Evaluation, Selection and Planning The Implementation of a Pavement Management Optimization Model

Phase II Report

Prepared for

The Pavement Management Optimization Committee
Gerald T. Solbeck, Program Management
Marlee Walton, Transportation Research
Brian R. McWaters, Design
Kevin B. Jones, Materials Laboratory
John E. Pierce, Information Services
Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010

Prepared by

T.H. Maze and Omar G. Smadi
Iowa Transportation Center
2521 Elwood Drive, Suite 125
Ames, Iowa 50010

May , 1994

EVALUATION, SELECTION AND PLANNING THE IMPLEMENTATION OF A PAVEMENT MANAGEMENT OPTIMIZATION MODEL - PHASE II REPORT

PROJECT MISSIONS

The missions of the research are to assist the Iowa Department of Transportation (Iowa DOT) to:

- Define pavement management (PM) optimization.
- Identify the characteristics of PM optimization systems being developed or implemented.
- Identify specific and achievable objectives for the Iowa DOT pavement management optimization.
- Evaluate different PM optimization methodologies.
- Identify a methodology to perform PM optimization that best satisfies the Iowa DOT's objectives.
- Develop a plan for the implementation of the PM optimization selected.

The project is divided into three (3) phases. The first phase has been completed and accomplished the first three missions (identified above). The second phase has been completed and accomplished the next two missions. Phase three will accomplish the last mission.

INTRODUCTION

The purpose of this report is to briefly document the activities and accomplishment of Phase II. A comprehensive report will be completed at the end of the third phase.

Because the work is exploratory in nature, it is being conducted utilizing a close working relationship between the Iowa DOT and the Iowa Transportation Center at Iowa State University

(ITC/ISU). The connection between the two organizations is being maintained through an Iowa DOT employee Pavement Management Optimization Steering Committee. The committee members and the ITC/ISU researchers meet informally on a regular basis but formally meet at least once per month. The work and the direction for the research is recursive, with each task being guided by information determined in the prior task.

The Pavement Management Optimization Steering Committee and other Iowa DOT staff have met for two major working sessions, one during each of the first two phases. The first session (part of phase one) was held in January, 1993 and covered a briefing on the project, a workshop on pavement management optimization, and a presentation of the objectives developed for the Iowa DOT's pavement management optimization system. The second session (part of phase two) was held in April, 1994 and reviewed the pavement management optimization models evaluated and recommended two commercially available pavement management optimization computer models. One of the two models is more appropriate for project and short-range network level analysis and the other's primary purpose is for planning and long-range network level analysis.

PHASE TWO - SELECTION OF AN OPTIMIZATION METHODOLOGY

During phase II, the researchers worked with the Pavement Management Optimization Steering Committee to select a pavement management optimization methodology. During phase II, the committee and researchers explored available optimization implementation options to the Iowa DOT following three different approaches. They included:

- Conducting site visits to other state transportation agencies. Each agency visited has its own unique approach to pavement management. The purpose of the visits was to attempt to understand why the agency chose to implement its own unique approach, how the agency implemented a pavement management optimization system, and the day-to-day interaction between the pavement management process and highway management decisions. Three state transportation agencies were visited; the Kansas Department of Transportation, the Texas Department of Transportation, and the North Dakota Department of Transportation. The Kansas Department of Transportation was one of the agencies to very early adopt a network level, mainframe computer, pavement management optimization system. The Texas Department of Transportation has had districts with pavement management optimization models and is now developing a sophisticated and expensive mainframe project and network level pavement management system. The North Dakota Department of Transportation has adopted a commercially available and widely used microcomputer pavement management optimization system. Ultimately, the committee and the researchers recommended the Iowa DOT adopt the same software package employed by the North Dakota Department of Transportation.

- Invite vendors with currently operating pavement management systems to make presentations (in writing or in person) on their pavement management system. Five vendors presented software packages. The five vendors included Deighton Associates Limited, PCS Law Engineering, Decision Focus, Inc., ERES Consultants Inc., and Pavement Management Systems Consultants. All the pavement management systems presented were microcomputer packages. Two packages were presented in writing only. Three vendors made presentations to the committee and the researchers. All presentations were made during the summer of 1993.

- The committee and the researchers selected two of the systems for bench testing. The bench testing consisted of requesting the vendor to provide on-site training on their software package (in both cases, a contract was established with the vendor for training) and the coding of Iowa pavement data for analysis by the software. The bench testing of the software involved application of the package to Iowa DOT roadways but only involved a mock application of the software. The application was considered mock because much more thorough model development and calibration process would be required if the models were actually implemented for use by the Iowa DOT.

Pavement Optimization Evaluation Working Session

To promote better understanding of pavement optimization and pavement management systems in general, several Iowa DOT staff members were invited to attend a pavement optimization evaluation working session. The purpose for the working session was to present the findings of phase two activities. These findings presented the following activities:

- Field visits to state highway agencies to investigate the pavement management optimization methodologies utilized.

- Pavement management system presentations by vendors.

- Sample applications (bench tests) for two different PMS optimization softwares.

- Final pavement management optimization system recommendations.

To support the work session, the ITC/ISU researchers developed visual aids covering the activities during phase two. Work session material is included in Appendix I.

AGENDA

<u>EXECUTIVE SESSION</u>: The first two hours of the work session will cover the findings and recommendations only.

1. Introduction:

* PMS Overview
* Project Background
* Phase I Overview
* Phase II Overview: Objectives
Work Plan

2. Software Selection Process:

* Attributes of software identified
* Bench test findings
* PMS optimization system recommendations
* Optimization system implementation and integration recommendation
* Future activities - Optimization implementation plan

3. PMS System Demonstration

<u>TECHNICAL SESSION</u>: The second two hours of the work session will cover the project activities to date and technical issues.

4. Summary of Filed Visits: Findings
Advantages
Disadvantages

* Kansas
* Texas
* North Dakota

5. Summary of PMS Consultant's Presentations: Optimization System Used
Advantages
Disadvantages
Cost

* Deighton Company, Canada
* PCS Law, USA
* Decision Focus and Clayton Sparks, USA and Canada

6. Software Training and Bench Testing: Procedure
Data
Results
Sensitivity Analysis

* Deighton PMS
* DFI and Clayton Sparks PMS

7. Discussion of Implementation Plan Process

FIELD VISITS:

Three different state DOTs were visited to investigate their pavement management optimization methodologies. Before planning the site visits, a questionnaire was developed to help in determining the critical aspects of each PMS investigated. The questionnaire is part of Appendix II. The three state agencies visited were: Kansas; Texas; and North Dakota DOTs. The following is a summary of each visit.

Kansas Department Of Transportation

Date of Visit: July 13th, 1993

Visiting Team:

Iowa DOT-	Gerarld Solbeck
	Marlee Walton
	Brian McWaters
	John Pierce
	Kevin Jones
ITC-	Tom Maze
	Omar Smadi

Introduction:

The total highway system the Kansas Department of Transportation (DOT) manages through their Pavement Management System (PMS) consists of roughly 10,000 centerline miles. The Kansas DOT has a comprehensive highway program to manage the entire highway network. The program consists of the following funding programs.

1. Major Modification Program (MMP) ($271 million, 200 miles)
2. Substantial Maintenance Program (SMP) ($76 million, 1200 miles)
3. System Enhancement Program (SEP) ($62 million)
4. Routine Maintenance Program (RMP) (8600 miles)
5. Bridge Priority Program (BPP) ($18 million)

The highway system is surveyed once every year in one mile segments. The survey starts in March and it takes three months to cover the whole highway network. The Kansas DOT's PMS is used in developing the Major Modification Program and the Substantial Maintenance Program. The following is a brief summary of each program and the prioritization and the optimization methodologies used.

Major Modification Program (MMP) (Prioritization Approach)

This program covers the interstate and non-interstate roadways and bridges. The program is based on a prioritization formula that determines the priority of each project. The formula weight the four factors in developing a priority for the projects as shown below:

Factor	Weight
1. Commercial traffic	14.0%
2. Rideability	18.9%
3. Pavement Structural Evaluation	44.7%
4. Observed Condition	22.4%

The project rankings, determined by using the prioritization formula, are then adjusted for several factors to reach the final result. These factors are:

1. State Transportation Plan (STP) classification
2. Traffic volume and number of lanes
3. Divided or undivided highway
4. Stabilized shoulders

Substantial Maintenance program (SMP) (Optimization Approach)

The largest (in terms of mileage) program managed by the PMS is the Substantial Maintenance Program (1200 miles). There are two systems used to assist in programming the SMP, the network level optimization system (NOS) and the project level optimization system (POS). The two systems are supported by the pavement management information system (PMIS). The following section provide a brief description of each system and covers the implementation and the optimization processes used by the Kansas DOT.

Optimization Methodology:

The following steps are carried out to perform the optimization process:

1. Divide network into uniform segments
2. Define the condition state
3. Define feasible actions and obtain cost
4. Forecast performance[1]
5. Determine maintenance policy[2]

Implementation:

The Kansas DOT PMS is divided into three different systems. Those are: The network optimization system (NOS); the project optimization system (POS); and the pavement management information system (PMIS).

1. Network Optimization System (NOS): In addition to the optimization information, the following information is needed:

- Rehabilitation budget
- Project locations
- Minimum performance requirements
- Feasible rehabilitation actions
- Constraints and objective functions (OF):

Fixed Budget (constraint) ---> Maximize Performance Standard (OF)
Fixed Performance Standard (constraint) ---> Minimize Cost (OF)

Pavement condition is forecasted utilizing a probabilistic approach (Markov chains). To use Markov chains, the highway network is divided into different categories. For each category a transitional probability matrix is developed to predict future pavement condition. Kansas DOT has 23 different pavement

---

[1]Performance: Change in the condition state over time for each pavement segment.

[2]Maintenance policy: A set of rules to assign an action to each pavement section for the entire planning horizon (5 years)

categories that depend on the following factors: Interstate or other; pavement type; roadway width; and load range. Linear programming is used to solve the optimization system on a mainframe computer

2. Project Optimization System (POS): The POS operates in two modes, the rehabilitation and the new design modes.

   a. Rehabilitation mode: It provides the necessary information for the substantial maintenance program (SMP).

      - Budget and performance are constrained by NOS
      - Works with portfolio of projects
      - POS performance models utilize engineering data and model NOS distress
      - Objective function: Maximize Relative Benefits

   b. New Design Mode: Not fully utilized by the Kansas DOT

3. Pavement Management Information System (PMIS)

   The PMIS is a very important part of the Kansas PMS. It contains all the necessary data to feed into the NOS and the POS. The PMIS performs the following functions:

   a. Provide NOS/POS support
   b. User friendly
   c. Standard and ad-hoc reports
   d. Relational database
   e. Provide a platform for the NOS/POS surveys:

      NOS survey
      - 4 two person crews (10-12 weeks)
      - 2 South Dakota Profilometers
      - 2 distress survey vans
      - Cost = ($11-$12)/mile

      POS survey
      - 2 three person crews (5-6 months)
      - 2 falling weight deflectometers
      - 2 vehicles and 4 pickup trucks
      - Cost = $70/mile
      - Total of 1200 miles

Resources Required

1. Computer equipment: Mainframe

2. Ingress database running on Unix

3. Programming language: SQL

4. Staff: 4 in the PMS office (experienced with computers)

General comments

1. Implementation Time: 3 years

2. Implementation Cost: $750,000

3. Office responsible for the PMS: Operation

4. Offices using the PMS: District, Planning, Operation, and Maintenance

5. Short falls:
    - Not easy to explain the optimization model
    - Limitation on the number of states (conditions)
    - Computer and data intensive
    - Requires an annual survey

Texas Department of Transportation

Date of Visit: July 19th, 1993

Visiting Team:

Iowa DOT-	Marlee Walton
	Brain McWaters
	John Pierce
	Kevin Jones
ITC-	Tom Maze
	Omar Smadi

Introduction

Texas Department of Transportation manages a large paved highway network that consists of 78,000 centerline miles. The agency is extremely decentralized. The Texas DOT has 24 districts that make their own pavement management decisions. Due to the decentralized style of operation, the Texas DOT is utilizing a bottom-up approach to pavement management systems. The Texas DOT has an annual highway maintenance budget of $2 billion of which $1.6 billion are used for construction, and $0.4 billion for maintenance.

Texas pavement management system (PMS)

The Texas DOT PMS is built into a pavement management information system (PMIS). The PMIS provides data to the districts to support district level pavement management activities. The PMIS objectives were developed through a committee process. The committee included representatives from the districts, the central office, university highway researchers, and from the universities transportation centers. A set of different pavement management objectives was developed, then the committee selected the appropriate pavement management objectives to be achieved through the development of the Texas PMIS.

The PMIS in its current status provides the following information.

1. History data (maximum of 20 years)
2. Pavement design procedures
3. Pavement condition data
4. Database capabilities in terms of data storage, retrieving, and reporting.

After the completion of the system, the PMIS will provide the following additional functions:

1. Pavement condition forecasting
2. Project selection and scheduling through the use of economical analysis
3. Project and network level pavement management analysis

The PMIS has been designed in-house, with help from universities and contract programmers. The PMIS serves as a tool for both the network and project levels analysis. For the network level analysis, the Pavement Management Section (PMS) and the Maintenance Management Section (MMS) are responsible for the decision making process. On the other hand, Construction, Design, and Material offices are responsible for the project level decision making. The whole system goes into a feedback loop to update and modify the PMIS. Figure 1 describes the Texas DOT PMIS structure.

As part of the PMIS, pavement condition forecasting system, which predicts the pavement network condition responses to various inputs, is carried out. The factors considered in modeling the pavement condition are:

1. Traffic
2. Materials
3. Design thickness
4. Climatic variables

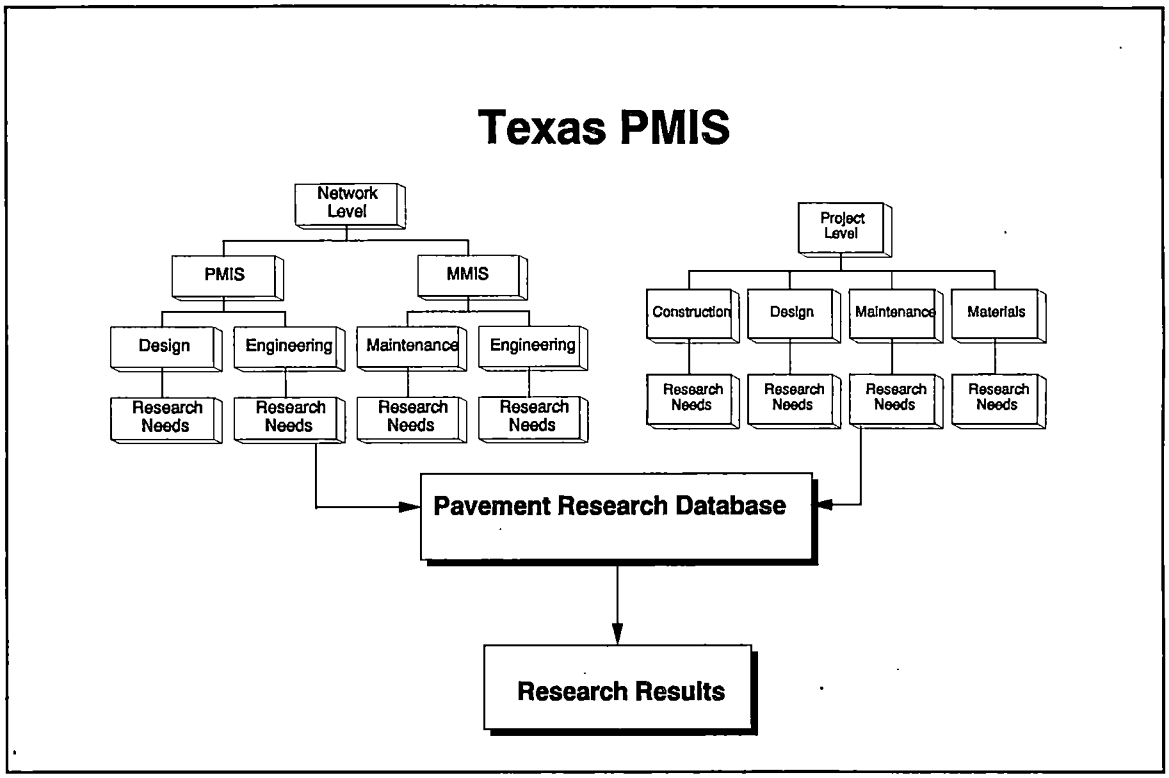


Figure 1 Texas DOT PMIS structure

This current and forecasted pavement condition information is used to support pavement management decision making. To perform pavement management optimization, the Texas DOT is utilizing a heuristic economic analysis methodology, incremental benefit cost, which performs network and project level analysis. The incremental benefit cost methodology utilizes the use of deterministic pavement condition forecasting methods. The Texas DOT PMIS uses performance curves (utility functions) for each distress to perform pavement condition forecasting. A very important part of the PMIS is the pavement management data (condition surveys, inventory). To insure data reliability and consistency between districts, the Texas DOT has developed the following procedures for performing the condition surveys. The district offices share equipment and the main office provides all the training for the evaluation teams.

1. Short-Term procedure (Different distress teams rating different districts)

2. Long-term procedure (Automate the data collection process)

3. Personnel for distress rating go through training annually (230 personnel in 1993)

4. Data is collected every year with a 50% sample (interstate network is 100%)

Pavement condition is determined through distress ratings. PMIS distress ratings are developed for:

1. Asphalt Concrete Pavements

2. Continuously Reinforced Concrete Pavements

3. Jointed Concrete Pavements

The rating measures are:

1. Surface rutting

2. Cracking

3. Patching

4. Other pavement defects (failures,joints,etc...)

These different rating values are then converted to a condition score. The PMIS has five different condition scores to describe the quality of Texas pavements:

1. Distress score

2. Ride score

3. Condition score (Distress and Ride)

4. SSI score (Structural Strength Index) (based on deflection)

5. Skid score (safety issues)

Pavement Management Solutions:

This section will describe the PMS process that the Texas DOT performs now and cover future plans for the PMIS. The funding, allocation, and selection of projects is performed now based on a prioritization approach. The future plan for the PMIS is to utilize a heuristic economic analysis approach (near optimization) utilizing the incremental benefit cost analysis. The following is a brief description of each approach.

1. Prioritization approach.

This approach will answer questions related to the maintenance and system condition. The allocation process between different districts is based on a ranking (prioritized) formula that consists of the following parameters.

a. Traffic (ESAL) 45%

b. Lane miles 45%

c. Pavement score 10%

2. PMS Optimization.

The optimization approach, as mentioned earlier, is included in the PMIS. The incremental benefit cost analysis used, which performs project level analysis, is a near optimization approach that utilizes the use of deterministic pavement prediction models. The following is a brief description of the procedure followed to perform the optimization.

a. Determine needs and impact analysis

b. Pavement network is divided into two types of sections:

- Data collection sections- 190,000 (a section of pavement, 0.5 mile long, on which the PMIS summarizes its pavement and other data)

- Management sections- 11,000 (a section of pavement of similar structure, that the engineer intends to maintain in a uniform manner)

c. Determine treatment Category:

- NN: Needs Nothing
- PM: Preventive Maintenance
- LRHB: Light Rehabilitation
- MRHB: Medium Rehabilitation
- HRHB: Heavy Rehabilitation / Reconstruction

d. Pavement condition is forecasted using performance curves.

e. Benefits are calculated using the area under the performance curve. Two values for the benefits are calculated, one from the ride score curve and the other from the distress score curve

f. Procedure:

- Consider a management section that went through the needs analysis

- Determines cost and needed treatment from step 1

- Determine the usefulness of the pavement from each distress using utility theory. (Utilities were determined by expert opinion and regression analysis)

- Forecast into the future (done for each individual distress)

- Repeat for all sections

Resources required:

1. PMS staff: 20-25 personnel

2. PMS engineering staff: 5-6

3. PMIS staff: 2 engineers and 3 engineering assistants

4. Computer equipment:
   - Mainframe system
   - Database platform (Adabase)
   - programming language (SAS)

North Dakota Department of Transportation

Date of Visit: July 29th, 1993

Visiting Team:

Iowa DOT-	Gerald Solbeck
	Marlee Walton
	Brain McWaters
	John Pierce
	Kevin Jones
FHWA-	Frank Howell
ITC-	Tom Maze
	Omar Smadi

Introduction:

North Dakota Department of Transportation (DOT) in comparison to the other states visited (Kansas and Texas) operates a smaller highway network. The DOT manages 7,300 centerline miles of paved system, with an annual budget of $200 million. $80 million is used for construction and $30 million for rehabilitation. North dakota DOT took a different approach in developing their pavement management system (PMS). Districts, cities, and counties were involved in the selection process as partners with the DOT. They selected a commercial PMS package (Deighton PMS), and it was customized to fit their needs. Now the PMS is used by the DOT, 4 different districts, and 7 different cities in the state.

Pavement Management System Database:

The North Dakota DOT started building their PMS database in 1985. They started with an infofile (flat data file). In 1991, the state DOT purchased a PAVETECH, a video inspection vehicle, for distress collection. After purchasing the PAVETECH and the PMS package, the database now resides in a relational database platform using dROAD (part of the Deighton PMS package).

PMS Optimization:

The North Dakota DOT PMS uses an optimization approach to perform the pavement management analysis. The optimization approach will perform the following functions:

1. Determine needs and impact analysis
2. Provides for project and network level analysis
3. Pavement performance prediction using performance curves (Deterministic)
4. Projects locations and costs as a result of the analysis

Optimization Methodology:

The North Dakota DOT PMS utilizes the incremental benefit cost methodology to perform the resource allocation analysis. The incremental benefit cost analysis is a heuristic economic approach that approximates optimal results. It's capable of performing network, as well as, project level analysis. The computer model will perform the following functions.

1. Pavement performance prediction

Performance curves are used for forecasting pavement condition using different indices. North Dakota DOT has two performance indices for each pavement category:

a. Structural Distress Index

b. Overall Performance Index

In total, the DOT has 42 different performance curves depending on pavement surface (3) and pavement class (13)

2. Calculate benefits (maximum analysis period of 50 years)
3. Generate strategies (maximum analysis period of 20 years)
4. Allocate resources through project selection and scheduling.

Resources Required

PMS staff: 4 personnel

Engineering staff: 2 engineers

Personal computer based system

Relational database platform (dROAD)

PAVEMENT MANAGEMENT SYSTEM PRESENTATIONS:

The committee first conducted a search of commercially available pavement management optimization packages which were suitable for large scale pavement management optimization capabilities. Ultimately five vendors were asked to make presentations to the Pavement Management Optimization Committee. Initially, three vendors were asked to make verbal presentations to the Committee. Two additional vendors were selected and asked to make written presentations. If the committee view the written presentations as promising, the two additional vendors would be invited to make verbal presentation. Three consulting firms were invited to present their Pavement Management Software package to the Pavement Management Optimization Steering Committee. The consultants invited to make presentation were selected through a search of commercial pavement management packages. Two additional consultant were asked to provide the committee with written presentations covering their software. Neither was invited to make a presentation to the committee. The following sections provide a brief summary of the 5 systems reviewed. The software vendors that submitted presentations were:

- Deighton Associates Limited
- PCS Law Engineering
- Decision Focus Inc. and Clayton/Sparks and Associates
- ERES Consultants, Inc.
- Pavement Management Systems Consultants

Deighton Associates Limited

Date of presentation: June 1, 1993

The Deighton Associates PMS software package consists of three different modules. Each module can be operated as a stand-alone or with the other modules. These modules are:

dROAD (Relational database)

dTIMS (Total Infrastructure Management System)

dMAP (Mapping application using AUTOCADD)

dROAD: The database structure consists of three components:

1. Perspectives: the basic highway network data structure can be divided into different perspectives. For example, history, inventory,

pavement management, and test data perspectives. Each perspective can have a different reference location method and different section lengths. Some perspectives might be point perspectives, such as accidents and sign locations.

2. Logical data groups: each perspective is divided into different logical data groups. For example, consider the pavement management perspective, It can be divided into different logical data groups according to the agency needs. Traffic, condition, geometries, and test data will be the logical data groups.

3. Database fields: each logical data group is divided into data base fields. For example, consider the traffic logical data group that belongs to the pavement management perspective. This group can be divided into different data elements, annual traffic, cumulative traffic, annual ESAL's, and cumulative ESAL's. The same can be done for all other logical data groups and perspectives.

The data base structure is very flexible and it can be used for other than pavement management systems functions. dROAD has been used by other agencies for sign management, safety management, and human resources management systems. A notable feature in the data base is dynamic segmentation. Dynamic segmentation allows the user to work with different referencing methods for the highway network, while being able to express the data from different perspective using different referencing methods. Figure 2 explains the relationship between perspectives, logical data groups, and database fields.

Highway Network Data Structure

Perspectives	Traffic	Inventory	Condition	History
Logical data groups	18K ESAL Truck data	" "	" "	" "
Database fields	1990 1991 1992			

Figure 2 Relationship between perspectives, logical data groups and database fields

dTIMS: dTIMS contains the decision tool used to perform pavement management optimization for both network and project levels analysis. The process is divided into four steps:

<u>Step 1</u>: Identify pavement condition indices. dTIMS allows the user to have multiple pavement condition indices. For example, an agency can have an overall pavement condition index like pavement condition rating (PCR) and also have different condition indices for individual distresses.

<u>Step 2</u>: Define performance curves for each condition index. Performance curves are used to determine pavement condition in the future.

<u>Step 3</u>: Define a set of feasible maintenance treatments for the highway network. Those treatments can be defined for different pavement types. Treatments can be divided into maintenance and rehabilitation.

<u>Step 4</u>: Define trigger values for the different maintenance treatment alternatives. The trigger is the minimum or maximum value for a certain condition index. If the trigger value is reached, a specific maintenance action will be applied. For example, a trigger might be the following: If the value of the pavement condition rating (PCR) is less than 40 then pavement reconstruction will be carried out.

The program then performs Incremental Benefit Cost (IBC) analysis for different budget scenarios to determine optimal project selection and scheduling. The IBC is a heuristic economic analysis technique that is used to approximate an optimal solution. The basic mechanics of IBC are described below.

1. Predict pavement condition using deterministic performance curves.

2. Calculate the benefits for each feasible maintenance strategy. The benefits are calculated using the area under the performance curve. The difference in the area between the routine maintenance and another maintenance alternatives (overlay or reconstruction) is called the incremental benefit.

3. Determine the cost.

4. Calculate the incremental benefit cost ratio.

5. Repeat steps 2, 3 and 4 for all feasible maintenance treatments and sections.

Figure 3 shows the incremental benefit cost calculations.

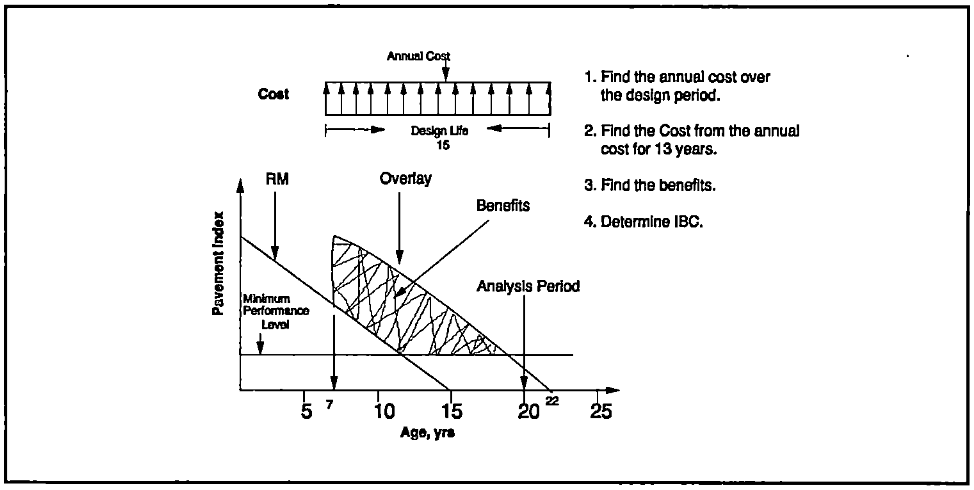


Figure 3 Incremental benefit cost calculations

dMAP:

dMAP is a mapping application that uses AUTOCADD version 11. It enables the user to display data from different perspectives in dROAD and also the results (pavement condition, maintenance actions) from dTIMS. dMAP is not a true GIS application, but it provides graphical representation for the pavement management data. To operate dMAP, the user has to code all the highway links into AUTOCADD which can be a difficult task depending on the availability and condition of the data.

PCS Law Engineering

Date of presentation: June 4th, 1993

The PMAP system (Pavement Management and Planning) is divided into different modules:

1. Database management. The database manager includes a relational structure and allows for dynamic segmentation

2. Reporting module. The package includes a flexible module for the creation of reports in tabular format, and it also allows creation of charts and maps and their inclusion in reports.

3. Pavement maintenance needs analysis.
   - Performance curves for pavement condition forecasting.
   - Maintenance needs depending on the pavement condition.

4. Multi-year budget analysis including:
   - Single year prioritization using a ranking technique. Pavement sections are ranked according to the pavement condition.

   - Multiple budget categories including maintenance and rehabilitation. Also the effect of different budget scenarios on the pavement condition can be determined.

The current version of the system is only able to perform prioritization analysis for one year and does not consider projects in the future when the model allocates resources to projects. Some future enhancement are scheduled for future versions of the software.

1. Project grouping module

2. Multi-year analysis

3. Convert to Microsoft Windows

4. Pavement type selection procedure

Decision Focus Inc. and Clayton/Sparks and Associates

Date of presentation: June 15, 1993

The software package provided by these two consultants was developed originally for the Road and Traffic Authority for New South Wales, Australia (RTA). Currently, the software is provided through a partnership between the two vendors, Decision Focus Inc., based in California, and Clayton Sparks Associates, based in Canada.

The software package provides an integrated approach to asset management. The software has a very extensive set of modules. Each module may be operated independently. The modules include:

RR (Road Register): it allows the user to inter data and perform queries and summaries

CMIS (Condition Management Information System): this is used to access the information in the condition database. It is capable of integrating any relevant condition database like roads and bridges.

LCC (Life Cycle Costing): its is used to compare costs for various maintenance alternative programs.

PPE (Pavement Performance Evaluation): it provides the engineer or the manager with a tool to analyze pavement condition data and obtain statistical information on pavement performance.

TNOS (Treatment scheduling Network Optimization System): this module is used to help road managers and engineers to allocate their highway maintenance budget to different projects in the most efficient manner.

FNOS (Financial planning Network Optimization System): this module is used to help road managers and engineers to predict the budget needed to maintain their highway network at a certain performance standard.

The algorithms built in the optimization systems (network and project levels) right now are:

1. Markov decision process (solved by a linear program) for network level analysis (resides in FNOS). This is a probabilistic optimization model that is used for network level analysis (maximum of 20 years). To run FNOS, the user should provide the following: Pavement condition states, transitional probabilities for forecasting, treatment alternatives, and performance standards. As results from FNOS, the user will get the required budget to maintain minimum performance standards and percentages of the highway network in each maintenance alternative.

2. An economical analysis model (solved by an integer program) for project level analysis (resides in TNOS). This is a deterministic optimization model used for project level analysis (maximum of 5 years). To run TNOS the user should provide the following: Section identification information, distress performance curves, maintenance alternatives and costs, and budget numbers. As results from TNOS, the user will get a schedule of projects selected to be maintained or rehabilitated for the analysis period. Cost numbers will also be provided as part of the results.

The vendors are proposing to include the capability to adjust condition prediction parameters based on conditional information. For example, statistical estimates of condition prediction parameters may be adjusted to reflect the expert opinion. This approach to parameter estimation is the Baysian approach. Also the use of Semi-Markov for the optimization process in FNOS is considered. Semi-Markov is different than Markov in terms of considering the time dimension. Semi-Markov will reduce the computations needed to reach an optimal solution. A discussion of Semi-Markov will be done in the next phase.

ERES Consultants, Inc.

Provided a written report followed by a phone interview

DSS (Decision Support Systems). The system characteristics are:

1. Personal Computer based system in windows environment
2. Can be linked to AUTOCADD or Intergraph for mapping or GIS applications
3. Uses deterministic performance prediction through the use of performance curves
4. Prioritization approach that does not consider multi year analysis

The prioritization approach adopted utilizes an economical analysis methodology (benefit cost ratio). The program will calculate the benefits by determining the area under the performance curve for each feasible maintenance action. The benefit cost ratio (B/C) will then be calculated for all feasible maintenance actions for all sections. Finally, projects will be prioritized according to the B/C value. The PMS program will perform the following pavement management functions:

1. Pavement performance prediction

2. Economic analysis (Benefit cost)

3. Life cycle cost analysis for different alternatives

4. Treatment strategy selection

Pavement Management Systems Consultants

Provided a written report followed by a phone interview

PMS (Pavement Management System). The system characteristics are:

1. Personal Computer based system

2. Deterministic performance prediction

3. Project and network level analysis

4. Economical analysis approach

The optimization approach adopted will perform the following pavement management functions:

1. Marginal cost effectiveness (MCE), an approximation of the incremental benefit cost analysis, which in turn is an approximation to optimization.

2. Performance curves for pavement condition forecasting. The program provides the user with built-in statistical regression techniques to help in building and calibrating the pavement performance curves.

3. Relational database that utilizes dynamic segmentation

4. Treatment strategy selection

As a result of the PMS presentations, and based on the needs and objectives of the Iowa DOT pavement management system, the Pavement Management Optimization Steering Committee and ITC/ISU researchers recommended further investigation in forms of training sessions and bench testing for two of the systems investigated. The following sections of the report provide a detailed description of these two activities.

PAVEMENT MANAGEMENT SYSTEM TRAINING SESSIONS:

As a result of the PMS reviews, the field visits, and the Iowa DOT pavement management optimization system objectives, two pavement management system training sessions were planned for two commercially available PMS packages. One of the main objectives for the PMS training sessions was to get the necessary training to perform a bench test using the Iowa DOT data for the two optimization methodologies selected. The three consultants involved were: Deighton Associates Limited (based in Canada), Decision Focus Inc. (based in California) and Clayton Sparks Associates (Canada). The training sessions were designed to provide the Iowa DOT staff, involved with pavement management system activities, with the necessary information about the two software packages. The two training sessions were attended by 8-10 Iowa DOT technical staff. The training sessions covered the following topics:

1. Data requirements for each optimization methodology
2. Analysis methodology including optimization and performance prediction techniques
3. Computer program operation
4. Software and hardware requirements

Deighton Associates Limited

1. One week training session.

2. Extensive training on the use of dROAD and dTIMS

3. An overview of dMAP (mapping application)

4. Initial data load into the relational database (dROAD). The data loaded into dROAD consisted of different components.

   a. section identification information:
      - section number
      - road name
      - begin and end mile posts

   b. geometric:
      - section length and width
      - pavement type
      - age

   c. Traffic information:
      - annual ESAL
      - cumulative ESAL

   d. Test data:
      - pavement condition rating (PCR)
      - cracking (transverse and longitudinal)
      - patching
      - ride (IRI)
      - average road rater (ARR)
      - relative structural rating

5. Initial data load into dTIMS. The data consisted of:

   a. Performance curves parameters for different pavement types

   b. Treatment strategies and cost

   c. Trigger values for each treatment strategy

6. Sample runs and analysis. Different analysis periods and budget scenarios were run in dTIMS. The effect of changing budget scenarios on pavement condition was noticed. The results from each sample run were in the following format:

a. Selected treatment strategies

b. Year of implementation in the analysis period

c. Cost numbers

d. Summary results including:
- average network condition
- maintenance backlog
- funding impact analysis

DFI and Clayton Sparks Associates

The software package provided by these two consultants was developed originally for the Road and Traffic Authority for New South Wales, Australia (RTA). Currently, the software is provided through the cooperation of two vendors, Decision Focus Inc. and Clayton Sparks Associates.

1. Two-day training session

2. Introduction to asset management

3. General training on the different software modules. More time was spent working with the network level analysis (FNOS) and the project level analysis (TNOS) packages. A sample data file was used for the computer runs. Different budget scenarios were used and the effect on the average network condition was noticed.

4. BSTAT (Bayesian Statistical analysis software) overview. BSTAT is a statistical package that is presented through a menu-oriented Excel add-in. The package allows the user to perform a wide range of classical and Bayesian regression. The user will start by entering the observed data, then prior judgment. BSTAT will then calculate all the model coefficients and present the results in graphical and tabular format.

PAVEMENT MANAGEMENT OPTIMIZATION SYSTEM BENCH TEST:

Two different PMS optimization packages were bench tested using Iowa DOT pavement management system data (including the interstate system and part of the primary system). The objectives of the bench tests were:

1. In depth investigation of the PMS optimization software
2. Review of the optimization methodologies used
3. Determine the effectiveness of each software using Iowa DOT pavement data

The bench tests were designed to consider the following elements:

1. Data items
2. Bench test procedure
3. Bench test results
4. Sensitivity analysis

The data used in the bench test depend a great deal on the analysis methodology used to achieve optimization (Project level vs. Network level and Probabilistic vs. Deterministic). The following data items were used in each test.

1. Performance data:
    - Performance curves (Deterministic)
    - Transitional probabilities (Probabilistic)
2. Treatment data:
    - Trigger limits
    - Improvements
    - Cost
3. Analysis parameters:
    - Pavement states (depend on the pavement condition)
    - Budget numbers
    - Analysis period
    - Economic variables

Bench Test Description:

1. dROAD (Deighton database software):

* All the Interstate (428 sections)

* US highway 30 and 71 (148 sections)

* Data elements:
    - i. Highway name, begin and end mile post, and direction
    - ii. Test data: Friction, ARR, IRI, PCR, Crack and Patch
    - iii. Traffic: Annual ESAL, cumulative ESAL
    - iv. Geometric: Length, width, and pavement type

* Items tested:
    - i. Data manipulation features
    - ii. Queries
    - iii. Dynamic segmentation
    - iv. Reporting flexibility
    - v. Importing and exporting data from and into dROAD

* Results summary:

  The relational database (dROAD) is extremely flexible and provide extensive database management capabilities. The software is easy to use and can be customized to user needs. Data was entered into dROAD in two different perspectives, the PMS and ride perspectives. The PMS perspective consisted of all the pavement management sections (varied lengths). The ride perspective included all the ride test sections (0.1 mile segments). To test the dynamic segmentation feature, the average value of the ride from many ride test segments was automatically calculated for each pavement management section by dROAD. The data can be transformed in different methods such as the average, sum, first occurrence, maximum and minimum. dROAD has an extensive list of built in tabular and graphical reports. Also additional reports can be designed by the user. dROAD provide for software security through the use of user ID's and passwords. Also users can be assigned access levels to limit their access to certain features like removing or adding records. dROAD imports from and exports to dBASE and ASCI file formats.

2. dTIMS (Deighton analysis software):

* All the Interstate (428 sections)

* Data elements:
    i. Performance curves (6 pavement types)
    ii. Treatment alternatives and cost (3 alternatives)
    iii. Trigger values (2 to 4 for each pavement type)
    iv. Improvements
    v. Constraints: Budget
    vi. All the data from dROAD

* Items tested:
    i. Performance prediction (Performance curves)
    ii. The application of trigger limits
    iii. Treatment strategy selection
    iv. Reporting capabilities
    v. Flexibility and ease of use

* Results summary:

  dTIMS provide the analysis tool for pavement management optimization on both the network and project levels. The software is easy to use and can be customized by the user. Performance curves, trigger limits, treatment strategies, and benefit calculations can be modified by the user. The Iowa DOT requested two minor modifications to the analysis methodology in terms of calculating the benefits and costs for the incremental benefit cost ratio. Deighton Associates agreed to modify the software for minimal cost. The modifications will be performed before purchasing the software. Reporting in dTIMS was not satisfactory to the Iowa DOT. To solve this problem, the results from dTIMS can be imported to dROAD with minor effort, this will give added flexibility in reporting and management of dTIMS results and data.

3. FNOS (RTA analysis software):

* All the Interstate (428 sections)

* Data elements:
    i. Section length
    ii. Test data: IRI, Relative Structural Rating, Crack and Patch
    iii. Treatment alternatives (3 alternatives)
    iv. Transitional probabilities (one for each treatment)
    v. Constraints: Budget and performance

* Items tested:
    i. Performance prediction (Transitional probabilities)
    ii. Pavement condition states
    iii. Reporting capabilities
    iv. Flexibility and ease of use

* Results summary:

    FNOS performs network level pavement management optimization analysis. Performance prediction is performed utilizing Markovian transitional probabilities. The software is easy to use and is flexible to be customized by the user. It provides a standard set of tabular and graphical reports. More reports can be created by importing the data into a database or a spreadsheet program. There was a concern about the number of condition states that describe the pavement condition. The maximum number of states was 72, but with the new version of the software, it was increased to 256. This will provide added flexibility to the Iowa DOT if more states are needed in the future.

PMS OPTIMIZATION SOFTWARE RECOMMENDATIONS:

As a results of phase II, the Pavement Management Optimization Steering Committee and the ITC/ISU researchers will recommend a pavement management optimization software. The selection process covered the following criteria:

1. Iowa DOT pavement management system (PMS) objectives.
2. Analysis methodology (optimization was one of the Iowa DOT PMS objectives).
3. Analysis level (the system should perform network and project levels analysis).
4. Software requirements (ease of use, flexibility, and customization).

Based on the previous criteria, results from the site visits, and the PMS presentations, two software packages were selected for further investigation (Deighton and DFI PMS's). To finalize the selection process, training sessions and bench testing procedures were developed for the two softwares. From the results of the bench tests, the following recommendations were made. The recommendations are divided into four sections.

1. Database:

dROAD from Deighton Associates was selected to manage the Iowa DOT pavement management optimization database. dROAD will be supported by data from the Iowa DOT PMIS and the Office of Materials test data. Two copies are required @ $10,000 each.

2. Project level analysis:
dTIMS from Deighton Associates was selected, with minor modifications to the analysis methodology (a one time cost of $5,000), to perform project level analysis. It utilizes the incremental benefit cost analysis to perform project selection and scheduling. Two copies are required @ $10,000 each.

3. Network level analysis:

FNOS (from Decision Focus and Clayton Sparks) was selected to perform the network level analysis. Results from both models (dTIMS and FNOS) will help the Iowa DOT pavement management staff to calibrate their PMS model parameters. The two models provide different analysis methodologies in terms of performance prediction and optimization. Two copies of FNOS are required @ $2,500 each.

4. Baysian statistics analysis:

BSTAT from Decision Focus Inc. was selected to help the Iowa DOT in developing and calibrating their performance prediction parameters. BSTAT can be purchased through an annual license of $3,750. A training session for the Iowa DOT staff on using BSTAT will cost $6,000.

<u>CONCLUSIONS:</u>

The main purpose of phase II was to recommend a pavement management optimization software that is based on the Iowa DOT pavement management objectives. This was achieved and the results were discussed in the previous sections.

During the next phase of the project, phase III, an implementation plan will be developed to help the Iowa DOT implement, operate, and calibrate the optimization model for their pavement management decisions.

PHASE III:

During phase III, a pavement management implementation plan will be developed. The plan will be based on results from phase II. Phase III will consist of the following activities:

1. Develop a physical and logical structure for the pavement management at the Iowa Department of Transportation before and after the computer models have been implemented. This will include:
   - The development of the physical organization and structure under current conditions. This will include:
     - Developing an inventory of current personnel which are partially or completely assigned to pavement management activities and a description of their functions.
     - Describe how pavement management currently supports departmental decision making in the allocation of resources, and promotes improvements to design, material, construction, and maintenance decision making.
   - Develop a description of the physical architecture of the future computerized pavement management system. The physical architecture will identify the location of the physical assets (computers and software) and identify the relationship between the pavement management system and other computer data support systems (e.g., the relationship with the PMIS). The description will also include recommendations for security and data access.
   - Identify the likely changes in resource requirements (personnel and equipment), changes in personnel functions, and changes in decision making practices after the system is implemented.

2. Develop a plan for the implementation of new models. Implementation will require calibration of pavement performance and decision making models. The plan will identify the resources and time required to develop a fully operational versions of BSTAT, dROAD, dTIMS and FNOS.

3. Conduct a state of the art and a state of the practice review of semi-markov pavement optimization process. A plainly stated description will be developed identifying the theory of semi-markov models, the advantages of semi-markov models in comparison to other probabilistic performance forecasting methodologies, and the status of efforts to develop a commercial pavement management system founded on the use of semi-markov performance prediction models.

APPENDIX I

Work session material

Optimization Evaluation Seminar

Prepared for the Iowa DOT

Prepared by the Iowa Transportation Center, April 1, 1994

Iowa Transportation Center

Project Objectives

- Define Pavement Management (PM) Optimization
- Identify the characteristics of PM optimization systems being developed or implemented
- Identify specific and achievable objectives for the PM optimization that best satisfies the Iowa DOT's objectives
- Develop a plan for the implementation of the PM optimization selected

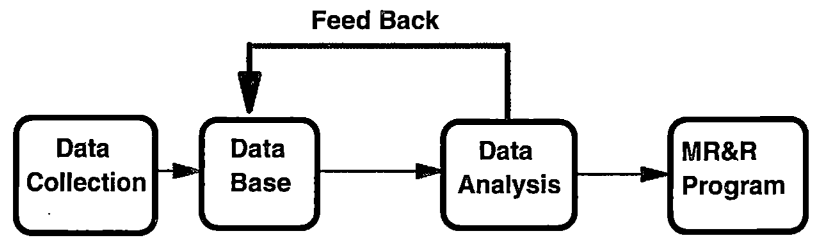
Iowa Transportation Center

Project Phases

- Objective Setting
  - Research Available Optimization Techniques
  - Prepare and Present a Working Session
- Selection of Optimization Methodology
  - Select Methodologies to Be Evaluated
  - Evaluate Candidate Methodologies
  - Present Seminar
- Develop Implementation Plan

Iowa Transportation Center

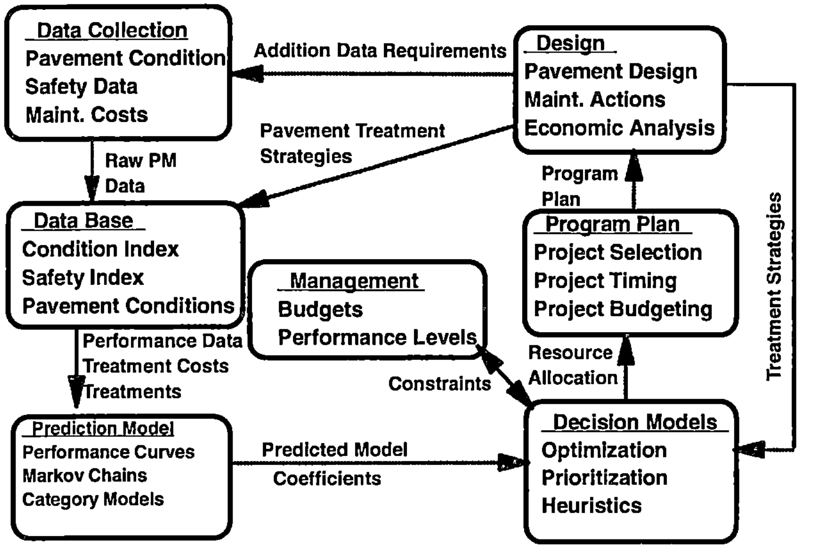
Fundamental PMS Functions



Pavement Management System

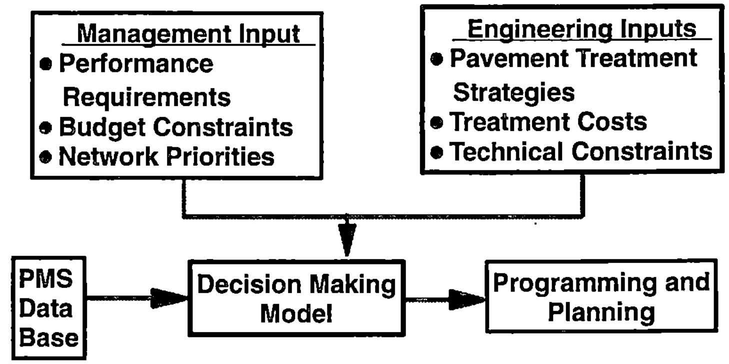
Iowa Transportation Center

PMS Modules



Iowa Transportation Center

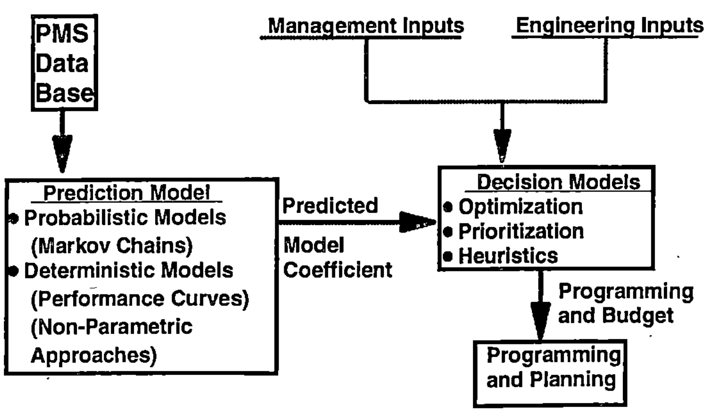
Fundamental PMS Functions



Inputs to Decision Making Model

Iowa Transportation Center

Fundamental PMS Functions



Iowa Transportation Center

Uses of Pavement Performance Prediction

Specificity

Project Level Analysis

Design Feedback

Estimation of the Type and Timing of Pavement M&R

Network Level Optimization

Iowa Transportation Center

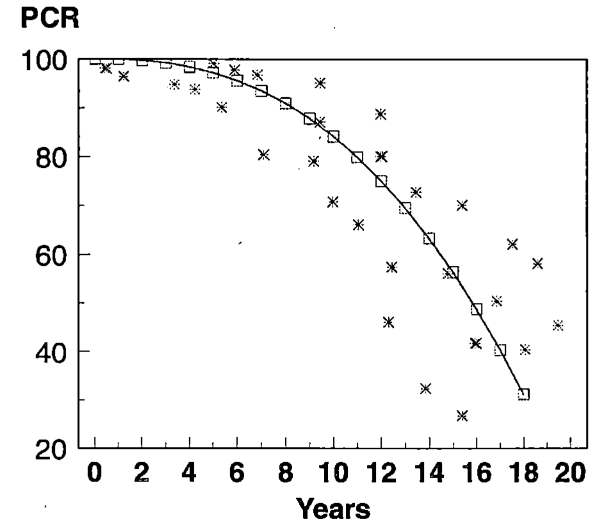
Types of Prediction

Assumption

- Deterministic, Assumes Away Measurement of Errors and Randomness
- Probabilistic, Loss of Specificity

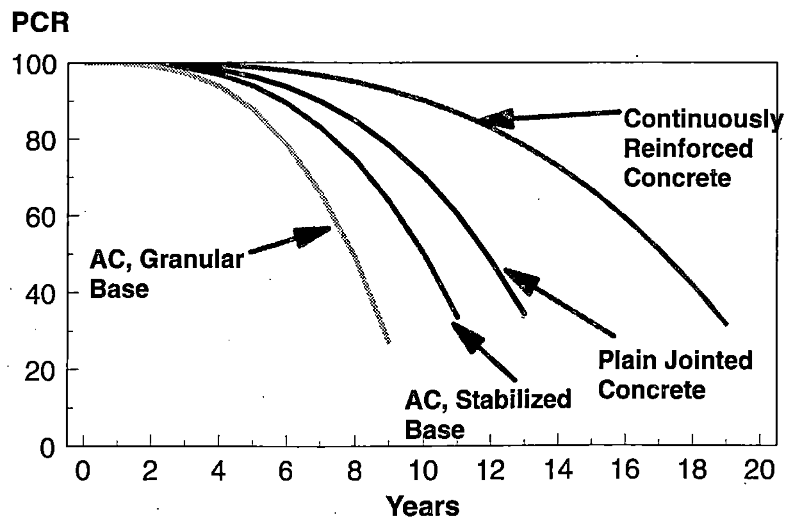
Iowa Transportation Center

Deterministic Performance Curve



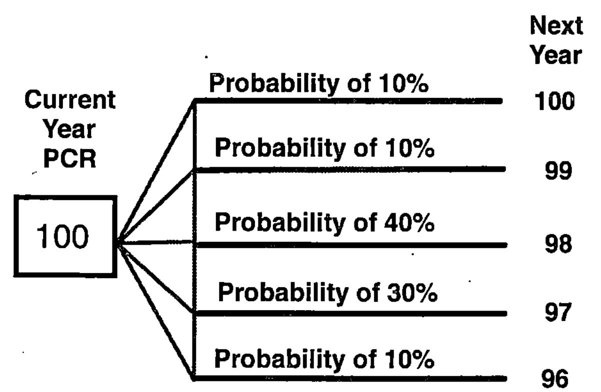
Iowa Transportation Center

Deterministic Performance Curves



Iowa Transportation Center

Probabilistic Prediction Model



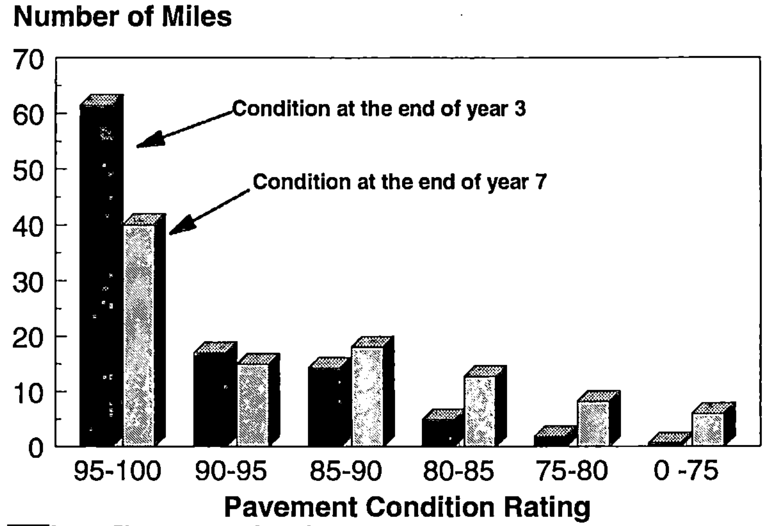
Iowa Transportation Center

Example Markov Chain

From PCR State	To PCR State					
	100 - 95	95 - 90	90 - 85	85 - 80	80 - 75	75 - 0
95 - 100	0.85	0.10	0.05			
90 - 95		0.65	0.30	0.05		
85 - 90			0.60	0.30	0.10	
80 - 85				0.55	0.30	0.15
75 - 80					0.40	0.60

Iowa Transportation Center

Distribution of Pavement Condition



Iowa Transportation Center

Phase I Findings

- Network Level Analysis
  - Markovian Optimization
    - Used by several states
  - Economic Analysis
    - Offers Project Level Solutions
  - Integer Programming
    - Offers Project Level Solutions
  - Prioritization

Iowa Transportation Center

Project Level Analysis

- Markovian Optimization
  - Unable to perform project selection
- Economic Analysis
  - Popular for project level selection
- Prioritization
  - Popular for project level selection

Iowa Transportation Center

Phase I Products

- Optimization Objectives
- Optimization Workshop
- State-of-the-art of pavement management practice
- Literature Database

Iowa Transportation Center

Phase II Objectives

- Evaluate PM optimization methodologies
  - Site visits, demonstrations, & bench tests
- Identify a methodology to perform pavement management optimization which best satisfies the Iowa DOT's objectives

Iowa Transportation Center

Phase II Overview

- Site Visits
  - Kansas DOT
  - Texas DOT
  - North Dakota DOT
- Site Demonstration
  - Deighton Associates
  - PCS Law Engineering
  - DFI & Clayton - Sparks
- Written Review
  - Pavement Management Systems
  - ERES Consultants

Phase II Overview - Continued

- On-site Training
  - Deighton
  - DFI & Clayton - Sparks
- Bench Test
  - Deighton
    - dROAD (Database)
    - dTIMS (Deterministic economic optimization)
  - RTA - PMS
    - FNOS (Markovian optimization)
    - TNOS (Combination heuristic - integer program)

Iowa Transportation Center

Software Selection Considerations

- Software Attributes
  - User Friendly
  - Consistency
  - Flexibility
  - Reporting Capabilities
  - Documentation
  - Technical Support
- Bench Test Findings

Software Attirbutes, Deighton

- dROAD and dTIMS
  - Easy to Use
  - Relational Database (Dynamic Segmentation)
  - Project and Network Level Analysis (20 Years)
  - Optimization - Heuristic using IBC
  - Useful Reporting Capabilities
  - Good Product Support

Software Attributes, RTA

- FNOS
  - Easy to Use
  - Quick Results
  - Network Level Analysis Only (20 Years)
  - Optimization, Markovian Optimization
  - Flexible
  - Expandible to Remaining RTA Packages

Software Attributes

- Deighton Bench Tested Software
  - dRoad
    - Database Capabilities
    - Dynamic Segmentation
    - Data Maniputlation
  - dTims
    - Performance Curves
    - Treatements
    - Triggers Values
    - Analysis Sets
    - Economic Analysis (heuristic)
    - Reporting

RTA PMS (DFI - Clayton&Sparks)

- FNOS
  - Condition States
  - Treatments
  - Transition Probabilities
  - Markovian Optimization (minimize cost or maximize condition)
  - Reporting
- TNOS
  - Performance Curves
  - Heuristic Coupled with an Integer Program
  - Data Intensive
  - Five Year Analysis Periods

Bench Test Description

- Deighton PMS Bench Test Parameters
  - dRoad Database
    - All 428 Sections of the Interstate
    - U.S. 30 and U.S. 71, 148 Sections
  - Date Elements
    - Highway, Mile Post and Direction
    - Test Data; Friction, ARR, IRI, PCR, Crack & Patch
    - Traffic; Annual ESAL & Cummulative ESAL
    - Location; Length, Width and Pavement Type
  - Dynamic Segmentation

Bench Test Description

- dTIMS
  - Interstate Only
    - Performance Curves, Five Types of Pavements
    - Treatment Alternatives and Costs
    - Trigger Values
    - Budget Contraints

Bench Test Description

- RTA FNOS, Interstate Only
  - Section Length
  - Test Data: ARR, IRI, Crach & Patch
  - Transition Matrix
  - Treatment Strategies and Costs
  - Budget and Performance Constraints

PMS Software Recommendation

- Date Base → dROAD
- Project Level → dTIMS
- Network Level → dTIMS & FNOS
- Performance Parameter → BSTAT

Iowa Transportation Center

System Operational Recommentation

- Estabilish A Single Point of Responsibility
  - Engineer With Primary Responsibility for PMS
- Current Solution is an Intermediate Step
  - Customization to Iowa DOT
  - Improvement of Decision Making Tools
  - Integration of Systems and Data Sources
  - Integration With Statewide Activities
- Upgrade within a 3 to 5 Year Frame

Iowa Transportation Center

TECHNICAL SESSION

PMS OPTIMIZATION WORK SESSION: PHASE II

Iowa Transportation Center

PMS PROJECT: PHASE II

- FIELD VISITS
- PMS PRESENTATIONS
- TRAINING SESSIONS
- BENCH TESTING

Iowa Transportation Center

FIELD VISITS

- KANSAS DOT
- TEXAS DEPT. OF HIGHWAYS
- NORTH DAKOTA DOT

Iowa Transportation Center

KANSAS DOT PMS

- JULY 13, 1993
- VISITING TEAM:DOT & ITC STAFF

GERALD SOLBECK
MARLEE WALTON
BRIAN McWATERS
JOHN PIERCE
KEVIN JONES

TOM MAZE
OMAR SMADI

Iowa Transportation Center

KANSAS PMS

- KANSAS COMPREHENSIVE HIGHWAY PROGRAM (1993):
  - MMP ($271 MILLION, 200 MILES)
  - SMP ($76 MILLION, 1200 MILES)
  - SEP (62 MILLION)
  - RMP (8600 MILES)
  - PBP ($18 MILLION)
- TOTAL SYSTEM (10,017 MILES)
  - PCCP: 728 miles
  - COMPOSITE: 1084 miles
  - FULL DESIGN BIT.: 2814 miles
  - PARTIAL DESIGN BIT.: 5319 miles

KANSAS PMS

MAJOR MODIFICATION PROGRAM

- SYSTEM:
  - INTERSTATE: ROADWAYS AND ASSOCIATED BRIDGES
  - NON-INTERSTATE: ROADWAYS AND ASSOCIATED BRIDGES
- PRIORITIZATION APPROACH:
  - COMMERCIAL TRAFFIC 14.0%
  - RIDEABILITY 18.9%
  - PAVEMENT STRUC. EVAL. 44.7%
  - OBSERVED CONDITION 22.4%

  ADJUSTED FOR:
  STP CLASSIFICATION
  NUMBER OF LANES
  DIVIDED / UNDIVIDED
  STABILIZED SHOULDERS

KANSAS PMS

SUBSTANTIAL MAINTENANCE PROGRAM

- IMPLEMENTATION PLAN:
  - NETWORK OPTIMIZATION SYSTEM (NOS)
  - PROJECT OPTIMIZATION SYSTEM (POS)
  - PAVEMENT MANAG. INFORMATION SYSTEM (PMIS)

KANSAS PMS (SMP)

- OPTIMIZATION METHODOLOGY:
  - MARKOV DECISION MODEL
  - LINEAR PROGRAMMING
  - NETWORK LEVEL ANALYSIS
  - MAXIMIZE USER BENEFITS
  - PROBABILISTIC PERFORMANCE PROJECTION USING TRANSITIONAL PROBABILITIES

KANSAS PMS (SMP)

- PMS OPTIMIZATION IMPLEMENTATION:
  - UNIFORM PAVEMENT SEGMENTS
  - ROAD CATEGORY
  - DISTRESS AND CONDITION STATE
  - ALTERNATIVE MAINTENANCE ACTIONS
  - TRANSITION PROBABILITIES
  - UNIT COST
  - CALIBRATION
  - UPDATES

Iowa Transportation Center

KANSAS PMS (SMP)

- NETWORK OPTIMIZATION SYSTEM:
  - REHABILITATION BUDGET
  - FEASIBLE REHABILITATION ACTIONS
  - CONSTRAINTS
  - OBJECTIVE FUNCTION:

    FIXED BUDGET -------> MAXIMIZE PERF. STANDARDS
    FIXED PERF. STANDARDS -------> MINIMIZE COST

Iowa Transportation Center

KANSAS PMS (SMP)

- PROJECT OPTIMIZATION SYSTEM:
  - REHABILITATION MODE:

    BUDGET AND PERFORMANCE CONSTRAINED BY NOS
    PROJECT PORTFOLIO
    POS PERFORMANCE MODELS
    OBJECTIVE FUNCTION

  - NEW DESIGN MODE

Iowa Transportation Center

KANSAS PMS (SMP)

- PAVEMENT MANAGEMENT INFORMATION SYSTEM:
  - PROVIDE NOS/POS SUPPORT
  - USER FRIENDLY
  - STANDARD REPORTS
  - RELATIONAL DATABASE
  - INVENTORY

    ONCE EVERY YEAR (ONE MILE SEGMENTS)
    3 MONTHS STARTING MARCH

Iowa Transportation Center

KANSAS PMS (PMIS)

- NOS INVENTORY:
  - 4 TWO-PERSON CREWS (10-12 WEEKS)
  - 2 SOUTH DAKOTA PROFILOMETERS
  - 2 DISTRESS SURVEY VANS
  - COST = ($11-$12) / MILE
- POS INVENTORY:
  - 2 THREE-PERSON CREWS (5-6 MONTHS)
  - 2 FALLING WEIGHT DEFLECTOMETER
  - 2 VEHICLES AND 4 PICKUP TRUCKS
  - 1200 MILES
  - COST = $70 / MILE

Iowa Transportation Center

KANSAS PMS

- RESOURCES:
  - MAINFRAME WITH MPSIII TO SOLVE LP
  - INGRESS DATABASE RUNNING ON UNIX
  - SQL PROGRAMMING LANGUAGE
  - STAFF: 4 IN THE PMS OFFICE

    (EXPERIENCED WITH COMPUTERS)

Iowa Transportation Center

TEXAS DOT PMS

- JULY 19, 1993
- VISITING TEAM:DOT & ITC STAFF

MARLEE WALTON
BRIAN McWATERS
JOHN PIERCE
KEVIN JONES

TOM MAZE
OMAR SMADI

Iowa Transportation Center

TEXAS PMS

GENERAL

- 78,000 CENTERLINE MILES (PAVED SYSTEM)
- EXTREMELY DECENTRALIZED (24 DISTRICTS)
- AGENCY USES THE BOTTOM-UP APPROACH
- MAINTENANCE BUDGET = $400 MILLION/YEAR
- CONSTRUCTION BUDGET = $1.6 BILLION/YEAR

Iowa Transportation Center

TEXAS PMS

- PAVEMENT MANAGEMENT SOLUTIONS (FUTURE):
  - NEEDS ANALYSIS
  - OPTIMIZATION
  - IMPACT ANALYSIS

Iowa Transportation Center

TEXAS PMS LEVELS

TEXAS DOT ADM.	NETWORK LEVEL
DISTRICT ADMINISTRATION AND DIVISIONS	↓
AREA ENGINEERS AND MAINTENANCE SUPERVISORS	PROJECT LEVEL

Iowa Transportation Center

TEXAS PMS

<u>PAVEMENT MANAGEMENT INFORMATION SYSTEM</u>

- PMIS WILL SUPPORT PMS DECISIONS
- HELP IN PAVEMENT DESIGN PROCEDURES
- 20 YEARS WORTH OF HISTORICAL DATA
- DATABASE KEPT AT THE UNIVERSITY
- DESIGNED IN-HOUSE WITH HELP FROM CONTRACT PROGRAMMERS

Iowa Transportation Center

TEXAS PMS (PMIS)

- COMPUTER BASED PAVEMENT PERFORMANCE MODELING SYSTEM:
  - TRAFFIC
  - MATERIALS
  - DESIGN THICKNESS
  - AVAILABLE FUNDING
  - CLIMATIC VARIABLES
- PMIS ACTIVITIES:
  - STORING AND RETRIEVING PM DATA
  - DATA ANALYSIS
  - REPORTING

Iowa Transportation Center

TEXAS PMS

- OPTIMIZATION METHODOLOGY:
  - INCREMENTAL BENEFIT COST
  - PROJECT LEVEL ANALYSIS
  - DETERMINISTIC UTILITY PERFORMANCE CURVES
  - TREATMENT SELECTION
  - PROJECT LOCATION
  - COST NUMBERS

TEXAS PMS

PMS OPTIMIZATION

- DETERMINE NEEDS AND IMPACT ANALYSIS
- TREATMENT CATEGORIES
- PAVEMENT CONDITION FORECASTING
- CALCULATE BENEFITS

TEXAS PMS

PMS PRIORITIZATION

- FUNDING ALLOCATION FACTORS:

ESAL	45%
LANE MILES	45%
PAVEMENT SCORE	10%

TEXAS PMS

- RESOURCES:
  - PMS STAFF: 20-25 PERSONNEL
  - PMS ENGINEERING STAFF: 5-6 ENGINEERS
  - PMIS STAFF: 2 ENGINEERS AND 3 ENG. ASSIST.
  - MAINFRAME SYSTEM
  - DATABASE PLATFORM (ADABASE)
  - SAS PROGRAMMING LANGUAGE

NORTH DAKOTA PMS

- JULY 29, 1994
- VISITING TEAM:DOT , ITC STAFF & FHWA

MARLEE WALTON
BRIAN McWATERS
JOHN PIERCE
KEVIN JONES

TOM MAZE
OMAR SMADI
FRANK HOWELL

Iowa Transportation Center

NORTH DAKOTA PMS

GENERAL

- 7300 MILES
- CONSTRUCTION BUDGET = $81 MILLION
- MAINTENANCE BUDGET = $28 MILLION
- REHABILITATION = $200 MILLION

Iowa Transportation Center

NORTH DAKOTA PMS

- OPTIMIZATION METHODOLOGY:
  - INCREMENTAL BENEFIT COST
  - PROJECT AND NETWORK LEVEL ANALYSIS
  - PERFORMANCE CURVES
  - TREATMENT SELECTION
  - PROJECT LOCATION
  - COST NUMBERS

Iowa Transportation Center

NORTH DAKOTA PMS

- RESOURCES:
  - PMS STAFF: 4 PERSONNEL
  - PMS ENGINEERING STAFF: 2 ENGINEERS
  - PERSONAL COMPUTER BASED SYSTEM (IBM)
  - DATABASE PLATFORM (dROAD)

Iowa Transportation Center

PMS PRESENTATIONS

- DEIGHTON ASSOCIATES
- PCS LAW ENGINEERING
- DFI & CLAYTON SPARKS
- ERES CONSULTANTS
- PAVEMENT MANAGEMENT SYSTEMS

Iowa Transportation Center

DEIGHTON PMS

GENERAL

- PC BASED SYSTEM
- dROAD (DATABASE)
- dTIMS (TOTAL INFRASTRUCTURE PMS)
- dMAP (MAPPING TOOL)

Iowa Transportation Center

DEIGHTON PMS

dROAD

- PERSPECTIVES
- LOGICAL DATA GROUPS
- DATABASE FIELDS
- RELATIONAL DATABASE
- DYNAMIC SEGMENTATION
- QUERIES AND REPORTING

Iowa Transportation Center

DEIGHTON PMS

dTIMS

- PAVEMENT PERFORMANCE PREDICTION
- PROJECT SELECTION
- PROJECT COST
- TREATMENT SELECTION
- OPTIMIZATION (IBC)
- BUDGET SCENARIOS
- REPORTING

Iowa Transportation Center

DEIGHTON PMS

dMAP

- ► MAPPING UTILITY
- ► AUTOCAD VERSION 10
- ► DISPLAY dROAD DATA FIELDS
- ► DISPLAY dTIMS RESULTS

Iowa Transportation Center

PCS LAW PMS

► PMAP (PAVEMENT MANAGEMENT AND PLANNING):

- ▸ PC BASED SYSTEM
- ▸ DATABASE MANAGEMENT
  DYNAMIC SEGMENTATION
- ▸ REPORTING
- ▸ NEEDS ANALYSIS
- ▸ SINGLE YEAR PRIORITIZATION

Iowa Transportation Center

DFI & CLAYTON SPARKS

► RTA PAVEMENT MANAGEMENT SOFTWARE

- ▸ PC BASED SYSTEM
- ▸ INTEGRATED ASSET MANAGEMENT TOOL
- ▸ RR (ROAD REGISTER)
- ▸ CMIS (CONDITION MANAGEMENT INF. SYSTEM)
- ▸ TNOS (TREATMENT SCHED. NETWORK OPT. SYSTEM)
- ▸ FNOS (FINANCIAL PLANNING NETWORK OPT. SYSTEM)

Iowa Transportation Center

DFI & CLAYTON SPARKS

► TNOS:

- ▸ PROVIDES PROJECT LEVEL ANALYSIS (5 YEARS)
- ▸ ECONOMICAL ANALYSIS MODEL (IBC)
- ▸ DETERMINISTIC PAVEMENT PERFORMANCE
- ▸ PROJECT LOCATION
- ▸ TREATMENT SELECTION
- ▸ COST NUMBERS

Iowa Transportation Center

DFI & CLAYTON SPARKS

- FNOS:
  - PROVIDES NETWORK LEVEL ANALYSIS (20 YEARS)
  - MARKOV DECISION PROCESS
  - OPTIMIZATION SOLVED USING LINEAR PROG.
  - MINIMIZE COST OR MAXIMIZE CONDITION

Iowa Transportation Center

ERES PMS

- DSS (DECISION SUPPORT SYSTEMS):
  - PC BASED SYSTEM IN WINDOWS
  - CAN BE LINKED TO AUTOCAD OR INTERGRAPH
  - DETERMINISTIC PAVEMENT PERFORMANCE
  - PRIORITIZATION APPROACH (MULTI-YEAR)
  - DOES NOT OPTIMIZE OVER TIME

Iowa Transportation Center

ERES PMS (DSS)

- PRIORITIZATION APPROACH:
  - PAVEMENT PERFORMANCE PREDICTION
  - ECONOMIC ANALYSIS
  - LIFE CYCLE COST ANALYSIS
  - TREATMENT SELECTION
  - PROJECT LOCATION
  - COST NUMBERS

Iowa Transportation Center

Pavement Management Systems

GENERAL

- PC BASED SYSTEM
- DATABASE CAPABILITIES
- DYNAMIC SEGMENTATION
- OPTIMIZATION (MARGINAL COST EFFECTIVENESS)

Iowa Transportation Center

Pavement Management Systems

- DETERMINISTIC PERFORMANCE PREDICTION
- PROJECT LOCATION
- TREATMENT SELECTION
- COST NUMBERS
- OPTIMIZATION (MCE)

Pavement Management Systems

- OPTIMIZATION (MCE) METHODOLOGY:
  - BUDGET CONSTRAINT (MAXIMIZE EFFECTIVENESS)
  - PERFORMANCE CONSTRAINTS (MINIMIZE COST)
  - REPORTING: GRAPHICAL AND LISTED

TRAINING SESSIONS

- DEIGHTON SOFTWARE
- RTA SOFTWARE (DFI AND CSA)

PMS TRAINING SESSIONS

- DEIGHTON PMS:
  - ONE WEEK SESSION
  - dROAD AND dTIMS TRAINING
  - INITIAL DATALOAD INTO dROAD
- RTA PMS:
  - TWO-DAY SESSION
  - GENERAL TRAINING ON USING THE MODULES
  - INTRODUCTION TO ASSET MANAGEMENT
  - BSTAT OVERVIEW

BENCH TESTING

- DEIGHTON SOFTWARE
- RTA SOFTWARE (DFI AND CSA)

BENCH TESTING

- ELEMENTS CONSIDERED:
  - DATA
  - PROCEDURE
  - RESULTS
  - SENSITIVITY ANALYSIS

BENCH TESTING (DATA):

- ANALYSIS METHODOLOGY:
  1. DETERMINISTIC
  2. PROBABILISTIC
- PERFORMANCE PREDICTION:
  1. PERFORMANCE CURVES
  2. TRANSITIONAL PROBABILITIES
- TREATMENT STRATEGIES:
  1. TRIGGER VALUES
  2. COST
  3. IMPROVEMENT
- DATA PREPARATION (ASCI OR OTHER FORMAT)

BENCH TESTING (PROCEDURE):

- DATA PREPARATION
- DATA LOADING
- RUN SOFTWARE
- ADJUST FACTORS
- COMPARE RESULTS

BENCH TESTING (SENSITIVITY ANALYSIS):

- PARAMETERS FINE TUNING
- WHAT-IF QUESTIONS
- RESULT COMPARISON
- FINAL DECISION

Iowa Transportation Center

BENCH TEST

- **Deighton PMS Bench Test Parameters**
  - **dRoad Database:**
    - All 428 Sections of the Interstate
    - U.S. 30 and U.S. 71, 148 Sections
  - **Date Elements:**
    - Highway, Mile Post and Direction
    - Test Data; Friction, ARR, IRI, PCR, Crack & Patch
    - Traffic; Annual ESAL & Cummulative ESAL
    - Location; Length, Width and Pavement Type
  - **Dynamic Segmentation**

Iowa Transportation Center

BENCH TEST

- **Deighton PMS Bench Test Parameters**
  - **dTIMS:**
    - Interstate Only
    - Performance Curves, Five Types of Pavements
    - Treatment Alternatives and Costs
    - Trigger Values
    - Budget Contraints

Iowa Transportation Center

BENCH TEST

- **RTA PMS Bench Test Parameters**
  - **FNOS:**
    - Interstate Only
    - Section Length
    - Test Data: ARR, IRI, Crach & Patch
    - Transition Matrix
    - Treatment Strategies and Costs
    - Budget and Performance Constraints

BENCH TESTING (DEIGHTON PMS):

- dROAD:
  - DATABASE CAPABILITIES
  - DYNAMIC SEGMENTATION
  - DATA MANIPULATION
- dTIMS:
  - PERFORMANCE CURVES
  - TREATMENTS
  - TRIGGERS
  - ANALYSIS SETS
  - OPTIMIZATION
  - REPORTING

Iowa Transportation Center

BENCH TESTING (RTA PMS):

- FNOS:
  - STATES
  - TREATMENTS
  - TRANSITIONAL PROBABILITIES
  - OPTIMIZATION
  - REPORTING
- TNOS:
  - DATA INTENSIVE
  - 5 YEAR ANALYSIS PERIOD

Iowa Transportation Center

SOFTWARE SELECTION

- FACTORS CONSIDERED:
  - SOFTWARE ATTRIBUTES
  - BENCH TEST FINDINGS
  - RECOMMENDATIONS

Iowa Transportation Center

SOFTWARE SELECTION

- SOFTWARE ATTRIBUTES:
  - USER FRIENDLY
  - CONSISTENCY
  - FLEXIBILITY
  - REPORTING CAPABILITIES
  - DOCUMENTATION
  - TECHNICAL SUPPORT

Iowa Transportation Center

SOFTWARE ATTRIBUTES (DEIGHTON PMS):

- dROAD AND dTIMS:
  - EASY TO USE
  - RELATIONAL DATABASE (DYNAMIC SEGMENTATION)
  - PROJECT AND NETWORK LEVEL ANALYSIS (20 YRS)
  - OPTIMIZATION (IBC)
  - REPORTING CAPABILITIES

Iowa Transportation Center

SOFTWARE ATTRIBUTES (RTA PMS):

- FNOS:
  - EASY TO USE
  - QUICK RESULTS
  - NETWORK LEVEL ANALYSIS (20 YRS)
  - OPTIMIZATION (MDP)
  - FLEXIBLE

Iowa Transportation Center

PMS RECOMMENDATIONS

● SOFTWARE SYSTEM:

- DATABASE ⟹ dROAD
- PROJECT LEVEL ⟹ dTIMS
- NETWORK LEVEL ⟹ dTIMS & FNOS
- PERFORMANCE DATA ⟹ BSTAT

Iowa Transportation Center

PMS RECOMMENDATIONS

● COMPUTER HARDWARE:

- PC BASED SYSTEM (IBM COMPATIBLE)
- 486 DX 66 MHZ
- 16 M OF RAM
- LARGE AND FAST HARD DISK
- COLOR MONITOR

Iowa Transportation Center

PMS RECOMMENDATIONS

● **SOFTWARE COST:**

- ► dROAD ($10,000)
- ► dTIMS ($10,000)]
- ► FNOS ($2,500)
- ► BSTAT ($3,750 / YEAR)

APPENDIX II

Questionnaire

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
▪ **GENERAL INFORMATION**	
1. Highway agency visited:	
2. Contact person(s):	
3. Name of system:	
4. Date of visit	
5. Personnel making the visit:	
▪ **COMPLETENESS**	
1. System Design:	
- Functionality as a part of a complete roadway management system.	
- Type of location referencing used.	
- Ability to accommodate future changes and maintenance to the system.	
- Ability to support multiple users.	

QUESTIONNAIRE FOR SITE VISITS	COMMENTS
- Network level capabilities:	
. network-level programming and budgeting	
. network-level maintenance treatment selection	
. network-level prioritization or optimization	
- Project level capabilities:	
. project-level evaluation	
. implementation: scheduling, specifications, and control	
. monitoring and feedback	
. project level maintenance treatment selection	
2. Resources Required:	
- For system implementation:	
. computer equipment:	
* Mainframe	
* Network	
* Work station	
* Personal computer	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
. software language used for development.	
. time requirements	
. number and level of staff trained	
. duration of training process	
- Data base system used.	
- For system operation:	
. training	
. number of staff	
. level of staff experience in computers	
. level of staff experience in engineering	
. system maintenance:	
* computers and breakdowns	
* personnel	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
■ **USER EVALUATION**	
1. Efficiency:	
- Appropriateness of response times when dealing with input and output:	
. network analysis	
. project analysis	
. standard reports	
. ad hoc reports	
- Interface with data storage system.	
- Efficiency of operation.	
2. User Friendliness:	
- Ease of use of the system and software:	
. quality of help screens	
. quality of user documentation	
. integrity of software	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
- Flexibility for specifying scope and constraints of analysis.	
- PMS database:	
. data reporting and enquiring	
. data manipulation	
3. Reporting:	
- Format types: tabular, graphic, mapping.	
- Relevance and usability of standard reports.	
- Flexibility of standard vs ad hoc reporting.	
- Output from the model.	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
4. Error checking and Security:	
- Data entry and checking:	
. Reliability of entry	
. validation and integrity checks	
- Security:	
. of software	
. of application	
. of data and access to data	
5. System use:	
- Acceptance	
- Efficiency	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
▪ **MODEL**	
1. Technical Analysis:	
- Type of decision model.	
. Mathematical program used	
. Network or project level analysis	
. Objective function	
2. Validity and Calibration:	
- Applicability to:	
. existing pavement types	
. prevailing environments	
. roadway classification	
. existing vehicle classification	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
- Prediction of pavement deterioration:	
. accuracy	
. reliability	
. distinction of major distress types	
. deterministic or probabilistic	
- Prediction of maintenance effects:	
. distinction between major treatment types	
. influence of prior condition	
. allowance for construction quality	
- Provision for calibration by user through parameters.	
3. Sectionization:	
- Pre-analysis.	
- Uniform treatment (post-analysis).	
- Contract packaging (post-programming).	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
4. Prioritization:	
- Approach used.	
- Multi-year, multi-section, multi-option optimization.	
- Constrained budget optimization.	
- Facility for user-specific objective function.	
■ **DATA MANAGEMENT**	
1. Data Requirements:	
- Rate each data category for:	
. appropriateness of detail to network level	
. appropriateness of detail to project level	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
2. Method of Data Collection:	
- Flexibility.	
- Facility for automation.	
- Productivity.	
- Staff resources.	
- Equipment resources.	
- Training requirements.	
- Reliability.	
- Use of sampling.	
- Network vs project level differences.	
- Survey planning	
- Data reduction:	
. availability of software	
. flexibility of software	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
3. Data Storage and Management:	
- Archiving of data from database.	
- Interface between form of data collected and data analyzed.	
- Ease of future enhancement of data management.	
■ PERFORMANCE PREDICTION	
1. Method used.	
2. Ease of prediction.	
3. Flexibility in predicting future condition.	
4. Interface between PMS and prediction.	
5. Data requirements.	
6. Accuracy.	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
■ BENEFITS	
■ IMPLEMENTATION TIME:	
■ IMPLEMENTATION COST:	
■ OFFICE RESPONSIBLE FOR THE SYSTEM:	
■ OFFICES THAT USE THE SYSTEM:	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
▪ SHORT FALLS:	
▪ USERS RECOMMENDATIONS:	

QUESTIONNAIRE FOR SITE VISITS	
	COMMENTS
▪ CHANGES TO THE SYSTEM:	
▪ COMMENTS:	