organizational structure for the operation of the pavement management system and the level in the department that should initiate the pavement management process. In general, most ODOT employees welcomed the introduction of a pavement management system. The specific comments are listed in the following sections.

DESIGN OFFICE

Within the Design Office, five members of the ODOT staff were interviewed. They included Richard Hankins, Assistant Director of Design, Don Cheatham, Rural Design Engineer, Bruce Taylor, Urban Design Engineer, C. Norman Blacklee, Assistant Traffic Division Manager, and Alan Soltani, Pavement Engineer. In summary, all desired more objective and thorough pavement design and condition information. The desired types of information focused on three areas. The three areas are:

1. <u>Pavement descriptive information:</u> Much of the information which describes the material properties of the pavement, construction conditions, age, sources of

materials, etc. is either awkward to access or unavailable, or stored in the memories of employees. Access to pavement descriptive information is useful feedback in making future design, reconstruction/-restoration, and specification decisions. As acceleration in the rate of retirements of senior employees takes place, many of the more experienced employees will no longer be available to supply descriptive information derived from their personal experiences. As a result, the development of an accessible pavement data base will be even more crucial to less experienced employees that are replacing retirees.

2. Traffic Load Data: More exact data are needed on the repetitive axle loadings that pavements have received in the past and they are expected to receive in the future. Accurate axle load data permit the development of pavement designs and restoration designs which are appropriate for the expected loading exposure. Further, knowledge of the number of axle loadings experienced by a pavement provides a yardstick for evaluating the pavement's relative performance over time.

3. Pavement Condition Data: Pavement condition and performance data are currently unavailable in an objective format. Clearly, pavement condition data would be useful feedback information to aid in the evaluation of design and specification practices. However, condition data were felt to be even more useful in triggering

pavement maintenance and restoration treatments in attempts to avoid more extensive repairs when pavement distress becomes intolerable.

The individuals interviewed generally felt that it would be beneficial to access a pavement management system which has the ability to predict pavement conditions. Pavement condition prediction capabilities could be used to plan and schedule pavement maintenance and restoration in a preventive capacity rather than waiting to perform corrective repairs. When asked what measures of pavement condition would be valuable in making decisions regarding the triggering of maintenance and restoration treatments, the Rural Design Engineer provided the following list:

Portland Cement Concrete Pavements

1. D-Cracking
2. Faulting
3. Pumping
4. Corner Breaks and Punchouts
5. Joint Spalling
6. Seal Condition at Joints and at the Edges of the Pavement Where it Meets the Shoulder.
7. Shoulder Condition
8. Coverage and Severity of Transverse Cracking.

Asphalt Concrete Pavements

1. Rutting.
2. Stripping.
3. Coverage and Severity of Transverse Cracking.

4. Coverage and Severity of Alligator Cracking.
5. Condition of Sealed Cracks.

OPERATION OFFICE

Within the Operations Office, four ODOT staff members were interviewed. Staff interviewed included, Delbert Carman, Construction Engineer, Jack Telford, Materials Engineer, David Golden, Maintenance Engineer, and Joe James, Transportation Specialist. The major points discussed in the interviews with Operations Office personnel were:

1. It was felt that in the past, sufficient funds have not been devoted to all levels of maintenance. Funding has not been adequate to develop a strong preventive maintenance program. As a results, pavements must be maintained in a more expensive corrective mode and maintenance resources are used to remedy pressing emergencies ("putting out fires"). If a pavement management system is initiated it must have the ability to systematically address the long term preventive pavement maintenance needs. It was suggested that a pavement management system should permit the Department to budget and program major maintenance at least three to five years in advance.
2. Information should be included in the pavement management system describing the material properties of the pavement, the base, and the subgrade. Although materials information is currently kept, it is not

accessible.

3. Maintaining a high level of involvement in the pavement management process at the field division level was stressed. It was felt that the field divisions were in the best position to understand the local conditions and considerations in the pavement management process.

4. Mr. Golden particularly stressed the importance of preventive maintenance. He felt that the highest priority should be placed on keeping water out of the pavement through preventive surface sealing.

PLANNING AND RESEARCH OFFICE

Within the Planning and Research Office, five staff members were interviewed. They included J.D. Chambers, Assistant Director of Research and Planning, Jerry Cannedy, Current Planning Branch Manager, James D. Henry, Planning Director, C. Dwight Hixon, Research Engineer, and Jim Schmidt, Assistant Research Manager. All individuals interviewed stressed the importance of involving the field divisions in the pavement management process. The major points discussed in the interviews were:

1. Mr. Chambers and Mr. Cannedy were quite concerned that a pavement management system would be used to make major maintenance and restoration decisions in lieu of the current role played by engineers in the field divisions. They felt that the pavement management decisions were best made by experienced staff that are familiar with the local conditions. They believed that

the best pavement management process requires a great deal of judgement and engineering experience. They felt that because of the complexities of judgemental decisions, a computerized system would have a great deal of difficulty in accounting for the complexity of the process. Further, the tremendous data requirements of a computerized system which could emulate the judgmental process would probably be too expensive. However, if the pavement management system is used as an aid to decision making, rather than making the decisions by itself, then a pavement management system is likely to be a worth while tool.

2. One of the key functions the pavement system should provide is a systematic approach to the allocation of resources to competing projects throughout the state, and the allocation of maintenance funds between field divisions. It has been perceived that the distribution of funds has not always been based on the systematic, comprehensive, and equitable appraisal of engineering criteria.

3. The results of the pavement management system should be integrated with the results of the "Needs Study." The Needs Study and pavement management system should be coordinated to complement one another. For example, a pavement rating using a scale of 100 points could be used to complement the sufficiency rating from the needs

study.

4. The pavement management system should provide adequate information to allow all surface treatments to be appropriately designed. For example, it is felt that in some cases, surface treatments are designed without sufficient data on the structural capacity of the existing pavement. To alleviate this problem, specific pavement tests may be required before the placement of a surface treatment is approved.

FIELD DIVISIONS

Visitations were made to four of ODOT's field divisions; the division offices in Ada, Perry, Tulsa, and Buffalo. The individuals interviewed at each of the division were:

Ada Field Division:

Bob Tollison, Division Maintenance Engineer

Bill Mead, Division Construction Engineer

Perry Field Division:

R.L. Stringer, Division Engineer

Tulsa Field Division:

S.C. "Pete" Byers, Division Engineer

Frank Chiles, Division Maintenance Engineer

Buffalo Field Division

H.L. Richards, Division Engineer

David Cline, Division Maintenance Engineer

There was a surprising amount of commonality in the comments of the field division personnel interviewed. All felt that they generally know where their pavement problems are, and if sufficient funds were available for maintenance, the field divisions would be able to take care of the problems. In general, most of the division personnel felt that maintenance is not funded at a level high enough to permit systematic management of pavements. Currently field engineers feel mired down by attempting to correctively repair highways and funds are inadequate to allow them to generate a regimented preventive maintenance program.

Every person interviewed in the field divisions stressed the importance of the field divisions taking a leading role in the pavement management process because they felt that they were closest to the problems. One field division engineer commented that the divisions could benefit from a new management tool but the division "did not need ODOT's headquarters to tell them the problems that they already know about."

The strongest difference in the attitudes of field division personnel was related to their receptiveness of a computerized pavement management system. The most receptive division offered to be the Guinea pig division to test a pavement management system. The least receptive division was skeptical of the utility of a pavement management system and felt that a pavement management system would encroach on the ability of division's personnel to perform their job. Probably the most negative comment voice by a field engineer was the fear that a pavement management system would perform the functions currently conducted by the division maintenance engineer.

The major points addressed during interviews at the field division include:

1. Some field personnel believed that they would be expected to preventively maintain all pavements once the pavement management system was in-place. They assumed that preventive maintenance procedures would be based on the assumptions that pavements had received adequate preventive maintenance in the past, the roadway was adequately designed, quality materials were used in the pavement construction, and pavements were constructed using proper techniques. However, for several portions of the primary system, one or more of these assumptions was likely to have been violated. Further, these pavements were likely to be beyond the stage where preventive maintenance is economically feasible and these pavements should receive extensive rehabilitation or be reconstructed. As a result of poor prior practices, particularly a lack of sufficient preventive maintenance, an objective pavement management system may not be able to take into account past inadequacies and the system may recommend inappropriate preventive maintenance procedures.
2. The state of Oklahoma varies in environmental conditions and in the properties of materials. Wherever possible, these differences should be accounted for in the pavement management systems.

3. One field division encouraged the use of microcomputers in the pavement management process. By allowing pavement management to be conducted on microcomputers, the pavement management process could be decentralized. The decentralization could even be reduced to the county level if the system were allowed to operate in a decentralized mode on microcomputers. Other divisions indirectly reflected this opinion, through their reluctance to have pavement management centrally housed on the ODOT mainframe computer. By housing all pavement management programs and data on the mainframe computer, the divisions felt as though they would be left without control over the process.
4. One division discouraged the use of a new layer of management to administer pavement management in the field division. It was felt that a new position would create an obstacle in the mid-management ranks. Instead pavement management activities should be blended into the existing functions of field division personnel.

FINANCE AND PROGRAM DEVELOPMENT

Within Financial and Programs Development, three ODOT staff were interviewed. They included, Bud McAlister, Assistant Comptroller, E.B. Kidd II, Assistant Division Manager of Data Services, and Eddie Mile, Jr., Division Manager of the Programs Division. All three saw themselves in the role of supporting a pavement management system. Although all three were very interested in the pavement management process, all felt that initial conceptualizing of the functions of a system should be the role of ODOT engineering and planning staff.

TOP MANAGEMENT

Three individuals in top management level were interviewed at ODOT. They included Neal McCaleb, Director, B.C. Hartronft, Chief Engineer, and Monty C. Murphy, Deputy Director. All three individuals were very supportive of the development of pavement management system. However, their philosophies on the operation of the pavement system varied.

The pavement management process can flow in two directions, or a combination of the two. The first way of conducting the pavement management process represents a flow from the top-down. In the top-down approach the pavement management process is centralized within the headquarters. All data are collected, the system is operated, and administered by headquarter staff. Network level pavement management is conducted within the headquarters and field personnel are allowed to critique the projects selected in the centralized system. Once agreement is reached, the pavement management program is proposed to top management by the centralized pavement management staff. The reason why this is considered a top-down approach is that the plan is initiated centrally and flows downward to the field for implementation.

In the bottom-up approach, pavement condition data are collected at the field division level, and pavement improvement programming starts in the field. Pennsylvania follows a bottom-up approach and the first step in developing a pavement improvement program starts with the county manager. Then, the total state program is generated by piecing together the field programs. Headquarters staff review the recommendations of the field personnel, and if the recommendations are consistent with stated policies, the field personnel recommendations are accepted.

The two approaches could be blended so that some programs are allowed to flow from the bottom-up and some flow from the top-down. For example, ODOT routine and special maintenance planning could be allowed to flow from the bottom-up, while planning 4-R, 3-R, reconstruction, and betterment work could flow from the top-down.

The three top managers did not agree on the direction of the pavement management process. The majority of the top managers believed that a bottom-up process would be most productive.

The major points stress in conversation with ODOT top management included:

1. Instituting a pavement management system will require the field divisions to become current with the state-of-the-art of computer aided pavement management techniques. The updating of technical requirements at the division level requires that resources be made available to help upgrade the technical capabilities of the field divisions.
2. The functions of the pavement management system, at a minimum, should be threefold: 1) The pavement manage-

ment system should be able to identify needs; 2) The pavement management system should be able to prioritize the needs; and 3) The pavement management system should be able to assist in the objective allocation of resources to competing needs.

3. The pavement management system must provide credible assistance in the decision making process. A system which provides unreasonable recommendations or implausible forecasts of future pavement conditions destroys the faith of the users in the process. A system that is inaccurate or unreliable is worse than not using a system.

4. The system should promote uniformity among the field divisions. Because the system will allocate resources and make recommendations based on measurable, engineering criteria, the objectivity of the system should promote uniformity between the practices of field divisions.

5. Top managers felt that the inclusion of skid resistance measurements in routinely collected pavement condition data would permit better coordination of improvements for safety reasons and improvement for all other reasons. Further, a regimented program of pavement friction testing would help reduce the legal liability from traffic accidents.

6. One of the strengths of the "Needs Study" is the relative ease of interpreting the study findings. The

"Needs Study" sufficiency rating provides a simple measure to prioritize needs. After the pavement management system has been operational and the system recommendations are found to be reasonable and reliable, the pavement management system findings should be incorporated into the "Needs Study" in a format similar to the 100 point sufficiency scoring system. By following a similar format for prioritizing the pavement management system recommendations are likely to enhance the usefulness of the system.

ODOT CURRENT PAVEMENT MANAGEMENT FUNCTIONS

The Department currently has an informal pavement management process. The primary highway system pavements are evaluated by the Field Division Engineers and the interstate system pavements are evaluated by engineers from the Design Division and the Field Divisions. The "Needs Study" provides an example of a well defined process for the programming of projects. Unfortunately, there is no parallel program for the selection of pavement maintenance and restoration projects.

Shown in Figure 4-1 is a matrix of the allocation of current pavement management responsibilities within the Department. The delineation of responsibilities is not always clear. For example, often the Design Division is asked to assist in developing the design of restorations but not on all projects. As part of the pavement management system development, a clear, step-by-step set of procedures and policies should be developed marking required

Section	Function	Top Management	Divisions	Design	Construction	Materials	Maintenance	Planning	Research	Traffic
[illegible] Programming	Retirement for Non-Pavement Reasons	Review of Process Projects Selected	Needs Study Data Collection		Plan, Schedule, & Administer Const.			Collect & Prep. Need Study Data		
	Reconstruction		Review Total System Needs, Off-Interstate	Review of Interstate Net. for Reconstruct.	Plan, Schedule, & Administer Const.					
	Special Maintenance	Allocates Budget	Submit Estimated Annual Needs To Maintain the Division	Review Needs on Interstate			Prepares Estimate State-wide Needs and Submit to T.M.			
	Routine Maintenance	Allocates Budget								
Interstate and [illegible] Programming	Retirement for Non-Pavement Reasons	Prioritize Projects	Program Projects Off-Interstate	Program Projects on Interstate	Plan, Schedule, & Administer Const.	Participates in Design and Q.A.				
	Reconstruction		Program Projects Off-Interstate	Program Projects on Interstate		Participates in Design and Q.A.				
	Special Maintenance		Programs All Special Maintenance			Participates in Special Requests	Develop State-wide Program based on Division Recommendation			
	Routine Maintenance		Programs All Routine Maintenance			Participates in Special Requests				
Pavement Evaluation and Performance	Pavement Surface Distress		Evaluate Distress Within Division	Evaluate Distress On Interstate						
	Pav't. Surface Performance									
	Pavement Structural Capacity			Collect Data on Int. & Proj. on Primary		Perform Eval. on Interstate			Conducts Defl. Tests	
	Pavement Structural Performance			Performance Data only on Interstate					Research Report	
	Pavement Skid Resistance		Uses Skid Data to Program							Perform Skid Resistance Test In Response to High Accidents
	Pavement Roughness			Development of Design Standards	Evaluation of Const. Methods				Conducts Roughness Tests on Control Section	
	Pav't. Roughness Evaluation									
	Pavement Maintenance Costs		Collects Costs for Budgeting				Collect Costs for Budgeting			
Pavement Performance	Materials			Collect & Review Perform. on Inter.		Perform Accept. & Monitor Testing				
	Traffic Loading							Est. Load Class from Traffic Data		
	Construction Condition			Review Projects for Methods Improvement	Review Proj. for Methods Impr.					
	Maintenance Procedures		Subjective Review of Pavt. Performance						Eval. new Maint. Materials	
	Environmental Conditions		Subjective Review of Pavt. Performance							
Pavement Design	Traffic Loading							Est. load from Classif. Counts		
	New Pavement			Conduct Design based on Est. Loadings		Participates in Design				
	Overlays		Design When Funded From Special or	Design for Projects Budgeted from		Participates in Design				
	Surface Treatments		Routine Maintenance Funds	Construction Funds and Special Requests		Involvement Upon Special Requests				
	Life-Cycle Costs									
Pavement History Inventory	Construction History				Contract Data			Ident. Job Limits		
	Material Specifications					Maint. Mtl. Spec.				
	As Built Conditions		Generated by Div.							
	Construction Costs				B.A.M.S.					
	Pvt. Network Description							Control Section		
	Maintenance Costs		Originated by Div.				Collect/Compile Maint. Cost Hist.	Inventory System		

Figure 4-1 Current Allocation Of Pavement Management Responsibilities

actions to program pavement improvements.

INTERVIEW CONCLUSIONS

All ODOT employees interviewed were interested in new tools that could help them do a better job of managing pavements. Although some were more receptive to computerized pavement management, all seemed to be cooperative and willing to do their part to see that the system is successfully implemented. The primary conclusions reached as a result of the interviews were:

1. Some employees were highly knowledgeable of pavement management systems, while others had serious misconceptions.
2. Most individuals interviewed believed that Field Division engineers were the most familiar with the pavement maintenance and restoration problems and therefore, they should have the greatest degree of control in planning major pavement maintenance and pavement restoration projects.
3. Several of the Field personnel feared that a pavement management system would create a new level of cumbersome and binding procedures. Some expressed the fear that their actions would be determined by a slow to unresponsive, central computerized system.
4. Many hoped that the pavement management system would provide them easy access to pavement descriptive data and condition information.
5. All top managers seemed committed to facilitating the successful implementation of a pavement management system.

CHAPTER V

RECOMMENDATIONS

These recommendations are made with the assumption that the Department will choose to conduct the majority of the pavement management system development itself. This does not mean to suggest that the Department should not borrow proven techniques from other states. The use of systems that have stood the test of time in another state clearly saves on the cost of development. For example, Colorado developed its system using the Arizona system as a model, Idaho borrowed the Utah system and modified it for their own use, and Hawaii borrowed and modified the California system. The recommendations are made with the assumption that ODOT will choose to develop, or at least direct the development, of the system using ODOT staff. Further, it is assumed that:

1. Sufficient personnel and financial resources will be devoted to the development and application of a pavement management system (later in the recommendations, the extent of funds and resources to make a successful system will be discussed).
2. Top management will provide continuous and long-term support to the development of a pavement system.
3. Through time other facets of the department's operation (i.e., bridges, traffic, and traffic control devices) will undergo similar automation of management information.

GENERAL RECOMMENDATIONS

While interviewing staff members, several individuals expressed misconceptions regarding the general area of computer usage and computer aided management, and the specific topic of computerized pavement management. To accept and fully utilize computer aided management systems in general and specifically pavement management systems, many ODOT employees must become more active computer users. Further, several ODOT employees expressed concern over being tied to the mainframe computer for pavement management and the unwieldiness of dealing with a centralized system.

During site visits to both the Arizona and the Pennsylvania Departments of Transportation, the abundance of microcomputers being used to conduct various management activities, including pavement management, was quite conspicuous. By distributing computer processing to the desktops of engineers, managers, and technicians, the task of computer usage becomes less cumbersome and reduces barriers to computer usage. To promote the receptivity of ODOT staff to the use of computers in management activities, and specifically in pavement management, the two following recommendations are made:

1. General familiarization of ODOT employees with computers and computer aided management in general, will help to promote the proper use of a pavement management system by the users and the use of pavement management system recommendations by non-users. At other departments of transportation and in other

industries, the deployment of microcomputers has lead to extensive automation of management activities. Therefore, the computer literacy gained when computing is distributed throughout the department and when employees are trained to use computers, despite the purpose (e.g., project management, scheduling, budgeting, etc.), helps to facilitate the implementation and use of a pavement management system.

2. Pavement management training should be provided to ODOT employees that will be involved in: 1) the pavement management system's operation and data collection; and 2) employees that will be involved in the use of pavement management information. Training should reduce the misconceptions held by employees and increase the receptiveness of ODOT staff to the pavement management process. Training should be conducted at two levels; general and indepth. The first level should cover fundamentals of pavement management and be offered to all managers and engineers with responsibilities for pavement design, construction, and maintenance, and to all administrative and planning personnel involved in programming and planning of pavement improvements. The second level of training should involve high and mid-level engineer managers that will be involved in the pavement management steering committee, and the managers of the pavement management system (the steering committee developed is discussed in the

"General PMS Development Recommendations"). These individuals should be thoroughly familiar with the pavement management process, what other states are doing in the pavement management field, and even with different philosophies of pavement management followed by the leading schools of thought. This will require sending lead individuals to attend indepth workshops. An effort should be made to send individuals to workshops sponsored by different groups to obtain the greatest variety of opinions on the pavement management process.

GENERAL PAVEMENT MANAGEMENT SYSTEM RECOMMENDATIONS

A number of recommendations are made that relate to general organization of the implementation and operation of the pavement management system. Each recommendation is discussed in detail in the following subsections.

Flow of the Pavement Process

Several of the field division personnel expressed concern that the implementation of a pavement management system would cause them to forfeit their discretion over maintenance programming within their division. However, if the pavement management process is allowed to start in the field divisions and flow upwards to ODOT headquarters, then divisions will not loose control over programming within their own division. This is the bottom-up approach. Not only were all field division personnel in favor of a bottom-up approach, but the overwhelming majority of ODOT staff interviewed in the headquarters believed that the bottom-up approach is more desirable.

Allowing the field divisions to become an active participant in the pavement management process helps to insure their acceptance of the process. Further, uniformity between divisions is promoted by requiring them to manage their pavements using a statewide uniform data base, policies, and decision making criteria.

Pavement Management Steering Committee

The development of a pavement system that fits the needs of ODOT should hinge on the decisions made by the steering committee. The committee should be made-up of knowledgeable managers from the divisions who have an interest in the pavement management process. Top management must assign this task as a job function and permit the committee members to be at least partially released from their routine duties.

The state departments of transportation that were visited used significantly different approaches in organizing a committee and in setting goals and deadlines for the committee. Iowa started with a "Pavement Management Committee" made-up of top level managers. Because of the demanding schedules of top managers, the committee tended to meet infrequently and the pavement management staff did not receive the direction they needed. As a result, the development of the Iowa pavement system tended to flounder. More recently, a "Pavement Management Task Force" was formed of mid-level managers. The Pavement Management Task Force members meet more frequently and they administer developmental activities while the Pavement Management Committee sets policies and review the Task Force activities. The development pace of the Iowa system has quickened since the Task Force has been established.

Pennsylvania established a "Special Task Force On Pavement Management" which was placed in charge of the development. The Task Force members themselves developed the pavement system and wrote the software. The Pennsylvania system was fully operational within nine months. However, this approach required roughly six man-years of effort from the task force members to move the Pennsylvania system from concept to a fully operational prototype system.

While Pennsylvania and Iowa both first established committees to oversee the system development, Pennsylvania committee was devoted full-time to directing the system development. As a result, the development of the Pennsylvania system was quick paced. The Iowa committee provided periodic guidance from high-level managers, which had to be augmented by a more frequent level of oversight by mid-level managers. Therefore, the Iowa system has been very slow to develop.

It is recommended that ODOT organize a committee of mid-level managers. The Department should pick individuals that it can afford to regularly release from existing duties for at least four hours per week during the developmental stages of the system and send to workshops which may last as long as two weeks. The committee should contain five to ten members that have backgrounds in the areas of Design, Maintenance, Planning, Materials, Construction, and Data Processing, and representation from the field divisions. Top management should provide oversight of the committee and charge the committee with establishing a management plan for the pavement management system. The management plan should include:

1. Establish clearly defined objectives for the pavement management system which have quantifiable measures of accomplishment. Objectives should be both short-term and long-term. All objectives should have corresponding deadlines for accomplishment. As part of the objectives, the functions of the pavement management system should become apparent. For example, suppose the committee sets an objective that the system should be able to allocate funds, budget, and program projects up to five years in the future with the goal of minimizing the life-cycle costs of the pavement network. Implied in this objective is that the system will be able to conduct adequate pavement performance forecasts, estimate revenue, establish priorities, and optimize the allocation of funds.
2. Identify output requirements for the various divisions of the Department. For example, if one of the objectives is to have the pavement management system automatically estimate budgets, then the system must be able to output the desire maintenance treatment for pavements calculated by areal measurement.
3. Identify data required to generate information for desired outputs. For example, if the system is to

select maintenance actions based on the threshold of deteriorating pavement conditions, then these conditions should be selected. As an illustration, when interviewed some ODOT professionals thought it was important to measure and collect the structural capacity of pavements on a routine basis. Others felt that measures of pavement condition would indicate a loss of structural capacity (i.e., cracking, faulting, spalling, punch-outs, etc.) and structural capacity tests should only be run when structural strength appears to be a problem.

4. Recommend appropriate changes or improvements in present practices. For example, the committee could recommend the collection of truck axle load data or the use of a performance based statistical specification for pavement.

5. Identify permanent management and staffing for pavement management. The permanent staffing of a engineer-manager, other professionals, technicians and temporary pavement condition survey labor represents a significant, recurring cost. For example, Iowa has a highway network which is similar to Oklahoma in distribution of primary and interstate miles and is slightly smaller than Oklahoma in length. Iowa spends roughly $500,000 on operation and administration of their pavement management system. The $500,000 does not include depreciation on equipment or facilities, and the

cost of computer storage and computer service, although it does include professional services for the development of computer software.

6. Determine a management oversight role for the committee's review and guidance of the permanent staff as they progress towards the implementation of a system.

Evolution of the Pavement Management Process

As the pavement management system evolves, the span of its functions can be expanded. Three levels can be identified in the maturity of a pavement management system. At the first level, with only the data collected on pavement condition for the first year, the system should be able to provide information covering the immediate-term. In other words, with only the most recent year's data the pavement managers can begin to identify current maintenance problems. As more years of condition data are collected, the system will reach the second level and it will be able to assist in identifying trends and the pavement management information can be used to conduct short-range planning. With several years of data, the system will reach the third level and can be used to identify pavement performance, forecast future needs, and conduct network level life-cycle costing. The Iowa pavement management staff believes they are currently ready to begin the third level. Iowa has been collecting pavement condition data for over eight years.

Pavement Management Data Base Development

The first step in the development of a pavement management system is the development and structuring of a data base. Since the utility of the system largely rests on the availability of data, the data base design is crucial. Since it is likely that the data base in its entirety will reside on the ODOT mainframe computer, it is strongly recommended that the data base system is designed so that portions of the data base can be easily exported to other computers for special analysis. For example, a maintenance manager may wish to download the most recent pavement condition data for a county to analyze the data using a microcomputer and a spreadsheet program.

It is very important that all the necessary data elements are included in the pavement management system data base in the initial design stage. It is common in the early stages of the development of a pavement management system that the design is focused on the data needed to plan and manage pavement maintenance and restoration. However, as the pavement management process matures, the pavement management system functions should be expanded. The expanded focus will require information beyond the data needed to manage pavement maintenance and restoration. For example, maintenance is commonly managed using current pavement condition data. However, to evaluate the performance of pavement designs requires that historical pavement condition data are married with pavement material and design data. Clearly, the pavement management system data base must be designed with the possible expanded future uses of the system in mind. At a minimum, the pavement system database should include:

1. A physical description of the highway network divided into a logical inventory system. The inventory unit

(e.g., a mile segment of highway) will be dependent on the pavement condition sampling scheme used. For example, the states visited all have different inventory units. Pennsylvania uses half mile segments, Arizona uses mile segments, and Iowa uses five mile segments. The network description should be compatible with other departmental uses of a computerized network description. For example, at some point in the future the Department may wish to integrate the pavement management system with such other systems as roadway design data, a traffic control device inventory, accident records, and a bridge and drainage structure inventory. To make it possible to integrate these roadway management systems, they should use a compatible network description.

2. Cost data covering the cost of pavement construction, maintenance and rehabilitation.
3. Pavement history data, including a history of the pavement condition, properties of the surface, base, subgrade and shoulder materials and their origins, construction conditions, design parameters (e.g., forecasted axle loadings), as built descriptions, types of maintenance applied and when, and other relevant information.
4. Traffic volumes and weight distributions.

Pavement Condition Data Collection

The fundamental measurement of pavement conditions requires roughness measurement equipment, skid resistance measurement equipment, and structural capacity testing devices. Some states have used or are experimenting with the use of an automated system for distress data collection (i.e., laser measurement devices). However, most states use visual distress surveys.

All equipment should be operated by the permanent pavement management staff. Programs should be developed for equipment calibration and quality assurance of the data collected by each type of equipment. Each type of equipment is discussed in the following paragraphs.

1. Roughness Measurement Devices: Most states use a ride meter of some kind to conduct network level measurements of roughness. Unfortunately, most ride meters suffer from a lack of accuracy and repeatability. Each of the states visited have two or more ride meters, where one of the two serves as a back-up. Profiling equipment (i.e., profilographs and profilometers) is much more accurate, but generally suffers from slow travel speeds, high initial cost, and high labor requirements for operation. However, advances are currently being made in the equipment that is available in the market. Currently, the South Dakota Department of Transportation has developed and is demonstrating a promising high speed road profiler. The South Dakota profiler is mounted in a common van. It uses an ultrasonic distance measuring devices to measure profile. The van travels at normal traffic speeds, has good

repeatability of measurements, and a fully equipped system can be built for under $80,000. The states of Nebraska and North Carolina are currently building copies of the South Dakota profiler.

2. Structural Capacity Measurement Devices: Falling Weight Deflectometer (FWD) measurements are the standard for the Strategic Highway Research Program, and as a result, the FWD is likely to become the standard device for pavement testing. One device should be sufficient for the state of Oklahoma, however, two may be required depending on the frequency of testing requirements and the reliability of the device.

3. Skid Resistance Measurement Devices: Most states use a locked wheel skid trailer. However, during the visitation to Arizona, their staff seemed very pleased with the operation of their Mu-Meters. Most states have two devices, so that one can serve as a back-up device.

4. Distress Measurement: Given the current state of the art of automated distress measurement devices, it is recommended that distress surveys be conducted visually. Visual inspection has the advantage of having a trained inspector making field judgements regarding distress type and severity while still at the site. Further, the inspector can serve multiple purposes while inspecting the pavement. For example, the inspector may also be trained to identify roadway defects, survey the condition of the shoulder and drain-

age structures, and identify the condition and location of safety features and traffic control devices. The inspectors should be trained centrally for consistency; however, they may be assigned to field divisions for data collection. Permanent pavement management staff should randomly re-evaluate pavements after the inspectors are completed as a quality control measure.

LIST OF CRITICAL ACTIVITIES AND TIME TARGETS

(Target Completion Dates are in Months after Project Start-Up)

ACTIVITIES	COMPLETION TIME TARGET
ACTIVITY I: TOP MANAGEMENT INITIATES PROCESS	
Top Management Formulates Objectives and Deadlines for the Development of a Pavement Management System, Selects the Steering Committee, Selects Permanent Manager, and Dedicates a Budget.	none
ACTIVITY II: TRAINING PROGRAM	
Widespread Training Program for ODOT Engineers, Planner, Managers, and Technicians.	6 months
In Depth Training Program for Steering Committee Members and Permanent Manager.	3 months
ACTIVITY III: STEERING COMMITTEE PLANNING	
Steering Committee Develops Management Plan o Detailed Short Term and Long Term Objective for Pavement Management System and Deadlines o Develop Administrative Procedures for PMS Staff o Develop Policies to Define the Role of the PMS Staff o Define a Budget, and an Organizational and Staffing Plan	12 months
Steering Committee Conceptualizes And Plans PMS o Identify System Outputs (both short-term and long-term output requirements) o Identify System Inputs (both short-term and long-term input requirements) a. Pavement Descriptive Data b. Pavement Condition Data c. Frequency of Data Collection d. How Condition Data Will Be Collected e. Inventory Unit Design o Identify Required Changes and Improvements In Current Practices o Identify Oversight Role for Steering Committee	

ACTIVITY IV: PROTOTYPE DEVELOPMENT 18 months

Permanent Staff Develops Prototype Pavement Management System

- o Development of Pavement Condition Data Procedures
- o Purchasing Necessary Equipment for Pavement Condition Data Collection
- o Develop a Simple Microcomputer Prototype Data Base and Software for Triggering Maintenance and Restoration Strategies or Borrow and Modify an Existing System

ACTIVITY V: SYSTEM TESTING AND BURN-IN 24 months

Prototype System Burn-In On One County

- o Data Collection Procedures Are Tested
- o System Results Are Tested for Reasonability
- o System Is Modified and Improved

Prototype System Is Appled To An Entire District

- o Software System Is Modified To Run on Mini and Mainframe Computers
- o System Is Used to Develop Special Maintenance 3-R, and 4-R Program Plan
- o Procedures Are Tested and Finalized

ACTIVITY VI: STATEWIDE IMPLEMENTATION OF SYSTEM 36 months

Preparations For Statewide Implementation

- o Equipment Is Purchased To Implement Condition Data Collection Procedures Statewide
- o Training and Quality Assurance Program Is Developed for Pavement Inspectors
- o Division Maintenance Engineers Are Trained for the Implementation of New Responsibilities
- o Training of Field Personnel in New Pavement Management Responsibilities

Application Of The Pavement Management System To The Entire State

- o Collection of Data Across the Entire State
- o Divisions Develop Plans for Special Maintenance, 3-R and 4-R Work
- o Individual Division Plans Are Reviewed and Coordinated At State Level
- o Pavement Management Systems Are Modified

ACTIVITY VII: DATA BASE DEVELOPMENT — 48 months

Permanent Staff Develops Requirements For Statewide Pavement Data Base

- o Requirements for Pavement Historical Descriptive Data
- o Requirements for Pavement Condition Data

Development of Statewide Pavement Data Base

- o Archives for Pavement Condition Base
- o Pavement Historical Descriptive Data

ACTIVITY VIII: LONG-TERM SYSTEM DEVELOPMENT — 60-96 months

Development of Automated Procedures For Improvement Programming

- o Prioritizing Projects
- o Optimally Allocating Resources Between Competing Projects

Use of Pavement Performance Data As Feedback

- o The Performance of Designs
- o The Performance of Materials
- o The Performance of Construction Techniques

Development Of Pavement Performance Curves

- o Life Cycle Cost Based Pavement Design
- o Pavement Condition Projections
- o Scheduling and Programming of Pavement Improvement Programs

Development Of Companion Pavement Management Ratings For The Needs Study

- o Development of a Composite Rating of Pavements
- o Development of a Five Year Pavement Improvement Programming Process

APPENDIX A

INTERPRETING DATA FLOW DIAGRAMS

The diagrams used to graphically illustrate the inputs, processes, data flows, and outputs of the Iowa, Arizona, and Pennsylvania pavement management systems are known as data flow diagrams. To understand why this graphical approach is much easier to develop and interpret than a written description for the specification of an information system, suppose that the specifications for a building had to be written rather than drawn on plans. It would take hundreds of pages of English text to describe the dimension and locations of each door, window, wall, column, joist, etc. Instead, a plan can provide the same information. The same is true with computerized information systems. One or two data flow diagrams can replace several pages of text. As the old saying goes, "one picture is worth a thousand words."

DATA FLOW DIAGRAMMING

The data flow diagram has only four types of symbols, each representing an activity in the flow of data. To illustrate each one, consider a simple example:

Suppose that field surveys are used to collect roughness data and to collect surface distress. These data are then verified and entered into a data store (a data base used to store historical data). Next the data may be processed to create Present Serviceability Index (PSI) for each segment of pavement surveyed.

Open-ended
Rectangle Store of Data

The data flow diagram uses only these four symbols. In the Planning stage it is not necessary to translate these flows, processes, and data records into computer programs or functions. The diagram simply describes the relationship between the various functions of the system. Later, in the Design stage, computer programmers can figure out the details.