MECHANISTIC DESIGN IMPLEMENTATION PLAN FOR FLEXIBLE PAVEMENTS AND OVERLAYS
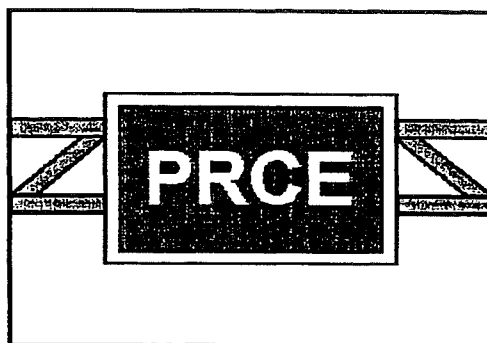
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Pavement Research Center of Excellence
Department of Civil and Environmental Engineering
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Title and Subtitle

Mechanistic Design Implementation Plan for Flexible Pavements and Overlays

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Abstract

The Michigan Department of Transportation practices regarding the design of flexible pavements and overlays were thoroughly reviewed. Based on the review, recommendations for improvement were made. It is recommended that *"the various flexible pavement design procedures and the design of asphalt overlays that exist in the State of Michigan be consolidated into a comprehensive, unified, optimum, and mechanistic-based pavement design process. The main objective of the new process is to increase the life and performance of the pavement and to minimize the user's and the agency's costs".* A plan for the implementation of the recommended process is presented along with its objectives, costs, and benefits.

Key Words : asphalt pavements, overlays, mechanistic, design, implementation

English	Metric
1 inch, in	25.44 mm = 2.544 cm = 0.0254 m
1 foot, ft	304.8 mm = 30.48 cm = 0.3048 m
1 yard, yd	914.4 mm = 91.44 cm = 0.9144 m
I mile (U.S.)	1,609 m = 1.609 km
1 mil	0.0254 mm = 0.0000254 m = 0.0254 μm
1 inch square, in^2	
1 foot square, ft^2	
1 yard square, yd^2	
I mile square (U.S.)	
1 pound mass, lbm or lb	
1 ton = 2000 lb	
1 slug	
1 pound-force, lbf	
1 ton-force	
1 pound per square inch, psi	
1 kip per square inch, ksi	
1 pound-force/square foot, psf	
1 pound-mass per cubic foot, pcf	
For asphalt overlays	
100 pounds per square yard $\cong$	
170 pounds per square yard $\cong$	

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CHAPTER 1

EXECUTIVE SUMMARY

The Michigan Department of Transportation is the primary manager of the largest asset investment made by the taxpayers in the State of Michigan, the transportation infrastructure. An effective highway asset management requires proper control of the various highway components (pavements, bridges, signs) and activities (design, construction, rehabilitation, and maintenance).

Pavement design is one of the most important activities in providing a good pavement structure at a minimum cost. Based on a critical review of both national and MDOT practice, this report scrutinizes the MDOT flexible pavement design procedures and presents recommendations and an implementation plan for improvement.

Pavements must provide two characteristic functions: good ride quality and adequate structural capacity to resist deterioration due to traffic and the natural elements. In general, the restoration of the pavement ride quality can be accomplished with a relatively cheap fix. Restoration of the structural capacity is rather expensive. Therefore, pavements should be designed to have good structural capacity and must be constructed to have a good ride quality.

The AASHTO 1993 software (DARWIN) for the design of flexible and rigid pavements was recently installed on PCs in all MDOT's Regions and in Lansing office. MDOT uses a version of the AASHTO procedure for the design of flexible and rigid pavements. The AASHTO procedure is based on providing pavement with smooth ride. The structural integrity of the pavement may not be assured. Based on a review of the AASHTO procedures, several shortcomings are cited and documented by the project team and various state highway agencies. For all pavement materials (roadbed soil, sand subbase, aggregate base, and asphalt concrete), the MDOT design engineers must assume or judgmentally assign the values of the material properties (modulus and layer and drainage coefficients) which are required as input to the AASHTO procedure. The main reason for these assumptions and/or assignments is that MDOT lacks a comprehensive program whereby the properties of the materials needed in the design procedure can be measured and verified.

Results of the evaluation of the current MDOT practice regarding flexible pavement design, construction, and quality control indicate that the practice is based on several procedures, standards, and specifications that are not necessarily compatible and/or complete nor do they fully address pavement performance. Based on the evaluation, it was concluded that improvement in the pavement design practice is long over due and the following recommendation was made:

> *The various flexible pavement design procedures and the design of asphalt overlays used by MDOT be consolidated into a comprehensive and unified process. The main objective of the new process would be to optimize the life and performance of the pavement and to minimize the life cycle costs.*

The objectives of the recommended process include:

1. Standardizing and unifying the MDOT practice regarding the design of flexible pavements and flexible overlays.
2. Measuring and cataloging the engineering properties of the roadbed soils and the paving materials.
3. Enhancing pavement management.
4. Improving the technical capabilities of MDOT.
5. Implementing the principles of total quality and teamwork.
6. Providing pavement structures with good ride quality and adequate structural capacity.

Based on the objectives, an implementation plan was recommended so that the pavement is:

- Designed on the basis of the measured engineering properties of the materials.
- Constructed on the basis of providing the measured engineering properties and good ride quality.
- Monitored to detect differences between the assumed and the actual pavement life and performance.
- Analyzed to provide feedback for improving the design process.
- Managed to provide the maximum services to the users at the least possible cost.

The implementation plan consists of four components:

1. Continuing Education and Training;
2. Material Characterization including laboratory and field testing and inventory data;
3. Total Quality Teamwork including standards, specifications, and quality assurance/ quality control; and
4. Pavement Management including design procedures, pavement performance models, and feedback.

A fully implemented mechanistic-based design process would result in MDOT measuring the engineering properties of the materials and applying engineering principles to enhance its ability to manage the transportation system and provide the users with better pavements at

reduced overall cost. However, the implementation of a mechanistic-based design process is a long-term operation in that it cannot be accomplished by simply issuing an executive order or by adoption. The successful implementation requires several short- and long-term steps including:

- Endorsement and continuous support
- Commitment from all parties
- Minimum initial investment in terms of resources and budget
- Continuing investment in terms of
    - continuing education (seminars, short courses, and training)
    - increasing technical capability
- Standardization of the design, maintenance, rehabilitation, and material design processes
- Characterization of the various paving materials and roadbed soils to support decisions regarding pavement design, maintenance, rehabilitation, and reconstruction
- Full utilization of the PMS data bank
- Possible organizational changes
- Utilizing QC/QA specifications to measure design parameters during and after construction

The implementation of these steps may require additional costs in the short-term. The long-term benefits however, should be cost saving, higher quality pavements, and enhanced capability of pavement management.

CHAPTER 2
RESEARCH PLAN

1.0   BACKGROUND

In 1985, the Michigan Department of Transportation (MDOT) recognized the need to assess the advantages and disadvantages of changing its flexible pavement and overlay design practices from an empirical-statistical method (i.e., AASHTO) to a mechanistic-based approach. The change could provide more accurate predictions of the pavement design service life (DSL) and better control of pavement performance relative to its design criteria.

Two important steps have been taken toward implementing a mechanistic-based design method. The first was accomplished in 1990 when Michigan State University (MSU), under a contract, provided MDOT a linear and nonlinear finite element pavement design program called MICHPAVE. MICHPAVE has gained notice nationally and internationally, but some user-confidence concerns developed during trial use in MDOT. MSU is aware of these user's concerns and has developed a proposal to correct them. In 1995, MSU completed another research project for MDOT that investigated causes and corrective measures for pavement rutting. This contract also produced a backcalculation computer program, called MICHBACK, to calculate layer modulus values using falling weight deflectometer (FWD) deflection data. It is intended that MICHPAVE and MICHBACK will be the cornerstones for any computer-based design and analysis of asphalt pavements and overlays in the forthcoming mechanistic-based design era.

2.0   PURPOSE

The purposes of this report are to:

1.   Summarize the problems encountered in the existing flexible pavement design practice based on results of interviews conducted with engineers in the districts (regions) and main office.

2.   Summarize the advantages, disadvantages and, when possible, the benefits of empirical and mechanistic-based methods for the design of flexible pavements and asphalt overlays.

2.   Present a plan for the implementation of mechanistic-based design process of flexible pavements and overlays.

The report is organized in five chapters as follows:

* Chapter 1 - Executive Summary
* Chapter 2 - Research Plan
* Chapter 3 - Overview of National Practice Regarding Flexible Pavement and Flexible Overlay Designs
* Chapter 4 - Evaluation of Michigan Practice Regarding the Design of Flexible Pavements and Flexible Overlays
* Chapter 5 - Implementation Plan

3.0   TERMINOLOGY

Empirical design methods - An empirical pavement design method is a procedure based on a statistically developed correlation equation between pavement layer thicknesses and traffic volume. All empirical design procedures are based on a set of pavement data that is limited to certain materials, environment, and traffic load factors. Empirical pavement design methods are often modified based upon experience and opinions. The AASHTO design method is one empirical design method.

Catalog-based design methods - Catalog-based design methods are procedures by which pavement cross-sections (layer thicknesses) are tabulated according to various combination of traffic volume, roadbed soil type, and environment. The design catalog could be generated using empirical or mechanistic-based pavement design procedures.

Mechanistic-based design methods - Mechanistic-based design methods are used to determine the cross-section (layer thicknesses) of asphalt pavements and/or the thickness of asphalt overlays based on the mechanical properties (their responses to loads) of the paving materials and subgrade soil.

Mechanistic-based design process - A mechanistic-based design process, on the other hand, consists of a comprehensive and systematic set of procedures that address the various practices and issues affecting pavement performance including pavement design, material characterization, quality control, construction, and feedback.

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Mechanistic-based processes for the design of flexible pavements and flexible overlays are an integral and crucial part of good asset management. The relationship between good asset management and mechanistic-based design processes is discussed in the next section.

4.0   PAVEMENT DESIGN PROCESS AND ASSET MANAGEMENT

The Michigan Department of Transportation is the primary manager of the largest asset investment made by the taxpayers in the State of Michigan, the transportation infrastructure.

Asset management is a comprehensive and systematic process of designing, constructing, maintaining, rehabilitating, upgrading, and operating physical assets in a cost effective manner. This implies that asset management must combine engineering principles, sound economic theory, and healthy business practices to provide tools to facilitate more organized and logical approaches to both short- and long-term decision making.

Asset management requires sound, reasonable, and appropriate decisions based on solid facts. To ensure resource optimization, good asset management must provide the decision makers ready access to quantitative and qualitative data drawn from good engineering, accounting, economics, services, risk, past data, and safety management systems. Asset optimization can be achieved with:

1.   Accurate estimation of needs (*Pavement Conditions*).

2.   Complete knowledge of the various components of the asset (*Inventory Data*).

3.   A factual prediction of future funding needs (*Cost Data*).

4.   A state-of-the-art knowledge and application of engineering principles and technology (*The Design Process*).

5.   Complete knowledge of the required material properties (*Material Characterization*).

6.   Efficient and sufficient resource allocation based on accurate and detailed data (*Program Strategy*).

Thus, a good and comprehensive highway asset management requires proper control of various highway components and activities. This may be achieved through the implementation of compatible management systems such as Pavement Management System (PMS), Bridge Management System (BMS), Maintenance Management System (MMS), etc. Each of these systems must be based on accurate and sufficient data to aid the decision-makers to arrive at accurate and balanced decisions. For example, an effective PMS must include:

1. *Complete Knowledge* of the various *physical components* of the asset (i.e., asset inventory).

2. An asset *monitoring program*.

3. A state-of-the-art *assessment of the material properties* used in the design of the various physical components of the asset.

4. A *comprehensive design process* based on complete knowledge of the characteristics of the materials and on the mechanics and causes of deterioration.

5. Preventive *maintenance, rehabilitation, and reconstruction programs* that are based on proper management systems.

A mechanistic-based design process would be an important component of pavement management and it would improve the overall asset management. To this end, a plan for the implementation of balanced and comprehensive mechanistic-based design process for flexible pavements and asphalt overlays was developed and is presented in Chapter 5 of this report.

5.0   PROBLEM STATEMENT

The Michigan Department of Transportation (MDOT) is evaluating a process to change its design procedures for flexible pavements and overlays from one based on the AASHTO Guide to a mechanistic approach. A formal comprehensive implementation plan is needed to identify the steps necessary for the change to take place and be acceptable to all participants. The plan would be presented to the Michigan Asphalt Paving Association (MAPA) for endorsement and requires approval by the Department Engineering Operations Committee (EOC).

6.0   PROJECT OBJECTIVES

The ultimate objective of this study is to formulate an implementation plan to produce a design process that will provide the most economical (lowest life/cycle cost) pavement structure or overlay that meets the design criteria. The design process should be based on "mechanistic principles" that include the material's engineering properties and the actual performance of the pavement over time. The modeling of historical pavement performance data would provide the relationships (answers) as to how to adjust material properties to achieve the desired results in performance. Such relationships (fatigue life and rut prediction models), however preliminary, were developed and they are a part of the MICHPAVE computer program. In a parallel project through the Pavement Research Center of Excellence (PRCE), MSU will improve the accuracy of these relationships by using historical pavement performance data. Nevertheless, the success and/or accuracy of any mechanistic-based design process depend upon how well the department tracks the pavement performance and measure its relationships to the pavement design process.

To optimize the benefits of the above objectives, the implementation plan must be designed with the following aspects in mind:

1.   Acceptability - The plan must be generally acceptable to MDOT and the pavement construction industry.

2.   Comprehensiveness - The plan must address the entire flexible pavement design process and its impacts, if any, on existing policy and the working structure of the department.

3.   Flexibility - The plan must be flexible to incorporate new and unforeseen changes such as new tests or new materials.

4.   Congruity - The plan must be continuous but dynamic in nature to respond to the changing needs of the various MDOT regions and the respective TSCs..

To this end, the implementation plan was developed through scheduled meetings with engineers from MDOT (i.e., various Design Squads, Material Engineers, Bituminous Engineers, Maintenance Engineers), and from industry (e.g., MAPA). The plan must include:

1. A summary of the existing MDOT pavement design practices.

2. Short lectures/discussion regarding the AASHTO 1993 Design Guide and the AASHTO DNPS86 and DARWIN computer programs (DNPS was used by MDOT until 1996 where it was replaced by DARWIN). These may include:

    a) Discussion regarding the types and roles of the input parameters to the AASHTO DNPS86 and DARWIN computer programs.

    b) The sensitivity of the AASHTO outputs (layer thicknesses) to the range of values of the input variables.

    c) The role of ESAL and the load equivalency factors in the AASHTO Design Guide.

    d) The role and impact of the values of the AASHTO drainage coefficients on the output (layer thicknesses) of asphalt pavement design.

    e) The AASHTO performance model (the pavement serviceability index and the pavement serviceability rating) and its relationships to the various input parameters of the design process.

    f) The reliability and accuracy of the AASHTO performance model and the AASHTO design process.

3. Training seminars regarding the design steps, the various concepts, the advantages, the benefits and costs, and the shortcomings of mechanistic-based design procedures. The training topics include:

    a) The required inputs in terms of traffic, material properties, drainage, design and performance periods, and environmental factors.

    b) The types of tests that must be conducted to properly measure the required material properties.

    c) The implication of the mechanistic design outputs (deflection, stresses, and

strains) and their acceptable limiting values (threshold values).

d)   The sensitivity of the outputs (including layer thicknesses) to the range of values of the input parameters.

4.   Design examples whereby several actual pavement cross-sections will be redesigned by using the existing pavement design practices, the developed pavement design process and mechanistic-based design methods. This objective however, was not fully realized because of the difficulties encountered in obtaining the engineering properties of the roadbed soil and pavement materials.

5.   Discussion sessions to compare the differences, advantages, benefits, costs, and shortcomings of the AASHTO Design and the mechanistic-based design processes.

7.0   Deliverable

The deliverable of this study is a comprehensive implementation plan that outlines the steps necessary to achieve the project objectives. The plan focuses on the "why(s)" changes are necessary and "how(s)" these changes can be implemented. The plan includes:

1.   The needs and reasons for MDOT to study, develop, and adopt a comprehensive flexible pavement design process (not only a design procedure) whereby the values of the input parameters needed in the design procedure reflect the material quality that would be used in the field.

2.   The impacts of the actions of various offices and divisions of MDOT (e.g., design, materials, construction, maintenance, traffic, etc.) on the pavement design process, in general, and on the pavement life, in particular.

3.   The benefits and costs of converting from a empirical to a mechanistic-based design procedure.

8.0   Research Plan

The project objectives and the deliverables of this study were achieved through the execution of several tasks that are presented below.

Task 1 - Review, Plan Development, and Approval

In this task, a thorough review was made of the existing MDOT pavement design procedure and its relationships to other MDOT activities (e.g., asphalt mix design, traffic, maintenance, etc.). The capabilities of MDOT to obtain the proper material properties that are needed in the AASHTO and in a mechanistic-based design procedure were also reviewed. The synopsis of the review included:

1. A short summary of MDOT's existing and past design practices, and what has been accomplished thus far to institute a changeover to a mechanistic-based pavement design process.

2. Assessment of the perception of the MDOT design engineers of the current design process and its advantages and disadvantages.

3. Evaluation of the current practices by which the required inputs to the design process are obtained and/or specified.

4. Appraisal of the MDOT capabilities to measure the material properties that are needed as inputs to the AASHTO and to the mechanistic-based design processes.

5. Estimation of the additional cost and/or saving that will be incurred by changing to a mechanistic-based design process.

Task 2 - Implementation

Based on the results of Task 1 and coordination with the members of the Technical Advisory Group (TAG) of this study, the steps that need to be taken by MDOT to achieve a full implementation of a comprehensive design process and to realize its objectives were identified and studied. These include:

1. Providing educational seminars on engineering principles relative to pavements, pavement performance, and life/cycle cost analysis.

2. Instituting organizational changes as to how work is performed or decided.

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3. Evaluating the relationships between the department's PMS and the pavement design process and the impact of the changeover on the PMS and other activities of MDOT such as asphalt mix design, maintenance, rehabilitation, and the project development processes.

4. Determining the necessary modifications to MICHPAVE and MICHBACK computer programs. Note that, MICHBACK in its current form is not able to do overlay design.

5. Establishing trial projects to compare design methods.

6. Conducting additional research to develop performance models for calibrating predicted service life with actual pavement service life values including the inclusion of non-load related factors that cause pavement deterioration.

Task 3 - Cost Assessment

Costs and benefits for instituting the change to mechanistic design and analysis were assessed. This assessment was based on cost information obtained from MDOT and the pavement construction industry.

Task 4 - Reports

Throughout the project duration, quarterly reports were submitted to the TAG members. The final draft final report was submitted for review and comments.

CHAPTER 3

OVERVIEW OF THE NATIONAL PRACTICE REGARDING FLEXIBLE PAVEMENT AND FLEXIBLE OVERLAY DESIGNS

1.0   INTRODUCTION

Pavement performance is a measure of how well a pavement serves the users over time. Hence, as shown in figure 3.1, pavement performance can be defined by the area between the performance curve and the threshold value of the distress index (MDOT considers a surface distress index of 50 as the threshold value). This implies that, although two pavement sections may have the same performance life of 20 years, as shown in figure 3.1, they may have substantially different performance levels, with the pavement having the lower distress index over time providing better performance. Further, pavement performance can be classified as functional performance which is based on the ride quality, and structural performance which is based on the structural capacity (e.g., cracking and rutting). In general, functional performance of a pavement section can be restored at a much lower cost than the restoration of its structural performance. Empirical pavement design methods (such as the AASHTO method) address the functional performance of the pavement. Mechanistic-based design methods, on the other hand, address the structural performance of the pavement as well as the ride quality.

In order to assure reliable pavement performance, the design and construction of flexible pavements and flexible overlays must be based on a comprehensive pavement design process that addresses the various factors affecting the pavement performance. These include: material characterization, the asphalt mix design and the pavement design procedures, the quality assurance/quality control and construction practices, the as-constructed pavement properties, the monitoring program, and feedback.

A successful pavement designer must be familiar with the various procedures, publications, standards, and specifications relevant to pavement performance. For example, the designer must be knowledgeable of the relationship between the asphalt mix design procedure and specifications and the as-constructed asphalt concrete properties. If such relationship is not known, reliable pavement performance cannot be assured and an important link in the pavement design process is missing.

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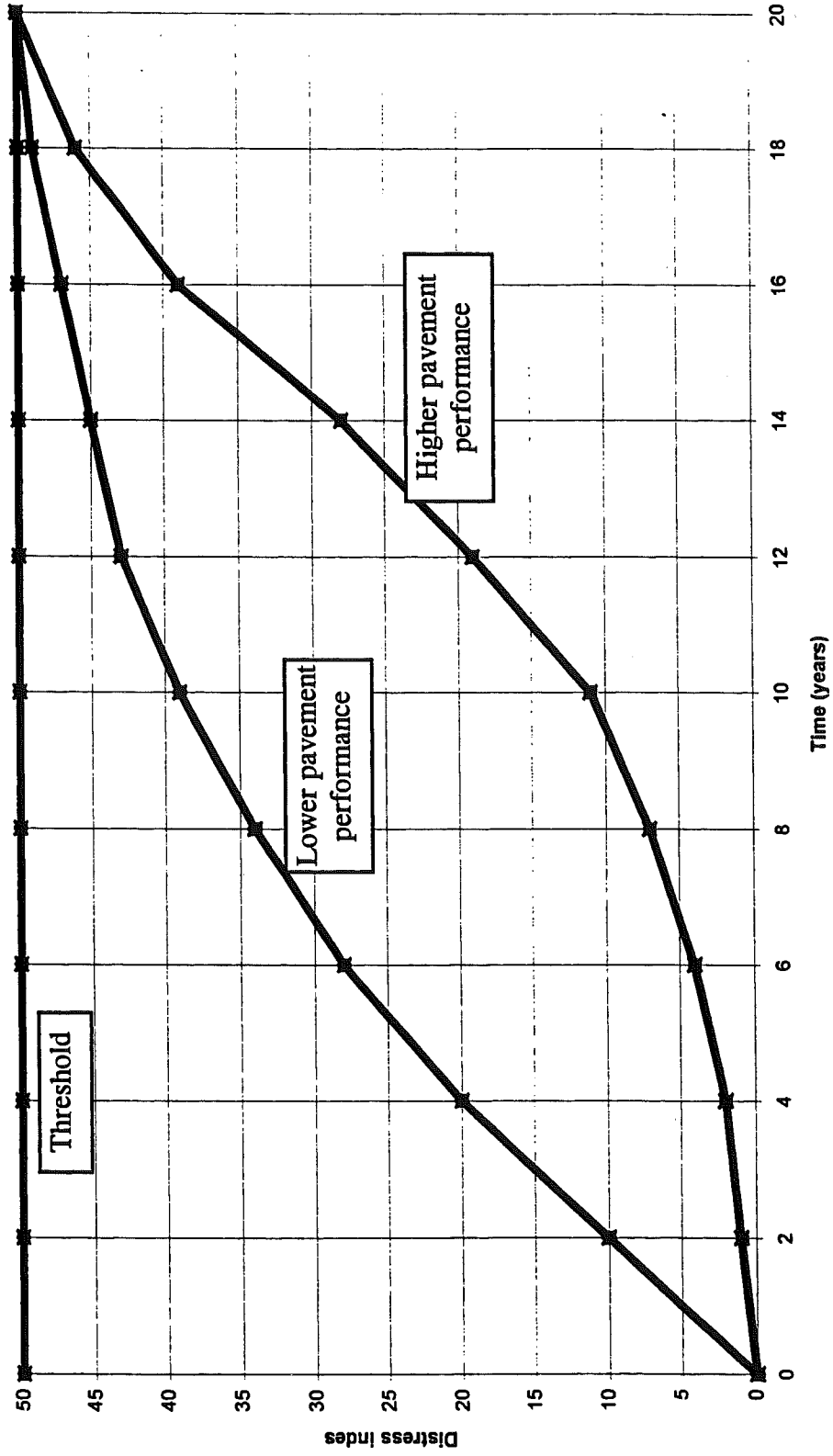
Figure 3.1.   Pavement distress index versus time and pavement performance.

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In the next sections, general review of empirical and mechanistic design procedures is summarized. As most State Highway Agencies (SHA) including MDOT use modified versions of the AASHTO procedure for the design of flexible pavements and flexible overlays, the basic AASHTO design procedure is summarized in section 3 of this chapter.

2.0   FLEXIBLE PAVEMENT DESIGN PROCEDURES

In general, the various available methods for the design of flexible pavement structures and flexible overlays can be divided into two broad categories, empirical and mechanistic. Although some engineers consider catalog design as a third category, in reality, all design catalogs are based on either an empirical or a mechanistic method. Nevertheless, each design category has its advantages and disadvantages and each can lead to erroneous results. Some important considerations regarding each design category are presented in the next two subsections.

2.1   Empirical Flexible Pavement Design Procedures

Empirical pavement design procedures are derived from experience or observation alone, often without detailed consideration of *system behavior* or pavement theory. Empirically derived relationships relating performance, load, and pavement thickness for a given geographical location and climatic condition are the basis for many empirical design methods. These methods or models are generally used to determine the required pavement layer thicknesses, the number of load applications required to cause failure or the occurrence of distress due to pavement material properties, subgrade type, and environmental and traffic conditions (1 through 6).

One advantage in using empirical models is that they tend to be simple and easy to use. Unfortunately, they are usually *only accurate for the exact range of conditions for which they have been developed*. They may be invalid outside the range of variables used in the development of the method. In addition, the engineering interpretations of most purely empirical equations are meaningless and/or misleading. The AASHTO, Corps of Engineers, Louisiana, and Utah design methods are among a large family of empirical pavement design methods that were primarily developed on the basis of observed field performance (1). Since MDOT uses a modified version of the AASHTO design method, its advantages and disadvantages are summarized in section 3.0 below.

Some SHA developed catalogs for the design of flexible pavements and flexible overlays. The development of the catalog was based on experience and observation of pavement behavior. In such catalog, the thicknesses of the various pavement layers and the type of the asphalt mix to be used are selected on the basis of traffic volume, subgrade type, and geographical location (environment). For example, a design catalog may specify a total pavement thickness (the thickness of the subbase, aggregate base, and asphalt layers) equals to the depth of frost penetration. This assures the protection of the roadbed soil against frost heave and potholes. In a few design catalogs (such as the Asphalt Institute) the pavement cross-section is determined on the basis of mechanistic concepts: traffic volume, subgrade type, materials, and environment. Similarly, several empirical procedures exist for the thickness design of flexible overlays. For example, the AASHTO overlay thickness design method requires the estimation of the remaining life factor of the existing pavement. This factor can be estimated using various procedures presented in the 1993 AASHTO design guide. However, the experience of many state highway agencies has indicated the inadequacy of the overlay design procedure due to the lack of sufficient guidance to estimate the remaining life factor (1, 5, 8).

2.2 Mechanistic-Based Flexible Pavement Design Procedures

Most existing mechanistic-based design procedures use two types of analysis, mechanistic and empirical. The mechanistic analysis is typically based on a theory (e.g., the elastic theory, the viscoelastic theory) and the engineering properties of the paving material. The empirical analysis is based on observations of pavement performance correlated to one or more of the mechanistic behaviors of the pavement structures. Thus, the basic differences among existing mechanistic-based design procedures are:

1.   The type of theory employed in the mechanistic analysis.

2.   The empirical (statistical) models used to predict pavement performance or pavement life.

A proper pavement performance prediction model that yields reasonable engineering interpretations is typically based on the mechanistic responses (stresses, strains, and deflections) of the pavement structure due to a passing wheel load. The performance models can be obtained using two approaches, statistical and theoretical. The statistical approach consists of relating the calculated pavement mechanistic responses to the observed pavement distresses (These are called mechanistic-empirical models) (1). The theoretical

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approach, on the other hand, models the pavement structure and its boundary values, and the load related distresses (e.g., rutting and alligator cracking) using various available theories (1, 5). The main disadvantage of the theoretical approach is that it tends to be complicated and it requires substantial material and boundary value inputs that are not available or are not measured by most state highway agencies (SHAs). The main advantage of the mechanistic-empirical models, on the other hand, is that the required inputs are readily available in most SHAs. Hence, such models can be developed using data from the pavement management system (PMS) data bank that contains pavement distress data and the necessary material properties to calculate the mechanistic pavement responses.

For any pavement section, the mechanistic response due to an applied load cannot be determined unless data relative to the pavement section in question, the engineering properties of the paving materials, the environment, and loads are known. Unfortunately, some of these data are not available in most SHA files. Consequently, procedures need to be developed and adopted to determine the values of the necessary but missing data elements. Such procedures must be comprehensive in nature and must address the pavement structure as an integral structural system not as separate and independent layers.

Currently, mechanistic-based pavement performance prediction models have certain limitations. For example, no models are available where the pavement roughness, stripping, or raveling can be accurately predicted. Such models need to be developed based on the PMS distress data.

3.0   THE 1993 AASHTO FLEXIBLE PAVEMENT DESIGN PROCEDURE

The AASHTO pavement design method for flexible pavements is based on results obtained from the AASHO Road Test conducted in the late 1950's and early 1960's in northern Illinois. The method is purely empirical and relates pavement performance measurements and the loss of serviceability directly to traffic volume and loading characteristics, the soil support value (SSV) of the subgrade or roadbed soil[1], layer coefficients, and environmental factors that were present at the road test. The methods (design equations) have been

[1] The 1993 AASHTO design procedure replaced the soil support value (SSV) by the resilient modulus of the roadbed soil. The resilient modulus can be defined as the ratio of the applied repeated stress (cyclic stress) to the recoverable strain of the sample. Hence, the resilient modulus of a material is equivalent to its elastic modulus. The former is typically obtained using a repeated load (simulating traffic action) and the latter using a static load.

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generalized to make them applicable to broader sets of design variables (1, 5). Recently, the AASHTO design equations were enhanced to include design reliability, the resilient modulus[1] of the roadbed soil, material variability and drainability, and construction quality. Furthermore, the pavement performance limits can be adjusted for environmentally-induced losses of serviceability such as frost heave. It should be noted that the AASHTO design Guide expresses pavement performance in terms of the initial (after construction) and terminal Present Serviceability Indices (PSI).

The pavement structure can be designed by using two evaluation periods: a performance period and an analysis period. The performance period is that period of time between construction and the first rehabilitation (e.g., overlay). The analysis period may include several performance periods. Thus, the analysis period is either equal to or longer than the performance period. The proper use of the performance and analysis periods depends on the agency policy. For example, if the agency practice is to build pavements for a 20-year period and then overlay the pavement for another 8 years, then a performance period of 20 years and an analysis period of 28 years should be used. Otherwise, if the state practice is to reconstruct the pavement after the 20-year period, then *the performance and analysis periods should be set at 20 years.*

The working of the 1993 AASHTO design procedure can be summarized in two steps:

Step 1 - The Required Structural Number (SN) - In this step, the 1993 AASHTO main flexible pavement design equation (equation 1) is used to calculate the structural number (SN) of the pavement. According to the 1993 AASHTO Design Guide, the calculated structural number (SN) represents the structural capacity of the pavement that is required to protect the roadbed soil from damage due to the given traffic (ESAL). The form of the AASHTO equation is stated below. It can be seen that the required structural number (SN) of the AASHTO design procedure is affected by 5 variables: the number of ESALs, the design reliability, the standard deviation, the loss of serviceability, and the resilient modulus of the roadbed soils).

Equation 1

$$\log_{10}(ESAL) = Z_R * S_o + 9.36 * \log_{10}(SN+1) - 0.2 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log_{10} M_R - 8.07$$

where: $\log_{10}$ = base 10 logarithm;

ESAL = the number of total equivalent single axle load that is expected to travel the pavement in the specified design period;

Z_R = standard normal deviate corresponding to a selected level of reliability;

S_o = overall standard deviation;

ΔPSI = serviceability loss during the design period;

M_R = the resilient modulus of the roadbed soil (psi); and

SN = the required structural number of the pavement.

Step 2 - Layer Thicknesses - In this step, the AASHTO procedure uses the following equation to obtain the required layer thicknesses for the given SN from step 1.

$$SN = a_1D_1m_1 + a_2D_2m_2 + a_3D_3m_3 \qquad (2)$$

OR

$$SN = SN_1 + SN_2 + SN_3$$

where: a_1, a_2, and a_3 = the layer coefficients of the asphalt concrete, aggregate base, and subbase layers;

D_1, D_2, and D_3 = the thicknesses of the asphalt concrete, aggregate base, and subbase layers;

m_1, m_2, and m_3 = the drainage coefficients of the asphalt concrete, aggregate base, and subbase layers; and

SN_1, SN_2, and SN_3 = the structural numbers of the asphalt concrete, aggregate base, and subbase layers.

Thus, $SN_1 = a_1D_1m_1$; $SN_2 = a_2D_2m_2$;   and $SN_3 = a_3D_3m_3$

In a typical pavement design exercise, the pavement designer must know the values of the layer and drainage coefficients of each pavement layer; the thickness of each layer, however, is unknown. Since the equation has three unknowns (D_1, D_2, and D_3), the AASHTO procedure uses layer analysis in three substeps to calculate the thickness of each layer. The working of the three substeps is explained below.

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Substep 2.1 - The Thickness of the Asphalt Concrete (D_1) Layer - In this substep, the AASHTO procedure uses the main design equation (equation 1) where the resilient modulus of the roadbed soil is replaced by the resilient modulus of the aggregate base. This assumes that the aggregate base is the roadbed soil and the pavement consists of asphalt concrete (AC) layer only. Thus, the main equation produces the required structural number of the AC (SN_1) or ($a_1D_1m_1$) to protect the aggregate base from the given traffic. Knowing SN_1, the thickness of the AC (D_1) can be calculated.

Substep 2.2 - The Thickness of The Aggregate Base (D_2) Layer - In this substep, the AASHTO procedure uses the main design equation (equation 1) where the resilient modulus of the roadbed soil is replaced by the resilient modulus of the subbase layer. This assumes that the subbase layer is the roadbed soil and the pavement consists of AC and aggregate base layers. Thus, the main equation produces the required structural number of the AC and aggregate base layers ($SN_1 + SN_2$) or ($a_1D_1m_1 + a_2D_2m_2$) to protect the subbase layer from the given traffic. Knowing D_1 from the previous substep, the thickness of the aggregate base (D_2) can be calculated.

Substep 2.3 - The Thickness of The Subbase (D_3) Layer - In this substep, the AASHTO procedure uses the main design equation (equation 1) along with the value of the resilient modulus of the roadbed soil. The equation produces the required structural number ($SN = SN_1 + SN_2 + SN_3$) or ($a_1D_1m_1 + a_2D_2m_2 + a_3D_3m_3$) of the AC, aggregate base, and subbase layers that is needed to protect the roadbed soil from the given traffic. Knowing D_1 and D_2 from the previous two substeps, the thickness of the subbase layer (D_3) can be calculated.

For each pavement layer, the values of the resilient modulus and the layer coefficient are inputs into the AASHTO procedure. The AASHTO Design Guide provides several charts that correlate the values of the resilient modulus of each layer to the layer coefficient. In addition, the AASHTO guide provides the following three equations for the calculation of the layer coefficients.

For the AC layer: $\qquad a_1 = 0.4[\log_{10}(E_{AC}/435)] + 0.44$

For the aggregate base layer: $a_2 = 0.249[\log_{10}(E_{base})] - 0.977$

For the subbase layer: $a_3 = 0.227[\log_{10}(E_{subbase}) - 0.839$

where E_{AC} = the resilient modulus of the AC measured at 68°F (ksi);
    E_{base} = the resilient modulus of the base material (psi); and
    $E_{subbase}$ = the resilient modulus of the subbase material (psi).

Furthermore, the 1993 AASHTO Design Guide provides detailed guidelines relative to estimating the value of the drainage coefficient (m_i) of each layer based upon two pieces of information:

1.   A descriptive assessment (excellent, good, fair, poor, and very poor) of the quality of drainage of the layer. The assessment is based on the time it takes for water to drain out of the layer.

2.   The percent of time during the year that the layer in question or the pavement structure would normally be exposed to moisture levels approaching saturation (e.g., spring condition).

It should be noted that the value of the drainage coefficient (m_i) for conditions at the AASHO Road Test is 1.0, regardless of the type of material.

One very important observation must be noted: because of the mathematical nature of the structural number equation ($SN = a_1D_1m_1 + a_2D_2m_2 + a_3D_3m_3$), lower values of the drainage coefficient results in greater layer thickness. From the engineering point of view, the quality of drainage cannot be substituted by increasing layer thickness. The decision of whether or not to improve material drainability must be based on the cost and benefits of such improvement. The cost includes the higher cost of better material or the cost of installing edge drain. The benefits include better pavement performance, longer service life, and reduced user costs by decreasing the frequency of pavement closure due to maintenance and/or rehabilitation actions.

4.0   OBSERVATIONS REGARDING THE AASHTO DESIGN EQUATIONS

Although the 1993 ASHTO design procedure is empirical in nature and is easy to use, the

user (the pavement designer) must be very experienced and must possess very detailed knowledge regarding pavement performance and behavior. The reason is that the AASHTO design procedure often yields misleading results or conveys a misleading message. To aid the pavement designer, several observations regarding the use of the 1993 AASHTO design procedure are presented below.

The structure (the two steps presented in the previous section) and the working of the AASHTO design procedure have several very serious implications. These include:

1.   The total structural number (SN) of the pavement calculated by using the AASHTO main design equation (equation 1) is the SN required to protect the roadbed soil and to carry the traffic during the design period for a certain serviceability loss. That is, according to the AASHTO procedure, the required SN is independent of the properties of the pavement materials. Stated differently, the AASHTO procedure suggests that any pavement structure built using any equivalent combinations of materials and layer thicknesses will provide the same pavement performance over the design period provided that the SN of the pavement is the same as that determined by using equation 1. Unfortunately, field data from the State of Michigan and other states do not support this assumption.

        For example, it is well known that an asphalt concrete with 3 percent air voids will perform much better than the same mix but with 12 percent air voids (low compaction). The latter will most likely experience severe premature rutting, stripping, and raveling. The AASHTO procedure compensates for the high air voids by increasing the thickness of the AC. Experience dictates that such a solution is not reasonable and does not work.

2.   The AASHTO structural number equation and the working of the layer analysis to calculate layer thicknesses lead to the following:

        a)   An AC thickness that is independent of the type, quality, and drainability of the subbase layer and the roadbed soil. It depends on the traffic volume (number of ESAL), and the resilient modulus values of the aggregate base and AC layers.

        b)   A base thickness that is independent of the type and quality of the AC layer and the roadbed soil. It depends on the traffic volume and the resilient

modulus values of the subbase layer and the aggregate base and on the drainability of the aggregate base.

c)   A subbase thickness that is independent of the type and quality of the aggregate base and AC layers. It depends on the traffic volume, and on the resilient modulus of the subgrade and the modulus and drainability of the subbase layer.

3.   The AASHTO procedure suggests that the total structural number of any flexible pavement section is the sum of the structural numbers of its layers ($SN = SN_1 + SN_2 + SN_3$). For each layer, the structural number is simply the product of its thickness, layer coefficient, and drainage coefficient ($SN_i = a_i D_i m_i$). Thus, no interaction between the pavement layers is considered. Further, any pavement layer influences the layer directly above it. It does not affect the layer directly below it. The distribution of an axle load applied at the pavement surface to the lower layers is a function of the material thickness, stiffness, degree of saturation, and quality. For example, a truck could be driven on a dry roadbed soil without much difficulty. When the same roadbed soil is saturated (spring thaw), the wheel of the truck may penetrate the soil up to the axle regardless of the thickness of the roadbed soil. Similarly, a 4-inch thick and stiff asphalt concrete layer will spread the load to a much wider area than a 4-inch thick and soft asphalt concrete layer. Hence, the aggregate base under the former will be subjected to a lower stress than under the latter. The higher stress will result in a lower performance. Stated differently, the AASHTO design procedure treats the pavement layers as "equal but independent" entities rather than one integral system. Experience dictates that defects in lower layers are reflected through upper ones and that defects in the upper layers cause premature deterioration in the lower ones. The pavement designer must have substantial experience and must use engineering judgement to decide whether or not the AASHTO procedure is producing an adequate or an optimum pavement cross-section for the given cost.

To overcome this problem, several State Highway Agencies have established, for each traffic category or pavement class, a standard flexible pavement cross-section. Although standard cross-sections alleviated one problem, they created a much larger one. Since standard cross-section are based on the experience of those individuals who designed, constructed, and observed pavement performance over an extended period of time, the practice deprives new pavement engineers of the challenge of

engineering the pavements. Because new engineers are not adequately trained on the fundamentals and principles on which standard pavement cross-sections are established, the problem is compounded when the experienced individuals retire from the agency or when one of the fundamentals or principles change (e.g., new material).

4. As stated in equation 1, the AASHTO main design equation is written in terms of the expected 18-kips ESAL, design reliability and standard deviation, the serviceability loss, the required structural number (SN), and the resilient modulus of the roadbed soil. The value of the constant in front of the resilient modulus is "2.32". This value remains the same when the layer analysis (substeps 2.1 through 2.3) is carried out. That is the constant is equally applied to the resilient modulus of the aggregate base, sand subbase, and clay subgrade. Furthermore, if the subgrade material is drainable or not, the value of the constant does not change. For this reason, the AASHTO procedure will produce unreasonably large subbase thickness for a low value of the roadbed modulus. For example, for a roadbed modulus of 10 psi (practically water), the required thickness of the subbase is about 20-feet. Thus, the AASHTO method implies that pavement can be build on a 10-psi material. For such modulus value, a proper or rational design procedure should produce a warning not a 20-feet thick subbase.

    One important point that should be noted here is that the AASHTO flexible pavement design procedure is empirical in nature. Its inherent distress mode is serviceability (ride quality). Hence, the use of the AASHTO method to produce rut and fatigue cracking resistance pavements is problematic and costly. In general, when the ride quality of a pavement decreases, it could be restored using a low-cost fix. However, when the structure of the pavement is weakened (fatigue cracking or rutting), the options to restore the structural capacity are much more expensive. Thus, engineering common sense dictates that the pavements should be designed with adequate structural capacity to resist load-related distress such as fatigue cracking and rutting and then constructed to provide good ride quality.

5. Finally, the effect of the drainage coefficient on the total structural number is inadequate. For example, one can assign a drainage coefficient to the subbase of 0.8 and a drainage coefficient to the aggregate base of 1.2 or vice versa. In reality, the two values must be dependent. A saturated subbase layer will also cause full or partial saturation of the aggregate base. Thus, the pavement designer must be

aware of this issue because the AASHTO Design Guide does not provide any guidance relative to the assignment of the drainage coefficient. Finally, despite the AASHTO message that the problem of poor drainage can be resolved by using thicker layer, higher layer thickness is not and must not be taken as a solution for bad drainage.

Because of the nature of the AASHO Road Test experiment, the present AASHTO model contains *several deficiencies and limitations*. These include:

1.   The AASHTO model may be narrowly applicable to the northern Illinois climate and the specific subgrade and paving materials used at the AASHO Road Test.

2.   The AASHTO model is *based on an accelerated procedure for accumulating traffic*, which includes only two years of environmental effects in conjunction with several years of traffic load.

3.   The AASHTO model is based on the *ride quality* (roughness or serviceability) of the pavement surface. *The model does not address the structural capacity* of the pavement or its response to load.

4.   The AASHTO procedure cannot be used to estimate the potentials for rutting and fatigue cracking or other types of structural distress.

5.   The AASHTO model allows the substitution of good quality materials by inferior ones.

The above deficiencies and other problems associated with the implementation of the AASHTO flexible pavement design procedures have been recognized by State Highway Agencies (SHA). To overcome the problems, some SHAs adopted standard cross sections for flexible pavements based on past experience. Others developed roadbed soil catalogues to estimate the soil support value (SSV). Still others established pavement sections based on highway classification and the average daily truck traffic (ADTT). These actions resulted in a state-of-the-practice that is different from one SHA to another. The differences stem from the fact that the material properties used by the various states are different and that the pavements are subjected to different load and climatic conditions.

For overlays, the state-of-the-practice for most SHAs consists of assigning the thickness of

the flexible overlay based on experience and available resources. Recently, some agencies (including Arizona, California and Illinois) have adopted mechanistic-based procedures to determine the thickness of the overlays using nondestructive deflection test data. These agencies have also reported that mechanistic-based design of overlays has resulted in an increase in the pavement service life that precipitated a net decrease in pavement cost.

5.0   OTHER EMPIRICAL DESIGN METHODS

Since the AASHO Road Test, many pavement performance and distress prediction models have been developed for both flexible and rigid pavements and have been incorporated into various design models. Each model was developed by using specific pavement database and model development techniques and is, therefore, subject to limitations and is generally applicable only for specific conditions. The reason is that none of these models were developed on the basis of material properties and the mechanistic responses of the various pavement layers to the applied traffic load. To generalize pavement performance models, the observed pavement distresses must be directly related to the mechanistic responses of the various pavement layers due to a passing wheel load (1 to 16).

Regardless of the accuracy of the pavement performance model, the success of the pavement design can be better assured if the practice of designing pavements becomes a process rather than a set of fragmented procedures (e.g., asphalt mix design procedure, quality control procedure, etc.). This and other issues related to a balanced and comprehensive design process are addressed in the next section.

6.0   PAVEMENT DESIGN PROCEDURES AND PAVEMENT DESIGN PROCESS

The design of pavement structures can be accomplished using empirical and/or mechanistic-based design procedures. For each procedure, the material properties can be estimated and used to determine layer thicknesses. When the layer thicknesses are determined and the cost is estimated, the pavement design is considered complete.

The design of pavement structures can also be accomplished using empirical or mechanistic-based design process. For each process, the paving materials are evaluated and the relevant properties are forwarded to the design engineer. Based on the material properties, the layer thicknesses and cost are estimated. During construction, tests are

conducted to verify whether or not the as-constructed material properties and layer thicknesses are similar to those assumed in the design procedure. Historical pavement distress data is obtained and analyzed to ascertain the accuracy of the assumptions made in the design procedure. Finally, results of the analysis of the distress data are used to fine tune the pavement design procedure.

The above scenario implies that a good pavement design process must be based on a comprehensive understanding and knowledge of several factors including:

1. The engineering properties and variability of the paving materials.

2. Accurate estimates of the traffic volume and load expected to use the pavement section in question during its design service life.

3. Future actions to be taken regarding the maintenance and rehabilitation of the pavement structure.

4. Accurate cost data relative to pavement material, construction, traffic control, and user costs.

5. Existing specifications and standards concerning the as-constructed pavement layers.

6. Quality control procedures and their role in maintaining the integrity of the assumed design values.

7. The asphalt mix design procedures and their role and/or inputs into the design process.

8. Past, present, and future pavement performance trends.

9. The material response to traffic load during the various seasons.

10. The availability of the various materials used in the design process.

11. The effect of additives (e.g., polymer, crumb rubber) on pavement performance and its rate of deterioration.

The understanding of these factors and their roles in pavement performance make the design of a pavement structure a comprehensive process with a well-established feedback system. Figure 3.2 depicts such a comprehensive process. It can be seen that the pavement design engineer or the pavement design office must have access to various types of information. Each item of this information affects the pavement performance and the quality of the pavement design process. These and other issues are discussed below.

In reference to figure 3.2, six of the boxes are numbered 1 to 6. Each of these boxes are listed in table 3.1 under the column titled box number. The next column "type of data" provides the same information as that listed in the corresponding box of figure 3.2. Justifications relative to the need of the data in a comprehensive pavement design process are provided in the next column. The remaining two columns list the average national practice and corrective actions. For example, the corrective actions relative to traffic data are:

1.   Periodically check and calibrate the ADT and the percent commercial traffic.

2.   Establish new values of the ESAL factors based on WIM, and truck classification data to be collected at the network level.

Finally, for most state highway agencies, a good portion of the types of physical property data presented in figure 3.2 and table 3.1 are mainly available (either on hard copy or in files) in various offices. The data needs to be made accessible to all employees so that managers, engineers, and technicians will be well informed to make the proper decisions.
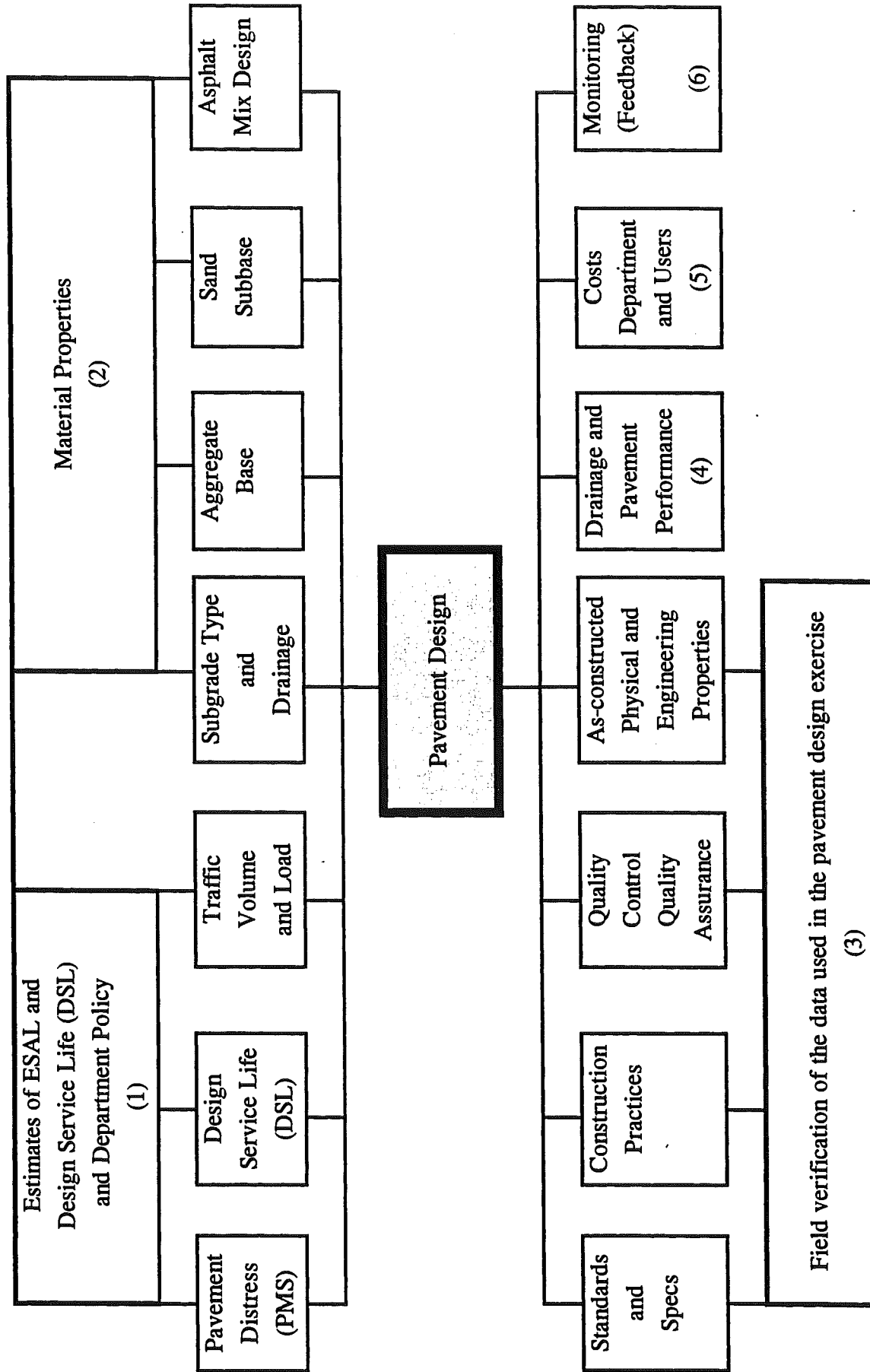
Figure 3.2. A comprehensive pavement design process.

Table 3.1. A comprehensive pavement design process, national practice, and corrective actions.

Box number	Type of Data	Justification of the Comprehensive Design Process	Average National Practice	Corrective Actions
1	Estimates of ESAL	Roads are not designed and constructed to last a certain number of years. They are designed for a certain number of repetitions of an Equivalent 18-kip Single Axle Load (ESAL). Hence, accurate traffic forecasting is crucial to the building of good quality roads.	Traffic data in terms of the Average Daily Traffic (ADT), Average truck daily traffic (ATDT) or percent commercial. The ESAL factor is obtained based on annual growth factor and estimates or WIM data when available.	Check the data (ADT and percent commercial) periodically to assure its accuracy. Establish new values of the ESAL factors based on WIM, and truck classification data to be collected at the network level.
	Estimates of design service life (DSL)	An estimate of the DSL is needed to calculate the total expected ESAL.	Fifteen to twenty years design life is assumed for flexible pavements.	Calibrate the DSL using the pavement distress data of the PMS.
	Estimates of the analysis period (AP)	An AP may include the DSL and the service life of one or more future overlays. AN Estimate of the AP is needed to calculate the expected ESAL.	For new and reconstructed pavements, use both performance and analysis periods.	Include two overlay cycles. Use DSL of 20 and a pavement analysis period of 40 years.
2	Material properties	The physical and engineering properties of the subgrade and paving materials must be known for accurate estimates of the material response to loads.	Material properties are assumed without testing or feedback.	Establish material evaluation procedures. Obtain the values prior to pavement design.

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Table 3.1. A comprehensive pavement design process, national practice, and corrective actions (continued).

Box number	Type of Data	Justification of the Comprehensive Design Process	Michigan Practice	Corrective Actions
3	Field verification of the data used in the pavement design exercise.	Standards, specifications, and QC/QA are designed to assure long-term pavement performance and to verify the assumptions made during the pavement design exercise.	Existing standards, specifications, and QC/QA do not fully address pavement performance or the pavement design assumptions.	Modify the existing practice to address pavement performance and design assumptions by obtaining the as-constructed properties.
4	Drainage	The existence or lack of proper drainage adversely affects pavement performance and design life.	All pavement materials have not been characterized by drainage coefficients.	Establish a standard regarding drainability of the material or drainage installation.
5	Costs	Accurate cost data (agency and user costs) are crucial to the evaluation of the cost and benefits of design alternatives.	Life cycle cost analysis is conducted. The benefits are based on the assumed DSL.	Establish a data bank concerning user cost and the cost of routine and preventive maintenance.
6	Monitoring	After construction, monitoring (distress) data are essential feedback that is needed for the calibration of the design practice and pavement performance models.	Monitoring data is collected but it has not been incorporated into pavement design.	Use the distress data to check whether or not the assumed DSL is accurate.

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CHAPTER 4

EVALUATION OF MICHIGAN PRACTICE REGARDING THE DESIGN OF FLEXIBLE PAVEMENTS AND FLEXIBLE OVERLAYS

1.0 BACKGROUND

During the year 1995, the Pavement Research Center of Excellence (PRCE) was established at Michigan State University with an office at the University of Michigan. The objective of the PRCE is to unify the state resources to solve problems related to the design, construction, maintenance, and rehabilitation of the highway network.

One of the PRCE approved projects is to work with MDOT to examine the existing flexible pavement design process and to develop an implementation plan to convert to a mechanistic-based design process.

During the project, various meetings with pavement design engineers and members of the Technical Advisory Group (TAG) were held. These meetings contributed to building a shared sense of understanding of the existing design process and helped the center personnel to think more explicitly about the expectations and accomplishments that are needed to solidify the pavement design process. The expectations include:

1. Intensifying the partnership between MDOT, academia, and industry.

2. Strengthening the technical capabilities of MDOT and contractors.

3. Expanding options into knowledge that makes differences to the economy of highway building and delivers a better ride quality to the users.

In order to draw a balanced plan for the implementation of mechanistic-based processes for the design of flexible pavements and flexible overlays, the MDOT pavement design practice and the existing flexible pavement design procedures were reviewed and are presented in this chapter.

2.0 MICHIGAN PAVEMENT SELECTION PRACTICE

Any project with pavement costs exceeding $1 million must follow the department's Life Cycle Cost Analysis (LCCA) policy to determine the pavement with the least life cycle cost. Pavement costs are defined as the cost of those pavement structure items above the subgrade elevation. Two MDOT publications have been developed to describe the procedure for

conducting LCCA. One method is used for new or reconstructed pavements; the other is for major rehabilitation with design service life (DSL) of ten or more years. Both procedures include a prescribed "maintenance schedule" for required preventive maintenance activities over the estimated DSL.

In LCCA, the time period to use for the pavement life has been equated to the analysis period which is 35 years for newly constructed or reconstructed pavements, and 20 years for major rehabilitation. An ongoing debate, regarding the length of the analysis period in terms of what pavement condition signal the termination of the pavement life, has existed since LCCA began.

The tasks and responsible groups involved in the LCCA process are described in figure 4.1. The responsibilities are divided among several divisions in the department's Bureaus of Highways. The overall responsibility of coordinating the LCCA process, as well as overseeing general pavement policy, is vested in the department's Pavement Selection Review Committee (PSRC). The PSRC is an official subcommittee of the Engineering Operation Committee (EOC) which decides all technical highway policy matters of MDOT.

The PSRC represents all pavement disciplines in the department, including a representative from each District. The committee approves all pavement design for any new or major reconstruction project. Its purpose is to promote uniformity in the application of proper methodology and standards across the state. An open discussion forum is maintained to encourage "new" approaches to pavement design and fix selection for rehabilitation needs. With the AASHTO Guide evolving toward a more mechanistic method, the committee has debated the need for the department to adopt such a methodology. The current project to develop an implementation plan for mechanistic design (presented in chapter 5 of this report) was created to resolve the question of whether or not to change.

In order to resolve the question of whether or not MDOT should adopt mechanistic-based design process, a review of the existing flexible pavement design and flexible overlay design procedures was made. First, a summary of the MDOT flexible pavement design and flexible overlay design practices is presented in sections 3.0 and 4.0 below. Relevant observations made during the review of MDOT practices are presented in section 5.0.

3.0   THE MDOT FLEXIBLE PAVEMENT DESIGN PRACTICE

As previously stated, the AASHTO 1993 software (DARWIN) for the design of flexible and rigid pavements was recently installed on PCs in all MDOT's Districts and in Lansing office.
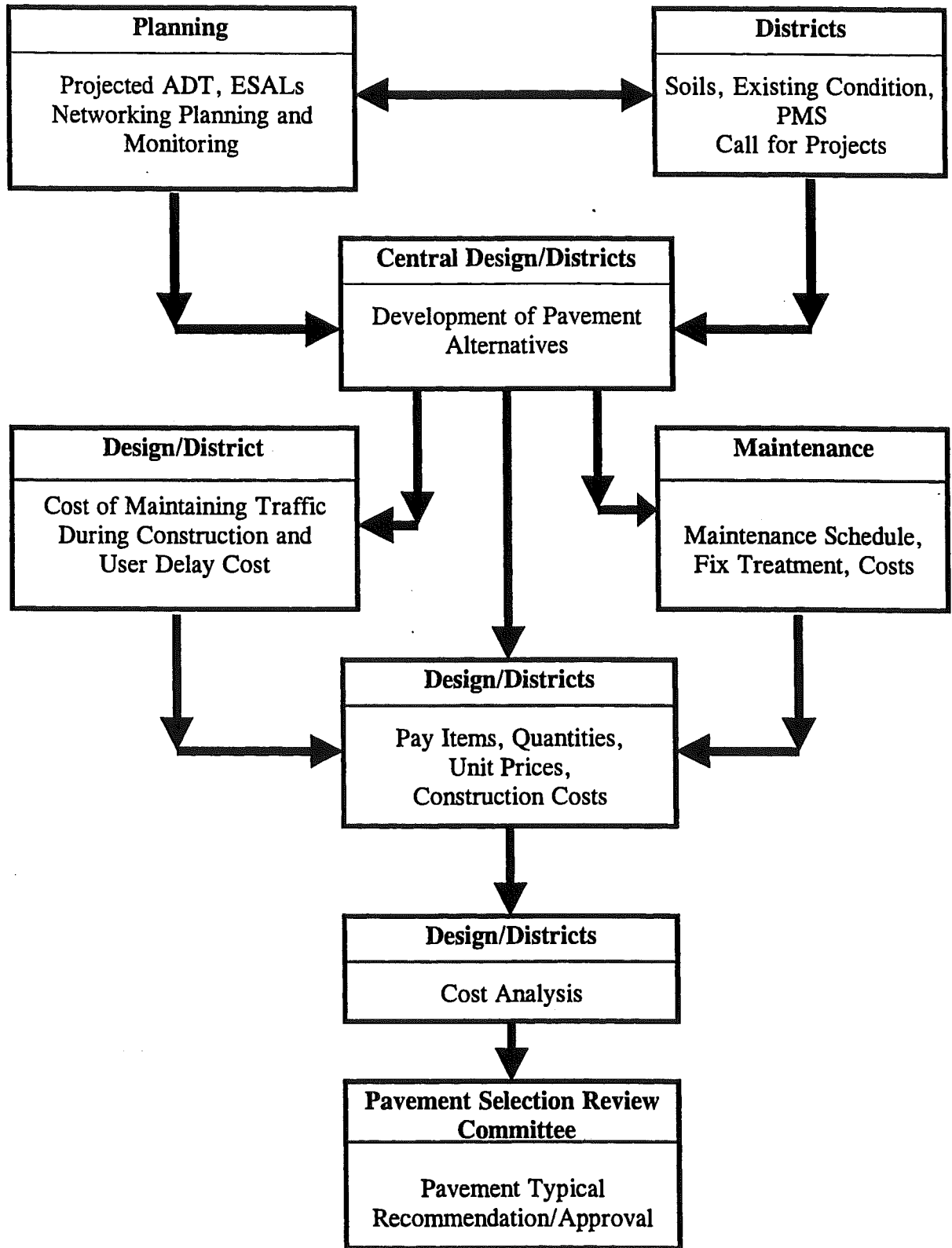
Figure 4.1   Tasks and responsibility in life-cycle cost.

However, some districts still use older versions of the AASHTO Design Guide. During the pavement design phase, many values of the required inputs are assumed or assigned certain values. These include the properties of the subgrade and paving materials (sand subbase, aggregate base, and asphalt concrete), and the drainage coefficients. A summary of this practice is provided below.

3.1   Roadbed Soil

The pedological soil classification system (developed on the basis of correlating soil series with experience and construction practices) is the foundation used in estimating the resilient modulus of the roadbed soil. First, the pedological soil classifications were used as a basis to develop standard pavement cross-sections. A soil support value scale was then developed for use with older versions of the AASHTO Design method. Later, correlation between the soil support value and the resilient modulus was developed and is shown in figure 4.2. In the existing pavement design practice, the resilient modulus of the roadbed soil (subgrade) is assigned a range of values compatible to figure 4.2.

3.2   Sand Subbase

The resilient modulus and thickness of the sand subbase are assigned on the basis of experience and to provide adequate protection of the roadbed soil against frost. The sand subbase is assigned a resilient modulus value of about 13,700 psi (an AASHTO layer coefficient of 0.1), a thickness of about 18-inch, and a drainage coefficient of 1.0.. Thus, the Michigan practice assumes the structural number of the sand subbase of 1.8 ($SN_3 = a_3 * D_3 * m_3 = 0.1 * 18 * 1 = 1.8$).

The 18-inch sand subbase provides the necessary protection of clay subgrade against frost penetration and it is not required when the roadbed soil consists mainly of sand or other well drained soil

3.3   Aggregate Base

The resilient modulus, thickness, and drainage coefficient of the aggregate base are assumed as 30,000 psi (an AASHTO layer coefficient of 0.14), 6 inches, and 1.0, respectively. This implies that the assumed structural number of the aggregate base layer is 0.84 ($SN_2 = a_2 * D_2 * m_2 = 0.14 * 6 * 1 = 0.84$). According to the AASHTO design procedure, the thickness of the asphalt layer is significantly affected by the value of the resilient modulus of the aggregate base. Therefore, the modulus of the aggregate base impacts the overall cost of the pavement.
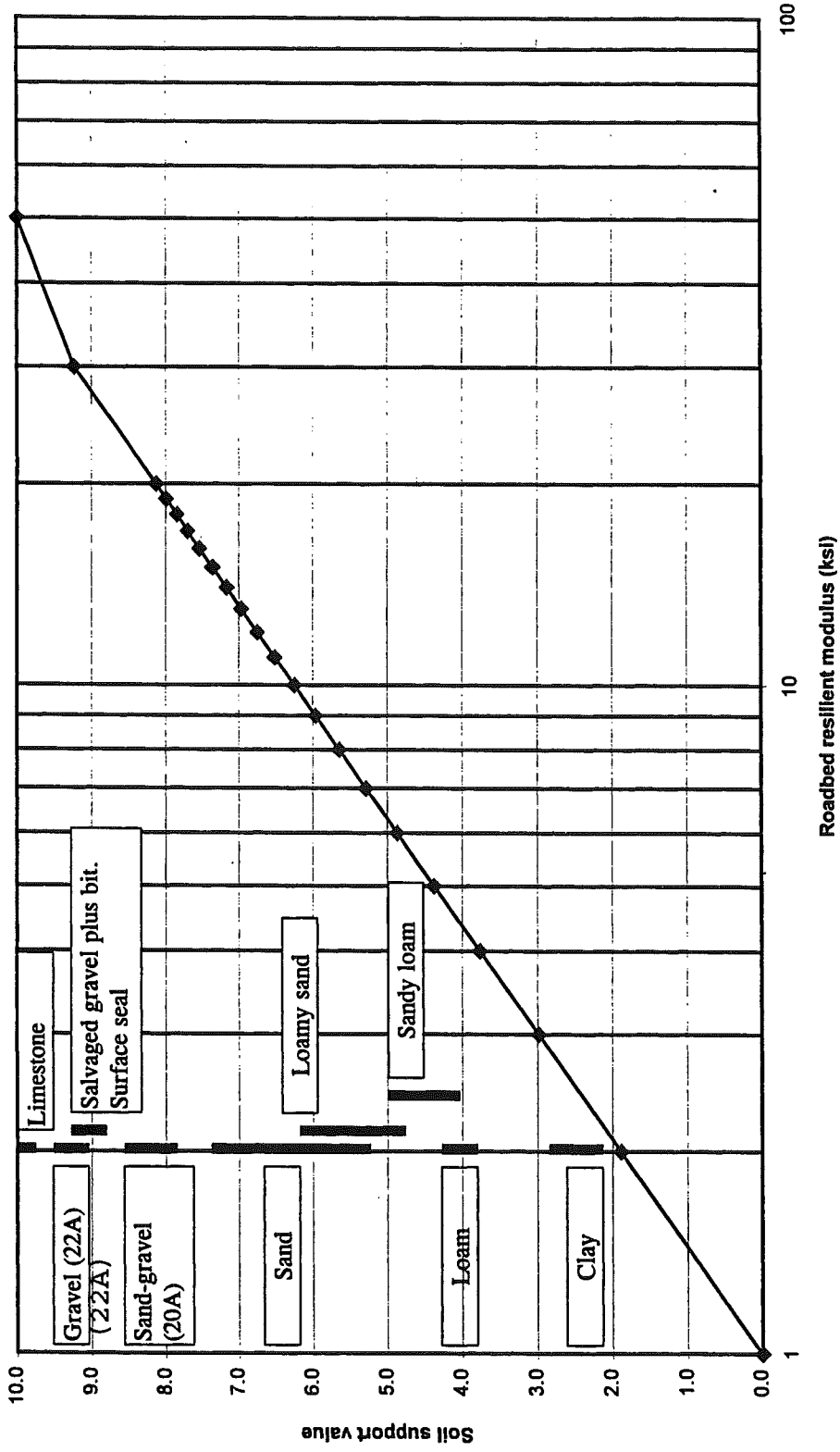
Figure 4.2. Soil support value versus resilient modulus for various roadbed soils.

Table 4.1. MDOT specifications regarding asphalt concrete materials.

Mixture Number	2B	2C	3B	3C	4B	4C	13	13A	11A	36A
VMA, minimum (%)	13.5	13.5	15	15	16	16	15.5	15.5	13.5	16.5
Air voids (%) Target	3	3	3.5	3.5	3.5	3.5	3	3	3	3
Fines/Binder Ratio maximum	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Fine aggregate Angularity, minimum	3	4	3	4	3	4	2	2.5	2.5	3
Flow (mm)	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0
L.A. Abrasion maximum loss (%)	40	40	40	40	40	40	40	40	50	40
Soft particles Maximum (%)	12	12	12	12	8	8	8	8	12	8
Stability (kN), Min.	5.3	5.3	5.3	5.3	5.3	5.3	4.0	4.0	4.0	4.0

3.4 Asphalt Concrete

The resilient modulus of compacted AC materials is a function of several variables including the aggregate gradation and nominal size, the grade (viscosity) of the asphalt binder, the asphalt content, the voids in mineral aggregate (VMA), the percent air voids in the compacted mix, the aggregate angularity, and temperature. Thus, different asphalt mixes will likely have different resilient modulus values. For example, relative to MDOT practice, the ten standard AC mixes listed in table 4.1 would likely have different modulus values and so the new Superpave mixes.

In Michigan asphalt pavement design practice, the asphalt concrete (AC) layer is subdivided into three courses: surface, leveling, and base.

a)   The AC Surface Course - The thickness and modulus of the AC surface course are assigned as 1.5 inches and 390,000 psi (an AASHTO layer coefficient of 0.42). While a 1.5 inch thick surface course is logical and consistent with the function of the surface course, the value of the modulus may not be representative. This value is used for all types of AC mixes for the asphalt course. The pavement design practice can be substantially enhanced if the modulus of each asphalt mix used as a surface course is evaluated and tabulated.

b)   The AC Leveling Course - Similarly, the thickness and modulus of the AC leveling course are assigned as 2.5 inches and 390,000 psi (an AASHTO layer coefficient of 0.42). While a 2.5-inch thick leveling course is logical and consistent with the function of the leveling course, the value of the modulus may not be representative for the same reasons stated above.

c)   The AC Base Course - The modulus of the AC base course is assigned a value of 275,000 psi (an AASHTO layer coefficient of 0.36). The required thickness of the base course is determined using the AASHTO software (DARWIN) for the design of flexible and rigid pavements.

3.5 Drainage Coefficients

The values of the drainage coefficients of the asphalt concrete (surface, leveling, and base courses), aggregate base, and sand subbase are assigned a value of 1.0. According to the AASHTO Design Guide, this value represents the conditions at the AASHO Road Test conducted in Ottawa, Illinois. Such conditions include the silt subgrade soil that had low permeability and high water holding capacity and

therefore, it was a highly frost-susceptible soil. In some areas in the state of Michigan and for some roads, the drainage conditions are good to excellent and much better than those encountered at the AASHO Road Test. Therefore, drainage coefficient values higher than 1.0 should be used. The reasons that the drainage coefficient is assigned a unit value for flexible pavements are that the value was used at the AASHO Road Test and that MDOT lacks a comprehensive program to evaluate the pavement materials.

3.6 Traffic

For design purposes, the traffic count in terms of 18-kip ESAL is estimated or calculated using the information presented in the latest published sufficiency-rating book or from traffic maps. The information can be found in terms of:

- The average daily traffic (ADT).
- The percent commercial (the number of trucks and truck-trailer expressed as percent of the ADT).
- The weighted average ESAL factor (when WIM data is available, the ESAL factor is calculated based on the weight data) For flexible pavements, the value may vary from 0.58 to 0.7 depending on the specific road location.
- An annual growth rate

It should be noted that the ESAL factor expresses the damage delivered to the pavement by each passing commercial vehicle relative to the standard 18-kip equivalent single axle load (ESAL). For example, an average ESAL factor of 0.65 implies that each commercial vehicle delivers to the pavement section 65 percent of the damage delivered by the standard 18-kip ESAL. Given the make-up of the commercial fleet in the State of Michigan, the ESAL factor is different from one class of vehicle to another.

4.0 THE MDOT FLEXIBLE OVERLAY DESIGN PRACTICE

The MDOT's practice relative to the thickness design of flexible overlay starts at the project development (project scoping) level. For completeness and benefit to the reader, the MDOT's project scoping process is summarized in Appendix A of this report.

The type of fix (overlay or other) is determined during the third step of the scoping process (after driving the pavements of the candidate projects). The selection of fix type can be dictated by two factors: available resources and improvement.

1.   Available Resources - Although, for many projects, an overlay is not the best fix

option, it could be selected because:

a)   The available resources are insufficient for the support of the best option.
b)   It is estimated that reconstruction of the project could be programmed, approved and budgeted within 6 to 10 years.

Hence, for some scenario, the main function of the overlay is to hold the project for several years until reconstruction can be programmed or additional resources can be secured.

2.   Improvement - Because of capacity, the project could be scheduled for improvement such as widening in the near future. Here again, the function of the overlay is to hold the project for several years.

During the third step of the scoping process, if an overlay is the selected fix type, the thickness of the overlay is determined. While determining the thickness of the overlay, the engineers (the scoping team) typically consider several factors including:

1.   The pavement class and the traffic level relative to the capacity of the pavement structure.

2.   Available budget.

3.   The pavement conditions including pavement distress data, ride quality index, rut depth, and for some projects, friction data.

4.   The estimated life of the fix.

5.   Subsequent to the interview, non-preventive maintenance overlays are designed using Darwin software and LCC analysis.

Recently, some districts/regions are requesting that the MDOT's Falling Weight Deflectometer (FWD) be used to conduct nondestructive deflection tests (NDT) along the candidate projects, and the deflection data be analyzed to determine the structural capacity and/or the properties of the existing pavement. Based on the results, the selection of the thickness of the flexible overlay is made. Such use of the FWD data however, is very much limited to a few districts and a few projects within those districts. Currently, no policy can be found regarding the use of the NDT for overlay or other purposes.

It should be noted that the MDOT has authorized the Pavement Research Center of Excellence (PRCE) to develop software for the mechanistic-based design of asphalt overlays. It is expected that the new computer program will be operational for testing by

late 1998 or early 1999. The software will be a part of the pavement analysis package which will include mechanistic- and AASHTO-based design and analysis of flexible pavements, analysis of the deflection data to determine the properties (resilient moduli) of the various pavement layers, and mechanistic-based design of asphalt overlays. The new software will be used friendly and will operate in Windows^c environment.

5.0 OBSERVATIONS REGARDING THE MDOT FLEXIBLE PAVEMENT DESIGN PRACTICE

It should be noted that, although MDOT uses a modified version of the AASHTO procedure for design of flexible pavements, the procedure does not address the pavement performance or its life. During their last meeting, members of the AASHTO Committee on pavement design discussed this problem and the shortcomings of the AASHTO design procedure and established the year 2002 as a target date to convert the AASHTO Design Guide to mechanistic-based procedures. The National Cooperative Highway Research Program (NCHRP) issued a funded research statement to accomplish the conversion. The study started in 1996.

As stated earlier, the Michigan Department of Transportation practice regarding the design of flexible pavements was carefully reviewed. The review process focused on a number of specific issues including:

1. The impact of the existing design practice on flexible pavement performance and total quality.

2. The cost of any desired improvement, modification, or changes of the existing pavement design practice.

3. The effects of any desired improvement on the existing technical capability of MDOT.

4. The impact of the design practice on inter- and intra-department communications (e.g., industry, and other divisions within MDOT).

5. The potential of changing the current design procedures to a comprehensive and exhaustive design process and the costs and benefits of such change.

6. The role of the pavement industry in the existing practice and in any desired improvement.

Results of the review indicated that:

1. Recently, the inconsistency in the flexible pavement design practice within MDOT has been resolved by installing the AASHTO 1993 software (DARWIN) for the design of flexible and rigid pavements on PCs in all MDOT's design offices.

2. The existing flexible pavement design process consists of several procedures such as pavement design procedure, material characterization procedure, asphalt mix design procedure, quality control procedure etc. Unfortunately, these procedures do not fully relate to each other or to the quality of the final products. For example, the quality control measures may relate to the average pavement performance. However, they do not verify the material properties (modulus and layer coefficient) assumed during the pavement design procedure. Likewise, the asphalt mix design procedure does not fully relate to pavement design.

3. MDOT lacks material characterization procedures whereby the engineering properties of the material needed in the design procedure can be measured. In lieu of this, the pavement design engineers make several assumptions regarding material properties without a due verification or feedback process.

4. The lack of material characterization procedures negates the purpose of some of the existing standard specifications. For example, table 4.1 provides the MDOT specifications relative to the asphalt concrete materials. It can be seen from the table that 10 different mixes are specified. Each mix has certain physical properties (e.g., voids in mineral aggregate (VMA), fine aggregate angularity, air voids, stability, etc.). The reason for the varieties of mixes is that they have different performance properties and only certain mixes are allowed on roads with certain classifications and traffic level. Since the mechanistic properties of the 10 mixes are neither specified and/or obtained, all mixes are assumed to have the same properties. This implicitly implies that all mixes provide the same performance.

5. The properties of the various pavement layers (AC, aggregate base, and sand subbase, and the roadbed soil) are typically assigned during the pavement design phase which takes place 6 to 12 months before the asphalt mix design is established. Although such lead time is given, the asphalt mix design procedure does not include the verification of whether or not the recommended asphalt mix satisfies the assumed properties.

6. The AASHTO design procedure (see chapter 3 of this report) yields the required total structural number (SN) which will support the traffic and protect the roadbed soil from damage. As stated in chapter 3, the total SN is the sum of the structural numbers of all layers ($SN = SN_1 + SN_2 + SN_3$). MDOT's design practice

assigns between 35 to 50 percent of this number to the sand subbase ($SN_3 = 1.8$) and about 15 to 20 percent to the aggregate base ($SN_2 = 0.84$). Once again, the reason for such assignment is to provide the proper subgrade protection against frost damage.

6.0 RECOMMENDATIONS

Based on the analysis of the existing pavement design, asphalt mix design, and quality-control procedures of MDOT, and on the inputs of various engineers, technicians, and managers from MDOT and the PRCE, it is strongly recommended that:

The various flexible pavement design procedures and the design of asphalt overlays used by MDOT be consolidated into a comprehensive and unified process. The main objective of the new process would be to optimize the life and performance of the pavement and to minimize the life cycle costs.

The recommended pavement design process would be based on mechanistic principles, the forecasting of the total design ESAL, and on the measured engineering properties of the materials. The specific recommendations regarding material properties and ESAL forecasting are:

1. Since the resilient modulus of the roadbed soil plays a critical role in the AASHTO design procedure (it impacts the required pavement structural number and hence, layer thicknesses), it is strongly recommended that *the assumed resilient modulus values be verified by using nondestructive deflection test data.*

2. The assumed values of the drainage coefficient and the resilient modulus of the sand subbase play a critical role in determining the thicknesses of the sand subbase and the aggregate base layers. Therefore, it is strongly recommended that tests be conducted to verify the assumed values. Nondestructive deflection and drainability tests can be conducted to obtain the resilient modulus and the drainage coefficient, respectively.

3. The value of the layer coefficient of the aggregate base has a significant impact on the thickness of the asphalt concrete and hence on cost. Therefore, it is recommended that the assumed layer coefficient values be verified using the appropriate test methods (nondestructive deflection tests or laboratory tests).

5. Although the pavement is designed to provide services for a certain number of years prior to rehabilitation, it is actually designed to serve a certain number of 18-kip ESAL before rehabilitation action is required. Therefore, it is

recommended that *the ESAL factor be estimated on the basis of WIM data, the class of the commercial vehicle, and damage models.* Presently, for some segments of the network, both weigh-in-motion and truck class data are available in the Planning Bureau of MDOT. The crucial part of the estimation of the ESAL factor is the damage model to be used. The AASHTO Load Equivalency Factor (LEF) is based on the relative damage of each truck with respect to pavement roughness (ride quality). Even if one assumes that the AASHTO LEF factors are accurate and applicable to the truck fleet operating in the State of Michigan, the factors cannot be used to estimate the equivalent damage relative to rut or fatigue (alligator) cracking. Therefore, rut and fatigue damage models should be developed on the basis of the PMS distress data. Such models can be used to determine the optimum ESAL factor to be used in the flexible pavement design practice.

The recommended flexible pavement design process was presented to members of the Michigan Asphalt Paving Association (MAPA). A plan for the implementation of the recommended process is presented in Chapter 5. The components and objectives of the recommended design process are presented in the next two sections.

7.0   OBJECTIVES OF THE RECOMMENDED MECHANISTIC-BASED DESIGN PROCESS

The objectives of the recommended mechanistic-based process for the design of flexible pavements and overlays include:

1.   Standardizing and unifying the MDOT practice regarding the design of flexible pavements and flexible overlays.

2.   Measuring and cataloging the engineering properties of the roadbed soils and the paving materials.

3.   Enhancing pavement management.

4.   Improving the technical capabilities of MDOT.

These objectives are detailed below.

7.1   Standardizing and Unifying the MDOT Practice

Unlike the existing practice, the recommended mechanistic-based design processes, when

fully implemented, will provide for consistent flexible pavement and flexible overlay designs throughout the state. The processes will be based on the following goal:

Optimize the pavement life and performance and provide the highest level of services to the taxpayers at the minimum life cycle cost.

The standardization of the pavement design practice should allow the pavement design engineers in the various districts (regions) to compare notes and to share their experiences and the decision-makers to make better decisions regarding asset management.

7.2   Engineering Properties

The process would include the documentation of the layer thicknesses *(inventory data)* and the engineering properties of the various types of subgrade and paving materials and their variations with season and temperatures. This objective can be accomplished by using destructive tests (coring, sampling and lab testing) and nondestructive deflection tests using the FWD. The inventory data allow MDOT's personnel to know and understand the various elements of the transportation infrastructure asset. This should lead to a more accurate decision making process regarding asset management. The availability of the engineering properties of the subgrade and paving materials should allow the engineers to assess the impact of the properties on the pavement performance. This should lead to better engineering decisions.

7.3   Enhanced Pavement Management

The new design process will be a part of pavement management. The cross-examination of the pavement design against the pavement performance data should allow engineers and managers to make better decisions to modify the design practice to select the proper timing and location (space), of fix actions (rehabilitation, preservation, and preventive maintenance) to be taken on a certain road segment.

7.4   Improving Technical and Engineering Capabilities

Because of its nature (mechanistic-based process), the implementation of the recommended design processes will require and lead to an increase in the technical expertise of MDOT. The understanding of the true pavement responses to load and environmental factors and their influence on pavement performance will allow engineers, managers, and contractors to

improve their understanding of the impacts of their decisions, practices, and material selection on pavement life, pavement performance, and pavement costs. Achieving an increased technical capability will likely require reorganization of staff. For example, a pavement design group or committee could be created where material, design, pavement, research, construction, and other specialties are represented in the group. This should allow sharing the information in a comprehensive manner and discussing the impacts of one action upon the others.

7.5   Total Quality Team Work

The recommended design process will be based on the real engineering properties of the material and the observed pavement performance. The process should provide a wealth of information to engineers, managers, and contractors. Hence, the process will be instrumental in accelerating the implementation of the principles of teamwork, partnering, and total quality. The new flexible pavement and flexible overlay design processes will likely enhance pavement quality and may provide better services to the pavement users at a maximum possible benefit to cost ratio. Further, the new processes will be an integral part of pavement management, which is a part of the overall asset management.

8.0   COMPONENTS OF A MECHANISTIC-BASED DESIGN PROCESS

A comprehensive mechanistic-based process for the design of flexible pavements and flexible overlays consists of three components; education and training, information, and procedures. These three components are shown in figure 4.3 and are discussed below.

8.1   Education and Training

This component consists of learning the fundamentals of mechanistic principles by sponsoring and holding seminars, short courses, on-site training, and annual meetings. The participants of the seminars and short courses will be drawn from the various regions/ districts, transportation centers, the MDOT's Lansing Office, and the industry. The purposes of these short courses and seminars would include:

1.   Presenting and discussing state-of-the-art knowledge of the mechanistic-based design process.

2.   Generating conversation among the participants to share their experience and to seek solutions to their problems.

3.   Enhancing partnering between MDOT, industry and academia.

The on-site training will involve training of personnel on the use of the design procedures and the impact of the accuracy and variability of each piece of information on the pavement performance. For example, on-site training may involve the training of engineers and technicians drawn from both MDOT and the industry on the use of the design software such as MICHPAVE and MICHBACK.

As is in the current practice, the main purpose of the annual meetings is for sharing experience. For example, if a one-day annual meeting of the PDE from the various districts is held, the PDE will share their experiences. One district will learn from the experiences of another districts. Similarly, during the annual meeting of the PMS engineers, the pros and cons of the present reporting of the PMS data can be discussed and the system could be fine-tuned to provide better pavements.

Finally, education does not end by attending one seminar or one short course. Follow-up and updating the existing learning is an avenue that must be individually and collectively taken in order to advance the state-of-knowledge. The mechanism and partial funding for the educational component of the mechanistic-based design process is already in place. Researchers and faculty of the Pavement Research Center of Excellence (PRCE) would be heavily involved in this component. Other speakers/lecturers could also be invited to enhance the educational component.

8.2   Information

Complete, relevant, and accurate information forms the essential background on which decisions are made. Any design and/or management decision made on false and inaccurate or incomplete information is an arbitrary and potentially costly decision. Thus, a cost-effective design process must be based on several types of essential information including:

- Inventory data
- Material characteristics
- Standards and specifications
- PMS implementation and feedback

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COMPONENTS OF A MECHANISTIC-BASED DESIGN PROCESS

Procedures

- Design procedures

  - MICHPAVE
  - MICHBACK

- QC/QA procedures
- Construction

Information

- Inventory data
- Material characteristics
- Traffic data
- Standards and specifications
- PMS implementation
- Feedback
- Existing pavement (FWD)

Education and Training

- Seminars
- Short courses
- On-site training
- Annual meetings

- Updating

Figure 4.3. Components of a mechanistic-based design process.

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8.2.1 Inventory Data

This includes all data relative to the existing physical asset (network) including the as-constructed cross-section, material, geometry, and age. Currently, for the majority of the pavement network, such data may exist on paper or on microfiche and are not easily accessible. Pavement inventory data should be included in the PMS data bank. Summer helpers and temporaries could extract such data from its existing paper files, organize the data and store it in computer files that are compatible with the existing PMS data bank.

8.2.2 Material Characterization

For existing pavements, the falling weight deflectometer (FWD) would be utilized at the network level to determine the engineering properties required for the design of the thicknesses of the various pavement layers and the overlays. During the testing program, the pavement cross-section (layer thicknesses) would be verified (a check for the inventory data). The information can be summarized on a state map (similar to a traffic map) where the properties of the roadbed soil and the pavement cross-section data will be stated. The data can be used for the mechanistic design of overlay or new pavement.

For new pavements, laboratory tests would be conducted to measure the physical and engineering properties of the materials. The tested materials should include the subgrade soil, the subbase and base materials, and the compacted AC mixtures. In addition to the existing practice, properties such as the resilient modulus, plastic flow, and permeability should be determined.

8.2.3 Standards and Specifications

Standards and specifications regarding the as-constructed engineering properties for various asphalt mixes would be developed. As shown in table 4.3, current specifications address only the physical properties of the mixes. Two additional sets of specifications should be developed. These will specify the range of the resilient modulus of each mix and the as-constructed peak pavement deflection. The value of the resilient modulus is needed as input into the mechanistic-based design process and into the AASHTO design procedure. Deflections represent the pavement global (AC, aggregate base and subbase, and roadbed soil) mechanistic responses under loads and

can be calculated during the pavement design process. Hence, the main objective of the new specifications is to assure that the as-constructed pavement responses are similar to those calculated during the design process.

8.2.4 PMS Implementation

A complete PMS implementation would help MDOT achieve better and more cost-effective asset management. For example, the yearly call for projects and the determination of the optimum fix alternative should include consideration of the existing pavement conditions and the rate of deterioration. Such information can be found in the PMS data bank. Hence, the implementation of the PMS operation helps pavement engineers arrive at better and more balanced decisions. This implies a fine-tuning of the existing project development process as shown in figure 4.4. The shaded box represents an enhancement of the first step of the project development process. In this enhancement, the project development engineer (PDE) examines and analyses the PMS data before the initiation of the first field trip.

8.2.5 Feedback

Feedback is a crucial part of the information system that is essential to the pavement design process, asset management, the PMS operation, and the decision making process at both the network- and project-levels. The feedback system can be thought of as a system of checks and balances. The feedback data of the PMS helps the engineers to check and correct their procedures and/or assumptions. The feedback data can be used to assist MDOT to answer various key questions regarding the pavements. A sample of these questions is listed in table 4.4.

8.3 Procedures

8.3.1 Mechanistic-based design procedures

The mechanistic-based procedures for the design of flexible pavements and overlays to be implemented have already been developed (MICHPAVE and MICHBACK). Currently, they are being enhanced and updated to Microsoft Windows©-based computer programs. The procedures include pavement response models, material characterization models, failure criteria, and rut depth and fatigue cracking prediction models.

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Table 4.3. The MDOT specifications regarding the physical properties of asphalt mixes and the recommended mechanistic addition.

Mixture No. Mixture type	2B	2C	3B	3C	4B	4C	13	13A	11A	36A
VMA, min (%)	13.5	13.5	15	15	16	16	15.5	15.5	13.5	16.5
Air voids (%) Target (1)	3	3	3.5	3.5	3.5	3.5	3	3	3	3
Fines/Binder Ratio max. (2)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Fine agg. Angularity min (3)	3	4	3	4	3	4	2	2.5	2.5	3
Flow (mm)	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0	2.0-4.0
L.A. Abrasion max. loss (%) (4)	40	40	40	40	40	40	40	40	50	40
Soft particles Max. (%) (5)	12	12	12	12	8	8	8	8	12	8
Stability (kN), Min.	5.3	5.3	5.3	5.3	5.3	5.3	4.0	4.0	4.0	4.0
Resilient modulus										
Maximum Deflection (mm)										

The goal of the project scoping process is to develop a program for preserving the existing pavement system to meet the criteria established by the State Long Range Plan.

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6
Identify needs and assemble preliminary project list	Develop final prioritized scoping list	Collect and analyze detailed project information	Detailed scope and cost estimates	Final project prioritization and selection	Project submittal and approval

Download the PMS condition data, root causes of distress, and determine the rate of deterioration. Verify the field data during the pavement tour. Analyze the data to determine network needs and prioritize the fix strategy. Assemble preliminary project list and priority. For each project, determine the applicable rehabilitation alternatives. For each alternative, analyze the benefits and determine the life cycle costs. Use the PMS prioritization routine to select the final project list and the preferred alternative.

Figure 4.3. Proposed addition to the District Road Surface and Base Program Project Scoping Process.

8.3.2 QC/QA Procedures

The existing quality control and quality assurance procedures address some of the as-constructed physical properties of the pavement. Procedures to verify the structural properties of the pavement should be developed. Such procedures could be based on the as-constructed pavement deflection.

9.0 WHY MDOT SHOULD ADOPT A MECHANISTIC-BASED DESIGN PROCESS

As stated earlier, asset management is a comprehensive and systematic process of designing, constructing, maintaining, rehabilitating, upgrading, and operating physical assets in a cost-effective manner. This implies that asset management must combine engineering principles, sound economic theory, and healthy business practices to provide tools to facilitate more organized and logical approaches to both short- and long-term decision making. Such decisions include the pavement type and its design alternatives, the state of the health of the transportation network, the pavement fix alternative, and the type and location of the projects.

A comprehensive mechanistic-based design process provides a sound medium to engineer the vast asset (the transportation network) under the jurisdiction of the Michigan Department of Transportation. Such a design process must be based on representative engineering and physical properties of the paving materials and it must be a part of the overall asset management. A fully implemented mechanistic-based design process allows the Michigan Department of Transportation to:

- Improve asset management and its related decisions.
- Extend the pavement service life and consequently, reduce user delay costs..
- Optimize pavement performance based on engineering principles.
- Minimize the life cycle cost of the transportation infrastructure.
- Enhance performance modeling capability
- Increase/establish technical capability.
- Standardize the design process in the state.
- Engineer future conditions of the transportation network.
- Understand the root causes of deterioration and failure.
- Prescribe the proper fix alternative.
- Prepare for the implementation of the AASHTO 2002 design procedure.

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Table 4.4. A sample of key design and asset management questions that can be
addressed using the feedback data.

A sample of key design and asset management questions
• How does a certain pavement section truly perform and what is the accuracy of the assumed DSL in the design procedure?
• What preventive maintenance actions and schedule should be used for each category of pavement cross-section (thin, medium, thick section)?
• What are the effects of construction and maintenance practices on the overall pavement performance and costs? Are the as-constructed pavement properties similar to those assumed in the design method?
• What is the maximum and/or minimum overlay thickness for rigid and flexible pavements?
• What failure modes control the pavement deterioration in the various districts/regions?
• What is the most cost-effective timing of rehabilitation and what is the performance of various rehabilitation alternatives? For example, does a treated base perform as well as a non-treated base and what is the cost/benefit ratio of treated bases?
• What are the effects of material quality and existing standard specifications on the actual life and performance of the pavements?
• How accurate are the prediction models (e.g., pavement performance model, traffic forecasting) employed in the system?
• What are the effects of the funding levels on the strategy and conditions of the physical asset?
• What are the impacts of the rehabilitation strategy or policy upon the annual and the multi-year budgetary needs of the department or districts?

10.0 IMPLEMENTATION FACTORS

The implementation of a mechanistic-based design process is a long-term operation in that it cannot be accomplished by simply issuing an executive order or by adoption. The successful implementation requires several short- and long-term steps including:

- Endorsement and continuous support
- Commitment from all parties
- Initial, but insignificant investment
- Continuing investment in terms of
    - continuing education (seminars, short courses, and training)
    - increasing technical capability
- Standardization of the design, maintenance, rehabilitation, and material design processes
- Characterization of the various paving materials and roadbed soils
- Elimination of unsupported decisions regarding pavement design, maintenance, rehabilitation, and reconstruction
- Full utilization of the PMS data bank
- Possible organizational changes
- Additional resources (staff and budget)

The implementation of these steps may require additional costs in the short-term. The long-term benefits however, could be a net saving and the payback would be seen in better products and enhanced capability of pavement management. The benefits of the recommended design process are detailed in section 12 of this chapter.

11.0 CRITICAL SUCCESS FACTORS

The implementation of a mechanistic-based pavement design process improves asset management. The critical success factors in such implementation are:

1.   The design of a pavement structure must be based on a full knowledge of the engineering and physical properties of the paving material. Hence, the establishment of a material characterization scheme is a crucial step in the complete implementation of mechanistic-based design process or the AASHTO design procedure.

2.   Standards and specifications must be developed to address the physical and

engineering properties of the as-constructed pavement.

3.   The pavement design process must address the functional (ride quality) and structural aspects of the pavement.

4.   The construction of the pavement must be based on the verification of the design values as part of the QC/QA procedures.

5.   Continuous training and education must be undertaken to assure successful asset management.

These success factors can be achieved through continuous support of the implementation plan.

12.0   BENEFITS

The benefits of a standardized and comprehensive mechanistic-based design processes can be divided into three categories: benefits to MDOT, benefits to the users, and benefits to the industry. These are presented below.

12.1   Benefits to MDOT

Mechanistic-based processes for the design of flexible pavements and flexible overlays provide numerous benefits to MDOT. These include:

1.   Increasing the Pavement Service Life - Since the recommended processes are based on the engineering properties of the materials, the understanding of the root causes of pavement distress will be substantially improved. This understanding should lead in the long term to an increase in and/or more accurate prediction of the pavement service life. One may ask that what type of evidence can be provided at this time that will support the above statement? Unfortunately, none can be provided at this time that is directly related to the pavement network in Michigan. However, State Highway Agencies who have adopted mechanistic-based design procedures have claimed success in terms of increasing pavement life and decreasing costs. Furthermore, engineering logic dictates that designing and constructing pavements on the basis of understanding the material properties that affect pavement performance would lead to better pavements at reduced costs. For example, MDOT has debated for a long time

the benefits and costs of polymer additives, crumb rubber additives, slag aggregate in concrete pavements, open graded versus dense graded subbase and other various issues. For these items, the jury is still out. If pavement performance models were developed on the basis of material properties, the issues may have been settled long time ago.

2. Optimizing Pavement Performance - Since the recommended design processes are designed to respond to some of the needs for managing pavements, the project and fix selections and timing will be based on historical distress data and on the causes and rate of pavement deterioration. These would likely optimize pavement performance for a given cost.

3. Reducing Life Cycle Cost - The life cycle cost of a project is a function of the condition of the existing pavement, the type and timing of the fix, and the required future actions. The new process will address these issues through the proper use of the pavement distress data along with relatively accurate pavement performance models based on the engineering properties of the materials.

4. Establishing Comprehensive Pavement Performance Criteria - Currently, no pavement performance criteria exists in the State of Michigan. Pavement performance is a function of pavement design, construction, quality control, and the environment. A comprehensive set of pavement performance criteria includes the extent and severity of each distress where actions are needed. For example, a criterion should address the number of high severity transverse cracks or the distance between them in a unit length of the pavement before the pavement is rehabilitated. If such criterion is not developed and implemented, the pavement maintenance and rehabilitation programs cannot be optimized or standardized.

5. Augmenting Technical Capabilities - The understanding of the quantitative engineering properties of the paving materials and their responses to load enhance the technical capabilities of all engineers who are involved in the design processes. This understanding would allow engineers to evaluate the effects of new materials on pavement performance.

6. Continuing Improvement Using the Feedback System of the PMS - The new design processes include the collection and computerization of the inventory data, material properties, and the design inputs along with the historical pavement distress data.

Such data elements can be re-examined to determine whether or not the design process and consequently the pavement performance can be improved.

7. Enhancing Public and Legislative Communication - The new design processes will provide MDOT with a better understanding and more hard evidence of the causes of pavement distress and the effects of the various materials such as slag and excessive sand contents on pavement life and performance. Such understanding can be communicated to the public or to the legislators with hard data and true facts.

8. Improving Total Quality and Teamwork - The recommended design processes should unify the various MDOT divisions and contractors under one issue, providing better service to the users at minimum costs.

12.2 Benefits to the Highway Users

The highway users will also benefit from the recommended mechanistic-based design process. The benefits include:

1. Optimizing Benefit to Cost Ratio - When the recommended design processes are approved and fully implemented, the selection of projects and the type and timing of actions will be based on the causes and rate of pavement deterioration and the benefits of the action. This could minimize the total cost of managing the highway network.

2. Improving Services - Since the recommended design processes will be based on the engineering and physical properties of the materials, the process should provide better pavement structures. Hence, the service life of the pavement will likely be extended and/or more accurately predicted, the frequency of pavement closure will decrease which should enhance the pavement performance.

12.3 Benefits to the Industry

Mechanistic-based flexible pavement design process, if fully implemented by MDOT and the industry, would provide a better understanding of the impacts of construction quality, material properties, and other factors on pavement performance. Hence, the process could eliminate the guesswork that is being used with the existing industry practice. This would result in various benefits to the industry. These include:

1. Enhancing Partnering - Since the recommended design process is based on the understanding of the engineering properties of the paving materials and on the causes of pavement distress, both the industry and MDOT communicate by using similar and compatible terminology. Improving pavement performance is a healthy outcome and is beneficial to both parties.

2. Improving Technical Capability - The recommended flexible pavement design process requires engineering the pavement activities. Hence, the pavement industry may have to add engineers to their staff who can explain and manage the new process. This may enhance the technical capabilities of the industry.

13.0 COST ASSESSMENT

The implementation of uniform, comprehensive and mechanistic-based processes for the design of flexible pavements and overlays may precipitate initial and operational (continuous) costs. Some of the estimated costs are summarized in table 4.5. The research team could not accurately estimate other cost items that are associated with staffing and data collection. One of the reason is that, state highway agencies which have fully or partially implemented a mechanistic-based design process claim a net saving. No details regarding the additional costs and savings can be found.

13.1 Costs

The costs can be divided into initial investment and operational cost (continuing cost).

13.1.1 Initial Investment

The implementation of the recommended mechanistic-based process for the design of asphalt pavements and overlays requires an increase in the existing MDOT testing capability. Hence, an initial investment needs to be made to meet this requirement. The initial investment will include the cost of new acquisition of equipment or enhancing the existing capability as summarized below.

1. The addition of one FWD with the appropriate staff support - The existing FWD is capable of conducting deflection tests on approximately 8 miles of the network per day. *This excludes travel time and traffic control set-up*. Such an

Table 4.5. Cost and benefits of implementation of a mechanistic-based design process.

Item	Cost ($1000)	Collective potential benefits
Material Characteristics	250	1. Improving asset management
Education	25 to 50 per year	2. Increasing the pavement service life
Inventory data	10 per year	3. Improving the condition of the network
		4. Decreasing the life cycle cost
		5. Providing better services to the users
PMS Implementation		6. Increasing the technical capability of the department
Mechanistic-design		7. Optimizing pavement performance
		8. Reducing user delay
Feedback loop		9. Enhancing performance modeling capability

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addition will allow MDOT to:

a)   For existing pavements, double the rate at which deflection data can be collected to determine the engineering properties of the material. The information can be used for the design of overlays, reconstruction, and rehabilitation. The information could be collected in a catalogue form that can be made available to pavement engineers. For example, the engineering properties of the subgrade can be summarized on a network map (similar to traffic map) which can be distributed to all Regions/Districts and Transportation Centers.

b)   Identify the common denominators between various pavement sections with similar pavement performance trends. Based on these denominators, establish pavement performance-based criteria to be used in specifications and quality control.

c)   Enhance the pavement management capability by including deflection data and cross-sections of the existing pavements (inventory data) in the database.

Nondestructive deflection testing could also be subcontracted. This would eliminate the purchase of another FWD and the hiring of permanent staff. However, the cost of the subcontract will need to be included as a part of the overall cost of the new design process. It should be noted that preliminary assessment of the cost of such subcontract indicates that its cost is higher than MDOT acquiring an additional FWD with permanent staff.

2.   Enhance the material testing capabilities of MDOT to provide the engineering properties of the asphalt mixes, aggregate base, sand subbase, and roadbed soils. Again, material properties catalogue can be published and made available to engineers in all regions and the main MDOT office. Since this additional activity will cease when the catalogue is completed and only routine testing and verification will remain, it could be subcontracted to the private sector or other agencies.

13.1.2 Operational Cost (Continuous Cost)

The implementation of a mechanistic-based process for the design of asphalt pavements and overlay requires enhancement of the existing technical capability/expertise of MDOT. This will be accomplished through a continuing education program. Training courses and seminars will be designed and conducted to train engineers and technicians to understand the recommended design processes. The training should address the impact of the pavement design process on pavement performance. Such training was started in early 1996 under the PRCE contract.

14.0   Operational Changes

The existing operational practices separate the material design from the pavement design, the quality control practice from pavement performance, standards from pavement behavior, and so forth. For example, the asphalt mix design practice is based on measuring the physical properties (such as density and asphalt content) and stability of the mix. The quality control practices are based on verifying the density and the asphalt content and air voids of the mix. Sporadically, the gradation of the aggregate is also verified by extracting or incinerating the asphalt binder. In these practices, no structural properties are measured or verified at any time in the existing practices. Thus, the structural properties assumed during the project design phase are never verified and/or checked. To correct the existing practices, the operational changes that need to be implemented include:

1.   Rewriting specifications regarding material selection, asphalt mix design, aggregate gradation, and so forth. Such specifications must address the various activities and issues that affect pavement performance. For example, for each material type, the specifications should include a range of engineering properties that can be used in the pavement design procedure and be a part of the acceptance criteria. Another example could be the allowable sand content (- the number 4 sieve) of an asphalt mix. If the pavement distress data indicates that pavement performance will be adversely affected when the percent sand content exceeds 30 percent then such percentage should be reflected in the modified specifications.

2.   Revising construction quality control procedures to address the structural properties and performance of the pavement, for example, the as-constructed pavement

deflection and layer properties. The information can be used to:

- Verify whether or not the specifications have been met
- Check the pavement design assumption
- Develop pavement performance models

3. Creating a comprehensive database that includes cross-section, deflection, condition data, and so forth. Along with the addition of the proper software, this change would provide more complete information, which improve the acts of managing pavements.

15.0 ORGANIZATIONAL CHANGES

The implementation of the operational changes stated in the previous section may be enhanced by some accompanying organizational changes. These may include the establishment of a pavement design group or committee consisting of a pavement design engineer, an asphalt mix design engineer, a soil engineer, a construction engineer, a quality control engineer, a traffic engineer, and a research engineer. The function of the group or committee is to oversee the compatibility of the various activities, and the implementation, of the recommended design process.

16.0 SUMMARY

The problems with the existing pavement design practices in the State of Michigan were reviewed and are presented along with the existing flexible pavement design procedures and project scoping practices. Based on the review and the dimensions of the problem the following recommendation was made:

The various flexible pavement design procedures and the design of asphalt overlays used by MDOT be consolidated into a comprehensive and unified process. The main objective of the new process would be to optimize the life and performance of the pavement and to minimize the life cycle costs.

The objectives, and likely benefits and costs of the recommended design processes were also presented in this chapter.

A detailed plan for the implementation of the recommended processes for the design of flexible pavements and flexible overlays is presented in the next chapter.

CHAPTER 5
IMPLEMENTATION PLAN

1.0   INTRODUCTION

The problems and inconsistencies with the existing pavement design practices in the State of Michigan were discussed in chapter 4 along with a recommendation for the approval and implementation of integrated mechanistic-based processes for the design of flexible pavements and flexible overlays. For the benefits of the reader, the recommendation is restated below.

> *The various flexible pavement design procedures and the design of asphalt overlays used by MDOT be consolidated into a comprehensive and unified process. The main objective of the new process would be to optimize the life and performance of the pavement and to minimize the life cycle costs.*

This chapter provides a detailed plan for the implementation of the recommended process for the design of flexible pavements and flexible overlays.

2.0   IMPLEMENTATION PLAN

To meet the objectives and realize the benefits of the recommendation, an implementation plan was proposed and presented to the Engineering Operation Committee (EOC) of MDOT. This plan leads to responsive, uniform, comprehensive, and mechanistic-based processes for the design of flexible pavements and overlays. The proposed implementation plan requires the approval and continuous support of the members of the EOC. As shown in figure 5.1, the plan consists of four elements as follows:

1.   Continuing Education
2.   Material Characterization
3.   Total Quality Team Work
4.   Pavement Management

The action items following from these four elements are detailed below.
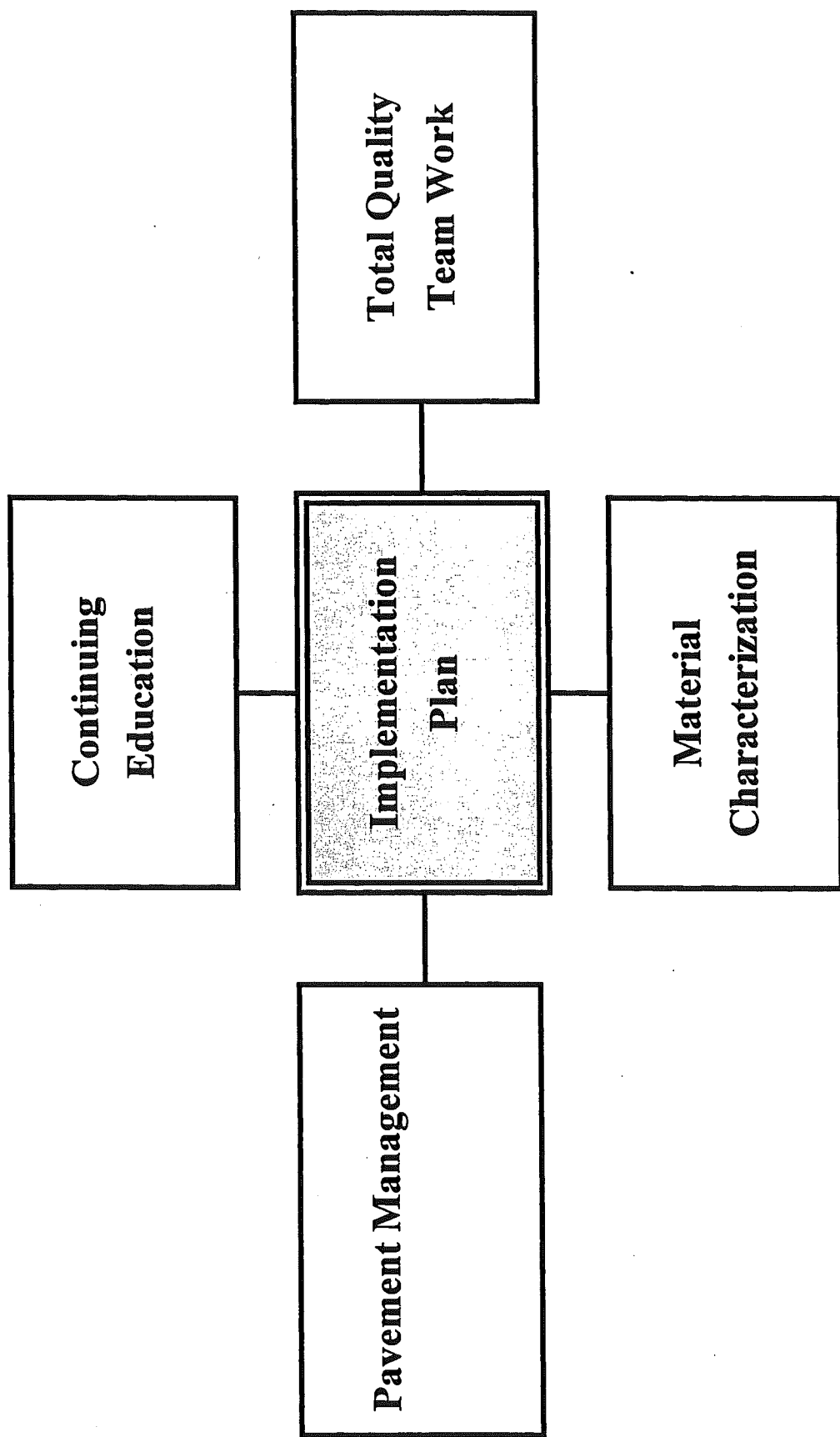
Figure 5.1. A plan for the implementation of a mechanistic-based process for the design of flexible pavements and overlays.

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2.1   Continuing Education

It is recommended that a series of training courses covering the fundamental of mechanistic principles regarding pavement design, asphalt mix design, construction quality, and quality control procedures and their impact on the pavement performance and management be designed and delivered periodically to those involved in the recommended design process. It should be noted that the PRCE contract includes an educational component. As part of this component, two short lectures concerning pavement design have been held. Representatives from the Lansing office and the districts attended the courses.

It is also recommended that the continuing education component include seminars given by experts within MDOT as well as outside experts. For example, the Project Development Engineer (PDE) and/or the Pavement Design Engineer of one district could conduct seminars to address various design issues and the ways they were handled in the districts. Such seminars could be held during an annual meeting of the PDE and design engineers. The benefits of the annual meeting in terms of sharing experiences could by far exceed the cost of the meeting.

Continuing education should not only consist of seminars and short courses. The term continuing education is an umbrella that can encompass many different activities. A good continuing education program should contain three main elements: Training Activities, Materials and Supplies, and Intra-Department Activities. Figure 5.2 provides a chart of some activities within each of the three elements. In addition, the spirit of in-house total quality teamwork should be enhanced. Such enhancement cannot be achieved by a simple distribution of literature or by inviting outside speakers. An effective continuing education program should include:

1.   Training on the use of the mechanistic-based software (MICHPAVE and MICHBACK) through seminars and hand-on training.

2.   Defining and improving the relationships of the prescribed job duties and pavement performance and the total quality of MDOT's products.

3.   Encouraging and rewarding innovation in pavement design, analysis, quality control, construction technology, and other areas that impact pavement performance.
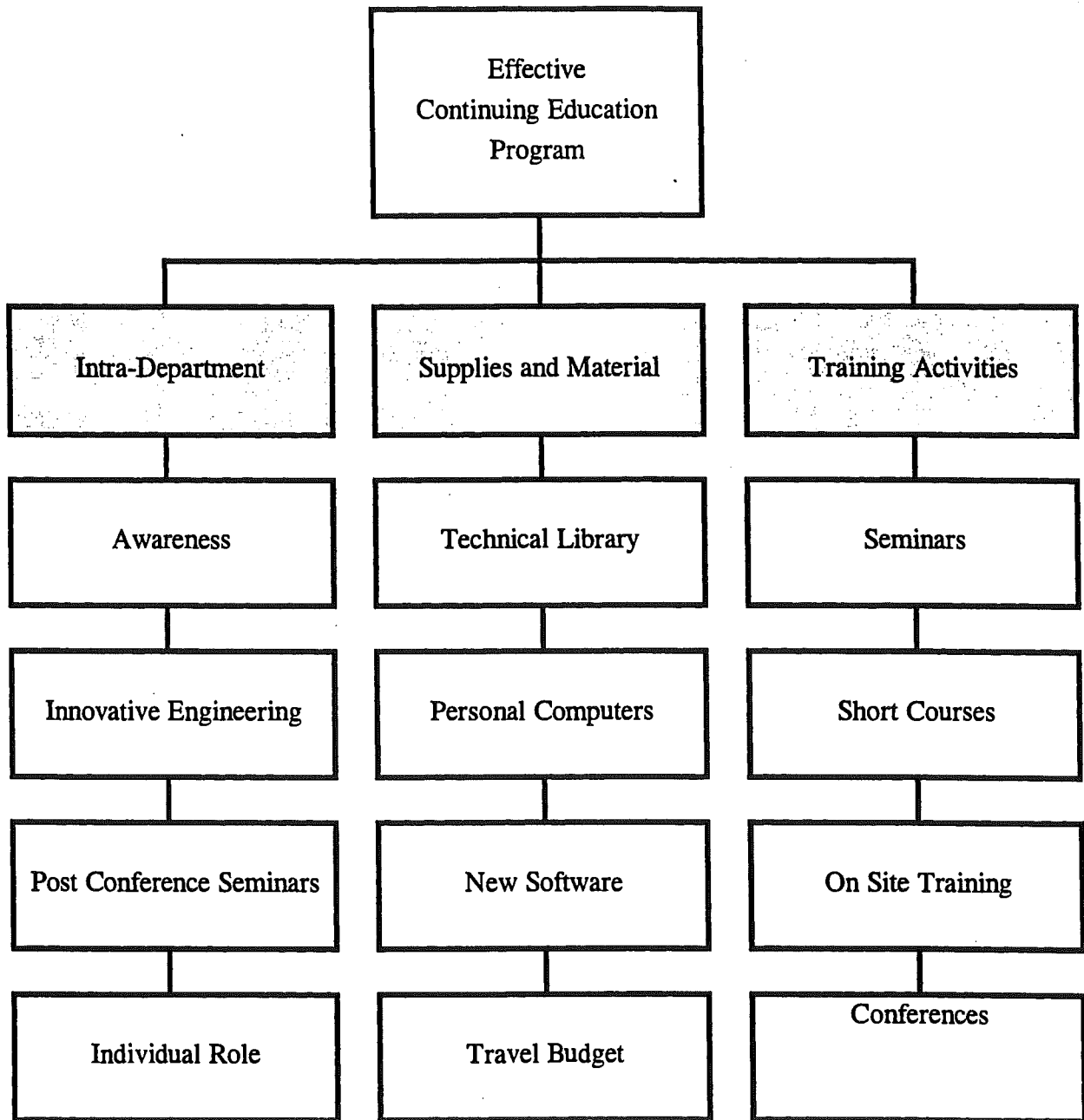
Figure 5.2. Various elements of a continuing education program.

4.   Providing literature regarding total quality teamwork and encouraging the employees to read such literature as a part of their job.

5.   Enhancing and periodically updating technical libraries by the addition of new volumes and new literature.

6.   Establishing in-house seminars where conference attendees share their learning with other MDOT employees.

7.   Using the existing mechanics of the training program, efforts could be undertaken to train personnel regarding the impact of each MDOT office on the performance of the transportation infrastructure.

2.2   Material Characterization

The accuracy and reliability of any design procedure is a function of the accuracy of the material data used in the design process, the as-constructed material properties, and the engineering models used to predict performance. Highway pavements are constructed on various roadbed soils and use several different materials in the subbase, base, and asphalt layers. For an optimum and rational pavement design, the characteristics (engineering and physical properties) of each material should be accurately known to the engineers who are involved in pavement design.

The properties of the paving materials can be obtained in the laboratory as well as in the field. However, the results of lab and field tests are not the same. Because of the differences in the boundary values and the methods of sample preparation, the lab results differ from those obtained in the field. However, the trends in the results are very much similar. For example, in the laboratory, the test results will show that the strength of the subgrade material decreases with increasing water content. The same conclusion can also be made from the results of field tests. Moreover, if ten asphalt mixes are tested in the laboratory and the mixes were then ranked by decreasing value of their resilient moduli, the ranking order will be the same as that which would be obtained from field tests. This indicates that laboratory tests can be used to

1.   Assess the sensitivity of the paving material and subgrade soils to various variables such as temperature, water content, and additives.

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2. Compare or rank the quality of paving materials. For example, laboratory tests can be used to rank angular and rounded sands or aggregate obtained from different sources.

3. Determine the optimum mixing conditions (such as asphalt contents, air voids, voids in mineral aggregate) and compaction efforts.

Field data or field tests, on the other hand, can be used to accomplish the same three objectives above as well as to obtain the in-situ characteristics of the paving material. There are two important issues relative to the characterization of the paving materials. These are:

1. Reliability - The reliability of the test results should be similar to that used in the design process. For example, if a pavement structure is to be designed using a 95 percent reliability level, then, similar reliability level should be employed in material sampling, testing, and data collection. If one is to assume that the test results are symmetrical and the samples are representatives, then the 95-percentile value of the results should be used in the design

2. Seasonal Variation - The properties of pavement materials change from one season to another and with temperature. For example, for clay subgrade soil, a minimum resilient modulus value can be obtained during spring-thaw condition. For asphalt mixes, the value of the resilient modulus is low at high temperatures. Hence, the properties of all materials should be obtained under the range of conditions expected in the field. The effect of each condition on the material response (stress, strain, and deflection) and on the long-term pavement performance should be evaluated before a design value can be selected.

In the field, material characterization can be accomplished by conducting non-destructive deflection tests (NDT) using a falling weight deflectometer (FWD). It is recommended that:

1. The FWD be used to obtain pavement deflection data. The data can be used with the MICHBACK software to calculate the values of the field modulus of each pavement layer and of the subgrade soil

2. The thicknesses of the various pavement layers be documented by coring the

pavement section or by using a penetrating radar.

The deflection and layer thickness data can be used to determine the resilient moduli of the pavement layers and subgrade. When the network testing is completed, the results (the resilient modulus values) can be summarized on a network map similar to that for the Average Daily Traffic (ADT) or catalogued. The results càn be used by the design engineers to obtain the properties of the materials that are needed in both the mechanistic-based design processes and the AASHTO design method. Once again, the results can be used to design a new pavement (reconstruct) and/or to design asphalt overlay.

Currently, one FWD (the KUAB model) is available and is located at the Construction and Technology Division of MDOT. However, one FWD is not adequate to cover the pavement network and responds to district's needs in a reasonable time frame. Two alternative solutions exist:

1.   Add another FWD and the proper staffing (2 FTE).
2.   Subcontract nondestructive deflection testing to the private sector.

Regarding nondestructive deflection tests, it is strongly recommended that:

1.   For existing flexible pavements, deflection data be collected at the following intervals:

    a)   For Interstate and where the desired design reliability is 95 percent, 250 feet. At this interval, 20 tests per mile will be conducted. If a project is less than 1-mile long or if the subgrade type changes (e.g., sand to clay) over a distance of less than 1 mile, a minimum of 20 tests per project or per subgrade type (clay versus sand versus silt) be conducted.

    b)   For US Roads where the traffic is more than 1200 ADT, 250 feet. For projects of less than 1-mile long or which have more than one type subgrade (e.g., sand, silt, or clay), see item "a" above.

    c)   For all Michigan Roads (M designated roads) with more than 500 ADT, 500 feet. For any project length, the NDT should be spaced at 500 feet or a minimum of 10 tests per project should be conducted.

d)   1000 feet for all roads with less than 500 ADT or a minimum of 5 tests per project.

2.   For newly constructed flexible pavements, nondestructive deflection tests be used as a part of the quality control/quality assurance procedures. The purposes of the tests are to determine whether or not the compacted material properties are similar to those used in the design process and to assess the quality of construction, which may result in incentive/disincentive. In this regard and for each pavement class, the maximum permissible pavement deflection should be specified for standard temperature (e.g., 68° F), season (e.g., spring), and load level (e.g., 9000 pounds). Such maximum deflection value can be obtained either from mechanistic analysis conducted at a certain reliability level or from the existing pavements by conducting FWD tests. Incentives and disincentives can be based, among other things (such as ride quality, segregation), on the maximum pavement deflection.

3.   Existing specifications be rewritten or modified to include pavement performance criteria such as the maximum permissible deflection under a given load magnitude.

4.   All deflection data (quality control, design, and/or pavement evaluation) be kept in the pavement management data bank.

Finally, existing procedures related to the characteristics of asphalt mixes used in the asphalt mix design phase, pavement maintenance and rehabilitation, construction, and quality control be modified to assure their compatibility with the mechanistic-based design processes and their comprehensiveness with the pavement performance criteria. Some examples are given below.

Example 1 - Quality Control - It is recommended that, nondestructive deflection tests be added as a part of the quality control practices. The reason is to gradually move to pavement performance-based specifications and to verify the quality of construction of the various pavement layers.

Example 2 - Asphalt Mix Design - It is recommended that, the resilient modulus test be added as a part of the asphalt mix design practice. The reason is to obtain the mechanistic properties of the asphalt mix to be used in the mechanistic-based design process and/or in the AASHTO design procedure.

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Example 3 - Pavement Rehabilitation - It is recommended that nondestructive deflection test be conducted to assess the properties of the various pavement layers and their variations along the project. The deflection data and the material properties can then be used to determine the required asphalt overlay thickness. It should be noted that MSU is currently developing software for the design of the asphalt overlay. The software will be a part of a comprehensive pavement design and analysis package that will be available in late 1998 and early 1999.

Example 4 - Pavement Construction - Existing quality control procedures and the as-constructed pavement deflection data cannot be used to assess some construction-related defects such as segregation. Therefore, it is recommended that, existing construction specification be enhanced to include periodic checking and, if needed, adjustment and calibration of the paving operation be undertaken to minimize segregation potential.

2.3   Total Quality Teamwork

The main guiding principle of the total quality teamwork defines the MDOT goal as providing safe, better, and more economical services to the highway users. The roles of the industry and academia in a total quality teamwork setting are to assist MDOT in achieving its goal. In the framework of total quality teamwork, MDOT personnel are the managers of the majority of the vast investment made by the users in the transportation infrastructure. Good management of such an asset cannot be achieved unless accurate information regarding the design, construction, maintenance, rehabilitation, and upkeep of the transportation systems are exclusively available. The majority of such information can be found in the various management systems such as pavement management system (PMS), maintenance management system (MMS), and bridge management system (BMS). The problem is that these systems are not fully implemented.

An effective asset or transportation infrastructure management cannot be accomplished by simply purchasing or writing a "black box" computer program (software) that generates reports regarding infrastructure conditions. Good asset management requires that all personnel in the department work together toward a unified goal "*Increasing the Performance of the Transportation Infrastructure at a Reduced Cost.*" Such work must be based on accurate data and a clear set of objectives. For example, the main objective of managing pavements is to optimize their performance at the least possible cost. Since pavement management is a part of the total transportation infrastructure management, its full

implementation represents an in-house implementation of total quality teamwork.
Parallel to the activities of achieving in-house total quality teamwork, other efforts to bring
the industry and academia to the team must be made. The primary objective of the total
quality teamwork is to provide the users of the transportation infrastructure better services at
reduced costs. Hence, the concept of total quality teamwork must emphasize that department
personnel, the industry, and academia are working together to serve the users.

Finally, as a part of the total quality team work, incentives could be designed as to recognize
certain MDOT unit (such as design squad, project engineer, project scoping unit, etc.) or
individuals for their outstanding effort. For example, group or employee of the month,
accelerated promotion or other incentives. To gain such incentive, the group should
demonstrate cooperative spirit and the types of services provided to other groups within
MDOT. The incentives should be designed to reward knowledge and commitment to quality.

2.4   Pavement Management

The term "Pavement Management" does not and it should not imply a computer program or a
black box. The term is used in reference to all the people of MDOT involved in planning,
financing, designing, constructing, maintaining, and rehabilitating the pavement network.
After all, pavement networks in Michigan and other states were managed long before the
computer was invented. Hence, pavement management represents all the actions of an
organization accomplished under the spirit of total quality teamwork to deliver an optimum
product to its customer. Every manager, engineer, technician, and personnel working on a
pavement-related issue is a part of pavement management. Computers are merely tools used
to help people analyze the problem at a faster rate and assess the impacts of multiple
alternatives. Commitment to total quality teamwork is providing better services to the
highway users. Commitment to pavement management is a commitment to total quality.
Commitment to accurate and detailed data is a commitment to total quality. In this regard,
pavement data obtained by various people within an organization should be kept as a part of
the overall database.

Recently, the MDOT has made a substantial investment in the pavement management
software development and in distress data collection efforts. The new software will be on
board by the early 1998. After successful beta testing, the software should be fully utilized
by MDOT employees. In order to utilize the PMS software, it is recommended that project
development (scoping) practice be based on the PMS data and on the analysis of the data as

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shown in figure 5.3. This includes the proper selection of applicable fix alternatives. After the proper selection of the applicable alternatives, the benefits of each alternative should be determined. Life cycle cost analysis (LCCA) of each alternative can then be conducted. The preferred alternative could be selected on the basis of that which provides the department with the highest benefit, the highest performance to cost ratio, or the highest service life to cost ratio.

Further, it is recommended that at the conclusion of the project scoping process, for each project, the material forwarded to the Pavement Selection Review Committee (PSRC) include:

1. A summary of the pavement distress conditions as obtained from the Pavement Management System.

2. Root causes of distress (such information can be obtained from the MDOT rehabilitation manual).

3. The distress points, the rate of pavement deterioration, and the remaining service life (RSL) of the pavement.

4. The benefits of each feasible rehabilitation alternative in terms of:

    a) The design service life (DSL) of the alternative.
    b) The impact of each rehabilitation alternative on the average remaining service life (RSL) of the pavement network.

5. The 35-years life cycle cost of each rehabilitation alternative.

6. For each project, the recommended preferred rehabilitation alternative.

Although under current practice, the PSRC receives the bulk of the above-recommended actions and/or information, the added items would enhance the PSRC decision making process regarding the annual rehabilitation program.

The pavement management component of the implementation plan contains several elements of the mechanistic-based process for the design of asphalt pavements and overlays. One of

The goal of the project scoping process is to develop a program for preserving the existing pavement system to meet the criteria established by the State Long Range Plan.

STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6
Identify needs assemble preliminary project list	Develop final prioritized scoping list	Collect and analyze detailed Project Information	Detailed scope and cost estimates	Final project prioritization and selection	Project submittal and approval

Download the PMS condition data, root causes of distress, and determine the rate of deterioration. Verify the field data during the pavement tour. Analyze the data to determine network needs and prioritize the fix strategy. Assemble preliminary project list and priority. For each project, determine the applicable rehabilitation alternatives. For each alternative, analyze the benefits and determine the life cycle costs. Use the PMS prioritization routine to select the final project list and the preferred alternative.
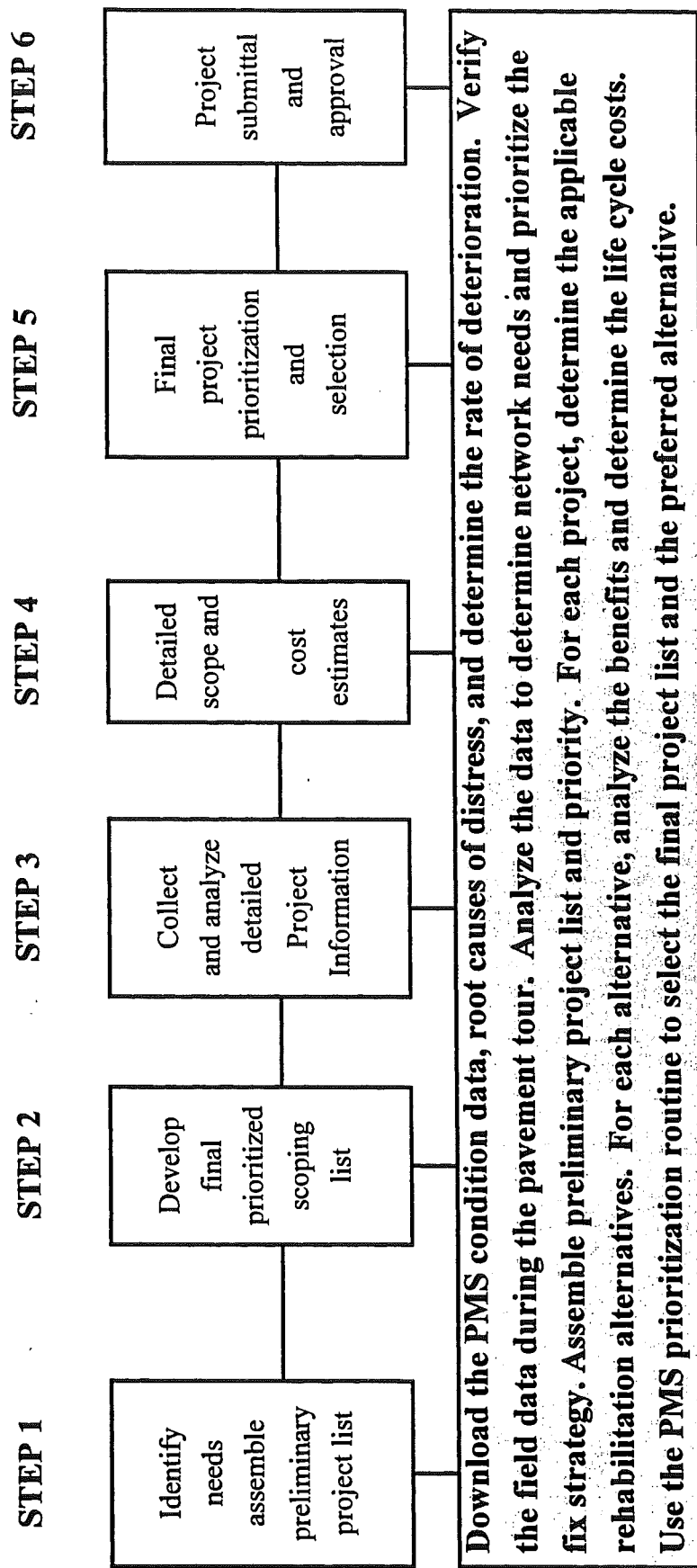
Figure 5.3. District Road Surface and Base Program Project Scoping Process.

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these elements is the pavement design and analysis software. This software includes three routines: MICHPAVE, MICHBACK, and the 1993 AASHTO design procedure.

1.   MICHPAVE - A linear and nonlinear finite element computer program developed by Michigan State University for MDOT. The method includes rut and fatigue models. MICHPAVE is currently being modified to improve its prediction models and to make the software operational in the Window© environment.

2.   MICHBACK - A layered elastic computer program for the backcalculation of layer moduli. MICHBACK is capable of reading the MDOT's FWD deflection data directly. The program is currently being enhanced to include mechanistic-based design of asphalt overlays.

3.   AASHTO - The AASHTO procedure for the design of flexible pavement structure will be a part of the pavement analysis package being designed by MSU for MDOT. The package will contain MICHPAVE, MICHBACK, and the AASHTO method. In this regard, any pavement section can be designed by using both the AASHTO and MICHPAVE. This should allow MDOT to examine both outputs (pavement cross-section) and determine which section is to be built.

3.0   IMPLEMENTATION TIME FRAME

Table 5.1 provides the recommended implementation time frame. Upon the approval of the implementation plan, the following implementation time frame is recommended:

1.   For New Asphalt Pavements - At the onset of the implementation, new asphalt pavements be designed by using both the AASHTO and MICHPAVE software. If the two methods produce the same cross-section, then that section can be constructed as designed. If the two methods produce different sections, it is recommended that at least half the project be constructed according to the AASHTO section and the remainder according to MICHPAVE. The two sections should be monitored over time as a part of the annual monitoring program of the PMS. The monitoring data should be used to determine the actual benefits and costs of the AASHTO and the mechanistic-based designs.

2.   For Asphalt Overlays - An asphalt overlay could be used to enhance the functional (such

as ride quality) or the structural characteristics of the pavement. Again, at the onset of the implementation, the thickness of the structural overlays should be determined using mechanistic method (MICHBACK) and the current method, which is based on engineering judgment. The overlay along a segment of the project should be placed according to one method and along the other segment according to the other method. Once again, the monitoring data could be used to determine the benefits and costs of the mechanistic method. The thickness of functional overlays on the other hand can still be determined based on experience and practicality.

3.   Material Characterization - Regardless of the design method (the AASHTO, MICHPAVE, or MICHBACK) material properties are essential for their implementation. Hence, it is recommended that nondestructive deflection test along the network be conducted as soon as possible. In table 5.1, it is estimated that FWD testing will commence during the spring of 1998.

4.   Continuing Education - It is recommended that seminars, short courses, and on-site-training be developed and held starting December 1997. These activities should be continuous.

5.   Pavement Management System - The implementation of PMS is crucial to the design, construction, maintenance, and rehabilitation of the pavement network. It is recommended that the activities for collecting inventory data be commenced during the summer of 1998. Temporaries and student helpers could be used to extract the data from the existing files and to input the data into computer files.

Table 5.1. Mechanistic-based design process, implementation time frame.

	Action	Starting Date	Ending Date	Responsibility
Continuing Education	Seminars	1998	Continuous	Academia and Construction and Technology
	Short Courses	1998	Continuous	
	On-site Training	1998	Continuous	
	In House Seminars	1998	Continuous	
	PDE Meeting	Annual	Continuous	
Material Characterization	FWD Testing	1998	2008	C & T
	Inventory	1998	2002	C & T
	Laboratory Testing	1998	2000	C & T
Quality Team Work	Specifications	1998	2002	MDOT
	Construction	1998	2002	C & T
	QA/QC	1998	2002	C & T
	AC Mix Design	1998	2000	C & T
PMS	MICHPAVE	1998	Continuous	Design
	MICHBACK	1998	Continuous	Design
	AASHTO	1998	Continuous	Design
	Project Scoping	1998	Continuous	Design
	PSR Committee	1998	Continuous	Design
	PMS Implementation	1998	Continuous	Design

APPENDIX A

SUMMARY OF
MDOT PROJECT SCOPING PRACTICE

APPENDIX A

SUMMARY OF
MDOT PROJECT SCOPING PRACTICE

1.0   VARIABILITY

Although the project scoping procedure in the State of Michigan consists of several common steps, the details of each step vary from one district to another. The reasons for such variation include:

1.   The available resources which include the staffing level and budget allocated by the Central Office.

2.   Past and current rehabilitation, reconstruction, and preservation practices.

3.   The size of the pavement network in terms of center-line miles and the traffic levels in terms of the average daily traffic (ADT) in the district.

4.   Pavement type (flexible, rigid, or composite).

The typical project scoping process in the State of Michigan consists of several comprehensive steps as shown in figure 4.2 and described below. Slight and occasionally significant variations in the detail of each step can be found among the Districts.

1.1   Step 1 - Identifying System Need By the Development of a Preliminary Project List

The project development engineer and staff are responsible for this step. The objective of step 1 is to identify system needs. First a "working list" is established consisting of candidate projects "non-program projects" that were identified in previous years but were not constructed because of budget constraints. Additional projects need to be identified from the specific tasks listed below. This step ends with a preliminary project list.

The goal of the project scoping process is to develop a program for preserving the existing pavement system to meet the criteria established by the State Long Range Plan.

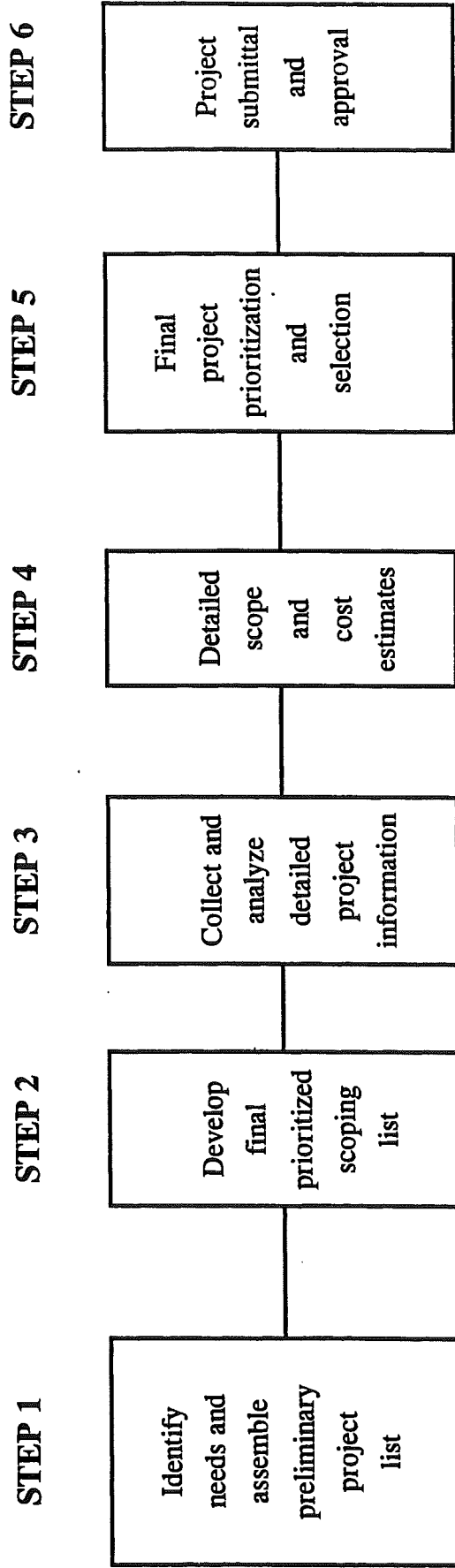| STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6
Identify needs and assemble preliminary project list	Develop final prioritized scoping list	Collect and analyze detailed project information	Detailed scope and cost estimates	Final project prioritization and selection	Project submittal and approval

Figure 4.2. District Road Surface and Base Program Project Scoping Process.

Several tasks are accomplished in this step. These are:

1. Advising the District Management Team of upcoming call-for-projects to review Statewide planning guidelines, goals, objectives and strategy for program development.

2. Reviewing the PMS and sufficiency data to identify candidate projects.

3. Soliciting input from District Staff by memo to all Sections, Resident Engineers, Maintenance Superintendents and Foremen.

4. Soliciting public and political input by review of complaint letters and responses from the District.

5. Soliciting input from the review of department obligations and promises.

6. Soliciting input by memo to MPO's and Rural Task Forces and work with TIP sub-committee.

7. Including projects that may need to be recouped to fit changes in previous strategy and/or priorities.

When reviewing projects to be placed on the preliminary list, the Project Development Engineer (PDE) and staff must take into account other funded projects from the other categories. Some projects may have to be moved directly to scoping and programming to meet the schedule of another project in the same area. The list should be a working list of total needs within the district and should include preliminary scope including possible expansion. The list should also include candidate projects for the improve/expand program as well as safety programs.

6.2 Step 2 - Development of a Final Prioritized Scoping List

The District's PDE coordinates this step with the objective to develop a final list of projects for which detail scopes are to be developed. The step starts with the preliminary project list (step 1) and ends with a finalized prioritized scoping list. The

tasks in this step are:

1.   Reviewing the preliminary project list with the District Project Scoping Resource Team with regard to specific considerations including: category of funding and estimated budget, consistency with system fix strategy goals, maintenance costs, customer input, district priority in the long term plan, geographic locations, traffic and corridor considerations, coordination with other projects in the area.

2.   Developing a final list of projects (by project category as appropriate) which identifies the order/priority for which detailed scopes are to be developed. It is essential that the justification for project selections and prioritization are documented. The final prioritized scoping list serves as a guide scoping efforts for potential projects for future programming.

6.3   Step 3 - Collection and Analysis of Project Information

The objective of this step is to identify, collect, verify and/or analyze information from various sources which will be needed for estimating the project cost. Examples include sufficiency data, accident analysis, pavement management information, right-of-way, sign inventories, guardrail inventories, soil borings, pavement cores, old construction plans, geometric review, traffic counts, and utility information.

Step 3 starts with the final prioritized project scoping list (step 2). This list contains projects with a realistic probability of being submitted and selected for inclusion in the program. The step ends with the completion of pages 1 and 2 of the seven-page Project Scoping Checklist. The first two pages of the Project Scoping Checklist provide general information about the project, justification for doing the project, and a concept of items which should be considered during scoping of the project. Estimates are not included at this point.

The objective of step 3 can be accomplished by executing the following tasks:

1.   Identifying and recording general project information (route, location, limits, etc.).

2. Identifying and recording items on the concept checklist (page 2) which are required for the project.

3. Requesting information and recommendations from various sources such as other district engineers, sufficiency rating book, PMS data, etc.

4. Collecting and compiling information.

5. Analyzing information received, reviewing recommendations received, and deciding what items to include in the scope of the work.

6. Performing life-cycle cost calculations.

7. Determining recommended fixes.

8. Forwarding fix recommendation to the Pavement Selection Review committee for concurrence.

9. Recording description and justification of the proposed work with reference to analysis and decisions made in Steps 5 and 6 (listed below).

During the collecting and analyzing of the project information, considerations must be given to all items listed on Page 2 of the "Project Scoping Checklist". The decisions should be based on design standards, desired fix life, available funding, and other criteria as determined by the district. Life cycle cost should be calculated by the methods recommended by the departmental task groups.

6.4 Step 4 - Detailed Scope and Cost Estimates

The project management engineer, if available, coordinates this step with the following objectives in mind:

1. Determining the complete scope of work.

2. Determining the estimated costs associated with the proposed scope of work.

3.   Completing pages 3-7 of the Project Scoping Checklist.

4.   Completing Project Concept Statement, including cost estimate.

Step 4 starts with the project scoping data collected in step 3, pages 1 and 2 of the Scoping Checklist, & the "Fix Strategy". The step ends with complete detailed scope and quantities (pages 3-7 of the Scoping Checklist), complete project concept statement, and final cost estimate.

The objectives of this step can be accomplished through the following tasks:

1.   Taking information collected in Step 3 and recording the detailed scope of the project.

2.   Computing and estimating quantities of items of work identified during the scoping data collection step. Verifying quantities obtained from various other sources.

3.   Preparing an accurate cost estimate of all items of work detailed for the project using historical cost information. Verifying cost estimates obtained from various other sources.

4.   Recording the individual and subtotal cost estimates on the concept checklist (pages 3-7) for the project.

5.   Determining the total project cost including contingencies, anticipated program year, and construction engineering.

6.   Preparing a phase breakdown of the project costs for submittal to programming. These include preliminary engineering, road construction, right of way (ROW), structure cost, and construction engineering.

During the development of the total estimated cost for the yearly program, consideration must be given to cost adjustments due to factors such as effects of material availability, project location and inflation. The type of contract anticipated for

a particular project such as incentive/disincentive, A+B, etc.) should be considered at this step because of the potential costs associated with the different contracts. Consideration for other costs such as a Motorist Information Plan, etc. should also be made during this step.

6.5   Step 5 - Final Project Prioritization & Selection·

The objective of step 5 is to develop a final list of proposed projects to be submitted for approval, selection and programming. The step starts with a completed detailed scope and quantities (pages 3-7 of the scoping checklist), cost estimates and project concept statement. The step ends when a prioritized project list is completed.

The Project Development Engineer (PDE) is responsible for taking the priority list, putting it into the proper format and submitting it to the screening committee. It should be noted that the composition of the programming team in each district may vary.

The objective of step 5 can be accomplished through the execution of the following tasks:

1.   Obtaining the list of potential projects, fully documented with the information outlined at the start of this step.

2.   Reviewing the list of potential projects with the appropriate parties of a district programming team.

3.   Comparing each project with specific considerations (listed below) and developing a list by priority (and category, if applicable) of projects to be submitted for approval to the project steering committee.

During the execution of step 5, several items should be given special considerations. These include:

1.   Coordinating with other programs that might have projects within the proposed projects limits of a particular "preserve job". These may   include: safety, bridge, guard rail, preventative maintenance, railroad, enhancement, economic development, and other projects.

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2. Coordinating with adjacent district's programs.

3. Obtaining inputs from metropolitan planning organizations (MPOs), rural ISTEA task forces and similar planning groups, including transit and non-motorized organizations.

4. Maintaining geographical balance within the district including constructions offices, pavement condition, and vehicle miles.

5. Considering maintenance costs which may include an analysis of how fast the existing roadway is deteriorating. Can routine or even heavy maintenance hold it for a while?

6. Maintaining traffic considerations including a detour route, staging and general constructability of the project within reasonable costs.

7. Consulting the district pavement management strategy including corridor improvements and fix life considerations.

8. Mixing various types of improvements to maintain viable options in the construction industry.

9. Considering the type of network; Interstate set-aside for 40 percent of work, NHS versus STP systems.

10. Reviewing funding limits/budget.

11. Special considerations that uniquely apply to certain districts such as $2 million maximum cost per project in the northern four districts.

6.6   Step 6 - Project (Program) Submittal and Approval

The objectives of this step are to evaluate and approve a three-year program for each district and to program the new projects so that design may begin. The step starts with the submission of the prioritized project list to the Project Screening Committee to review, select and program. The submitted projects have been prioritized and scoped

in detail by members of the district project development team. The step ends with project's selection and approval. After the Project Screening Committee has met with each district to finalize their three year program, a report of the selected projects is . submitted to the Highway Steering Committee for official approval. The projects are then added to the MAP database through Program Revision Requests.

The tasks in this step include:

1. Compilation of the prioritized project lists submitted by the various districts.

2. Checking information for accuracy.

3. Prioritizing the statewide group of projects using the Road Surface and Base (RSB) Prioritization Program.

4. Determining statewide strategy from projects submitted, and enter strategy into the Road Quality Forecasting System (RQFS) to determine long term results.

5. Producing reports and maps to assist the Project Screening Committee in evaluating projects.

6. Sending the results of the Project Screening Committee's review to each district.

7. Holding a meeting of the Project Screening Committee with each district to review their three year program.

8. Sending the final selections to the Highway Steering Committee for approval.

9. Placing the new projects on the MAP database.

Several factors are taken into consideration during the selection of the new projects. These include geographic balance, consistency with statewide goals and objectives, long term projected performance of MDOT's strategy from RQFS, District long range plan, results of the RSB prioritization program, Interstate and Non-Interstate balance, and NHS & Non-NHS balance.

It should be noted that, typically, for each candidate project, the pavement management engineer estimates the cost of the project and solicits inputs (step 4) of, and information from, various units within the district. Examples of the types of solicited information and the source of such information are summarized in table 4.2.

Table 4.2. Scope and estimates of the cost of candidate projects.

Units	Type of information/action	District
Maintenance	Investigating underground culvert, sewer, utility, etc. Obtaining inputs regarding areas of concern.	
Survey	Reviewing the candidate projects with design and construction. Determining the needed type of survey and its cost.	
Real Estate	Reviewing and determining the availability of right of way and its cost.	
Utility and Permits	Determining the need for utility relocation and its cost.	
Traffic and Safety	reviewing the candidate projects with construction to determine traffic control methods, geometric improvements, and their cost.	
Construction	Investigating soil cores or bore holes, recommending pavement design, and estimating construction cost.	
Design	Reviewing and recommend preliminary engineering and checking that guides and standards are followed.	
Resource Specialist	Determining potentially contaminated areas and possible tree removal and replacement and their costs.	
District Engineer	Reviewing the overall estimating procedure and traffic control policy.	