Wisconsin's Pavement Management Decision Support System

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The development of a comprehensive pavement management system (PMS) began in Wisconsin in 1987. Since its inception the objectives of the PMS have continued to evolve. Wisconsin has a geographic information system-based PMS that provides needed spatial and mapping capabilities. The backbone of the system employs pavement inventory data and a decision support system to develop improvement/maintenance programs. The system also provides a data base for complex pavement modeling efforts as well as network (statewide) planning efforts. Wisconsin's PMS is an expert system incorporating the knowledge and wisdom of Department of Transportation engineers/practitioners into decision rules for problem definition, treatment selection, and prioritization of projects/programs. First, the systems logic determines the problems associated with each pavement section (nominal 1 mi in length) and suggests a range of treatments to repair all of the problems noted. Highway emphasis levels that give more intensive treatments to the higher-emphasis routes are assigned. The pavement sections are then aggregated into improvement sections (a section whose length is generally more typical of improvement or maintenance projects), with low-, nominal-, and high-level treatment strategies recommended for the entire section. The final treatment selected is based on the relative impacts of these five factors: improvement in ride, improvement in distress rating, user inconvenience, initial cost, and life cycle cost. The final step takes all projects with their final treatment selections and places them into priority order by using the five factors listed above plus a determination of the remaining service life. The ultimate product is a recommended 6-year improvement program and a 3-year maintenance program.

The elementary principles of a pavement management system (PMS) have historically existed in Wisconsin in one form or another. For decades a group of experts in each district would annually evaluate pavement conditions (using their own rules and methodology), propose corrective treatments, estimate the associated project costs, and finally place the projects in a priority order. There was little uniformity in rules and methodology from district to district, consistency from year to year was not assured, and there were no objective measures of pavement conditions. In the 1970s ride data began to be collected, providing at least one needed measure of objectivity for the process. In the early 1980s a consistent, reliable, statewide pavement distress (condition) survey was added to the process and greatly advanced the state of the art. In 1987 a formal PMS began to be developed. The resulting system is well-documented; is designed to be used uniformly and consistently within the state; employs objective performance measures and expert system logic; and develops treatment strategies, costs, and prioritized pavement improvement/maintenance programs. Since 1987 the objectives for the PMS have continued to develop, including the objective of providing a network (statewide) analysis capability to maximize overall pavement performance within the constraints imposed by funding levels.

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This paper concentrates on that portion of the PMS that leads to the prioritized improvement/maintenance programs (the network capabilities are still rudimentary and are not discussed in any detail).

OBJECTIVES

There are numerous objectives for implementing a PMS for the Wisconsin Department of Transportation (WisDOT). These objectives range from network-specific (statewide) to project-specific analysis capabilities, for example,

1. To provide statewide planners and programmers with a way of analyzing the impacts of different treatment strategies.
2. To support upper management planning and programming decisions with objective data and expert system analyses regarding pavement condition and proposed treatment strategies.
3. To provide planners and programmers with prioritized listings of pavement projects, that is, a 6-year improvement program and a 3-year maintenance program.
4. To assist pavement designers in obtaining basic pavement condition and cross-sectional data.
5. To assist pavement management/pavement structural design staff in developing models of pavement performance.
6. To assist DOT engineers in developing treatment strategies based on the field performance of pavements.

APPROACH

To achieve the objectives outlined above, two steps were taken within WisDOT. First, a Pavement Management Unit was created to collect, manage, analyze, and report pavement condition data. Second, a decision support system [the Pavement Management Decision Support System (PMDSS)], which could use inventory data and decision logic to provide the backbone of Wisconsin's PMS, was developed. This system was designed to provide reasonable and reliable solutions to pavement condition problems regardless of the background or experience of the end user. The solutions selected by this system had to be consistent with both current engineering practice and WisDOT policy.

To provide the "reasonable and reliable solutions" discussed, PMDSS was formulated as an expert system. In other words the collective wisdom of DOT engineering practitioners was (and is) periodically sampled and encoded as decision rules for problem definition, treatment selection, and project prioritization (program development).

A further requirement relating to the development of PMDSS was that it be based on a geographic information system (GIS). GIS is able to provide several unique features that could not be provided with a standard relational data base. First, GIS can use spatial analysis routines to integrate pavement inventory, performance, and rehabilitation history data. Geographic locations of these different data elements can logically be linked together and combined for subsequent analysis by the PMDSS user. Second, the interactive graphics and display provide the user with an easy way to review and interpret complex data relationships. Third, the display and cartography tools can be used to show or map inventory data, proposed improvements/maintenance programs, and so on—a host of possibilities.

SCOPE

PMDSS performs analysis on all pavement sections that are part of the state trunk highway system, including all Interstate highways. The only restriction that exists is that, to be analyzed, the pavement section in question must have both a current pavement distress rating and a ride rating. The ride rating is not collected for many pavement sections in urban areas and therefore is not analyzed by PMDSS.

GENERAL OVERVIEW

From its earliest conception through the current implementation PMDSS has been viewed as a way to augment instead of replace the professional judgments of the planners, analysts, and engineers who use it. The distress assessments, problem identification, and rehabilitation recommendations made by the system represent the combined experience with pavement performance and rehabilitation of a diverse group of WisDOT highway engineers. As a result its knowledge base provides a consistent, uniform approach across many individual and organizational boundaries to ensure that departmental goals, priorities, and objectives are achieved.

PMDSS combines WisDOT's pavement inventory data, consisting mainly of pavement distress data, pavement ride data, pavement age, and pavement type, with a knowledge base consisting of rules for distress evaluation, problem identification, and rehabilitation recommendations. Because the knowledge base was compiled by using the expertise of WisDOT's highway engineers, the rules that make up the knowledge base reflect the department's current practices in pavement management and can be modified as those practices change. The results obtained from PMDSS should be comparable to what the user would get when using engineering judgment combined with departmental policy. It is important to emphasize that any treatment recommendation produced by the system can be overridden if local experience contradicts PMDSS logic.

The current version of PMDSS was constrained from dealing with problems of project-specific pavement design. In other words the system may tell the user that an overlay is needed, but the thickness of the overlay will not be specified.

CONCEPTS AND LOGIC

The following discussion provides an overview of the PMDSS concepts and logic.

Data Base

PMDSS uses six main data elements to perform its analysis. These six elements include the individual distresses that make up the pavement distress index (PDI), the PDI value itself, the pavement serviceability index (PSI; which is WisDOT's measure of ride), emphasis of the pavement, pavement type, and pavement age.

The primary analysis unit used by PMDSS is the pavement section, an approximate 1-mi stretch of pavement used to collect ride (PSI and international roughness index) and distress (PDI) observations. The ride and distress observations, the pavement section locations, and the pavement section types and ages are maintained in pavement information files (PIFs). The locations of these pavement sections remain fixed over the life of the pavement structure so that historical pavement performance data can be analyzed. The first step when using PMDSS for analysis is to update the decision support data base from the PIF system.

Emphasis Level

One data element that is used by PMDSS yet that is not stored and maintained in PIFs is the emphasis level assigned to a particular segment of highway. Those pavements with higher emphasis levels will have much higher performance expectations, and subsequently, more intense treatments will be recommended for them than for those pavements with a lower emphasis level. Emphasis level plays a role in (a) determining which pavement performance thresholds are used, (b) analyzing life cycle costs, and (c) determining what treatment to assign to a pavement section. Because emphasis level cannot be determined by some simple formula, each transportation district assigns the highway emphasis level locally. PMDSS uses three categories of emphasis: high, regular, and low.

High-emphasis pavements are those that, because of their relatively high levels of importance or traffic volumes, warrant a sustained high level of pavement quality and particular attention to minimizing user inconvenience.

Low-emphasis pavements are those that, because of their relatively low levels of importance or traffic volumes, are unlikely to be candidates for either geometric improvement or complete pavement reconstruction in the near future. These pavements can generally be preserved by maintenance activities. Low-emphasis roads include, at a minimum, all roads classified as collectors.

Regular-emphasis pavements are those that are not classified as high- or low-emphasis pavements.

Assessment of Pavement Distress

After updating the PMDSS data base with the PIF data, the distress observations, for example, cracking, rutting, and faulting, for each pavement section are assessed. This assessment involves taking the field observations of a distress and assigning a PMDSS severity. Tables such as the one shown in Figure 1 are used. Field observations generally involve noting both the severity and the extent of each distress. By using Figure 1, if the distress survey had noted alligator cracking with cracks of greater than ½ in. in width and covering 80 percent of the survey area, PMDSS would say that the pavement section had *severe* alligator cracking. This same procedure is followed for every distress on every pavement section.

Ride observations, or PSIs, are also assessed and assigned a ride quality level of satisfactory, questionable, or unsatisfactory according to set PSI threshold levels (Figure 2). Again, these threshold levels differ by highway emphasis. These ride assessments are later used by the system to define problems and to determine appropriate treatment levels.

EXTENT

SEVERITY	1-24%	25-49%	50-74%	75-100%
< 1/2 in	MINOR	MODERATE	MODERATE	SEVERE
> 1/2 in	MODERATE	MODERATE	SEVERE	SEVERE
Dislodgement	SEVERE	SEVERE	SEVERE	SEVERE

FIGURE 1 Alligator cracking extent assessment.

PSI VALUES

EMPHASIS	Satisfactory	Questionable	Unsatisfactory
High	5.00 - 3.00	3.00 - 2.25	2.25 - 0.00
Regular	5.00 - 2.50	2.50 - 2.00	2.00 - 0.00
Low	5.00 - 2.25	2.25 - 1.75	1.75 - 0.00

* PSI Scale is from 0.00 (worst possible) to 5.00 (best possible)

FIGURE 2 PSI threshold levels*.

Identifying Pavement Problems

The conceptual core of PMDSS revolves around establishing the nature of the pavement problem. Examples of problems would be "cracking due to pavement aging," "distortion due to use over time," and "slab break-up in jointed plain concrete pavement." Ten pavement problems are defined for asphalt concrete pavements, and 14 pavement problems are defined for portland cement concrete (PCC) pavements. A list of these problems is presented in Figure 3. An example pavement problem is defined as follows:

Problem Name: Insufficient Structure

We have this problem in an asphalt pavement when the following is true:

longitudinal distortion greater than or equal to MINOR
and/or
rutting greater than MINOR
and/or
alligator cracking greater than or equal to MINOR

As shown by this example, problems are identified by using rules containing specific combinations of PMDSS-assessed distress observations. All problem identification rules are statements designed to include (or exclude) problems on the basis of the assessed pavement indicators. Because the rules are central to the logic of PMDSS, they are embedded in the system and cannot be modified by the user.

In addition to indicating whether a particular pavement section has a defined problem, PMDSS will also determine whether a pavement section is deteriorating at a faster rate than expected. PMDSS will calculate a pavement's apparent age, which is determined by how old the pavement "looks," and compare this with the pavement's actual age. The apparent age is calculated by using a pavement section's current PDI and comparing this against the PDI deterioration model for that pavement type. For example, if a pavement section has a PDI of 80 and according to the deterioration model for that pavement type a PDI of 80 can be expected when a pavement is 21 years old, PMDSS will indicate that the section in question is aging prematurely if the actual age of the pavement is less than 21 years old.

Once the nature of the problem is identified, the severity of the problem is then defined. This severity level is determined by using the problem's decision elements. By using the insufficient structure problem as an example, the decision elements include the three distresses of alligator cracking, longitudinal distortion, and rutting. To determine the severity of a problem, a matrix such as the one shown in Figure 4 is used. Continuing the example, assume that the only distress noted on a particular pavement section is severe alligator cracking. In that case the matrix in the upper left corner of Figure 4 would be used (where it says Decision Element = Severe Alligator Cracking). The distress Longitudinal Distortion runs across the top of the matrix, whereas the distress Rutting runs down the side of the matrix. Because the section in question does not have longitudinal distortion or rutting, the severity of this problem will be determined by going down the 0 column for longitudinal distortion and across the 0 row for rutting. This will indicate a severity rating of *severe* for the problem (S = severe, M = moderate, m = minor, and 0 = none). This same process is performed for every problem on every pavement section. PMDSS will store up to three problems for all the pavement sections, rank ordered in terms of their severities.

Rehabilitation Recommendations

After the problems have been identified for each pavement section, the next step in the decision support process is to recommend a

ASPHALTIC CONCRETE PAVEMENT PROBLEMS

1. Cracking Due to Aging
2. Unexpected Bad Ride
3. Poor Mix - Flushing
4. Poor Mix - Soft
5. Unstable Mix Over PCC
6. Insufficient Structure
7. Unstable Base
8. Distortion Due to Use
9. Poor Aggregate - Asphalt Adhesion
10. Joint Deterioration in Asphalt over PCC

PORTLAND CEMENT CONCRETE PAVEMENT PROBLEMS

1. Faulting on Jointed Plain Concrete Pavement Without Dowels
2. Distressed Joints and Cracks on Jointed Plain Concrete Pavement without Dowels
3. Slab breakup on Jointed Plain Concrete Pavement without Dowels
4. Faulting on Jointed Plain Concrete Pavement with Dowels
5. Distressed Joints and Cracks on Jointed Plain Concrete Pavement with Dowels
6. Slab Breakup on Jointed Plain Concrete Pavement with Dowels
7. Faulting on Jointed Reinforced Concrete Pavement
8. Distressed Joints and Cracks on Jointed Plain Concrete Pavement
9. Slab Breakup on Jointed Plain Concrete Pavement
10. Pavement Deterioration
11. Patching Problem
12. Surface Distress
13. Base/Subgrade Problem
14. Unexpected Bad Ride

FIGURE 3 Pavement problems identified by specific combinations of distress observations.

Decision Element = Severe Alligator Cracking
Decision Element
Longitudinal Distortion

Decision Element Rutting	s	M	m	o
s	s	s	s	s
M	s	s	s	s
m	s	s	s	s
o	s	s	s	s

Decision Element = Moderate Alligator Cracking
Decision Element
Longitudinal Distortion

Decision Element Rutting	s	M	m	o
s	s	s	s	s
M	s	s	s	s
m	s	s	M	M
o	s	s	M	M

Decision Element = Minor Alligator Cracking
Decision Element
Longitudinal Distortion

Decision Element Rutting	s	M	m	o
s	s	s	s	M
M	s	s	M	M
m	s	M	M	m
o	M	M	m	m

Decision Element = 0 Alligator Cracking
Decision Element
Longitudinal Distortion

Decision Element Rutting	s	M	m	o
s	s	s	M	M
M	s	M	M	M
m	s	M	m	m
o	M	M	m	o

FIGURE 4 Example of matrices used to determine severity of a problem.

range of treatments that would repair all of the problems in the pavement section at the indicated severities. This process is performed by using decision tables such as those in Figure 5.

As shown in Figure 5 there are three different treatment tables, one for each emphasis level. More intense treatments tend to be assigned to higher-emphasis pavements.

There are 11 PMDSS-recognized treatments for asphalt concrete pavements and 11 for portland cement concrete pavements. The treatment lists for both asphalt concrete pavements and portland cement concrete pavements are given in Figure 6. These treatments are ordered so that Treatment 1 is the least intense treatment and Treatment 11 (Reconstruct) is the most intense treatment. It is ensured that a higher-number treatment will correct a problem that a lower-number treatment may correct, but not vice versa. For example, if PMDSS suggested Treatment 2 (Thin Asphaltic Overlay) to correct a particular problem on portland cement concrete pavement, it is assured that a higher-number treatment such as Treatment 10 (Rubblize and Overlay) could also correct it, but it would not be necessary to use such an intense treatment.

With portland cement concrete pavements a problem's severity along with the pavement's age are used to determine the range of treatments. With asphalt pavements a problem's severity and ride assessment are used to determine a range of treatments that will correct the indicated problem. Age is the predominant controlling factor for treatment selection for portland cement concrete, and ride is viewed as the predominant factor for treatment selection for asphalt concrete pavements. For example, by using Figure 5, if a high-emphasis pavement had a problem of severe insufficient structure and a ride assessment of questionable, the range of treatments that would correct that problem are Treatments 9 to 11. PMDSS will do this for up to three problems on a particular pavement section. PMDSS will then aggregate these three ranges into one range to be used to correct all the problems in a pavement section.

HIGH EMPHASIS

RIDE	PROBLEM SEVERITY: Min Hi	Min Lo	Mod Hi	Mod Lo	Sev Hi	Sev Lo
Good	0	0	8	7	9	9
Quest	8	7	8	8	11	9
Bad	9	9	11	9	11	9

REG. EMPHASIS

RIDE	PROBLEM SEVERITY: Min Hi	Min Lo	Mod Hi	Mod Lo	Sev Hi	Sev Lo
Good	0	0	0	0	8	7
Quest	0	0	8	7	9	8
Bad	7	7	9	8	11	9

LOW EMPHASIS

RIDE	PROBLEM SEVERITY: Min Hi	Min Lo	Mod Hi	Mod Lo	Sev Hi	Sev Lo
Good	0	0	0	0	7	7
Quest	0	0	7	7	8	8
Bad	0	0	7	7	11	11

Treatment Range

FIGURE 5 Example of matrices used for insufficient structure to determine range of treatments

FOR ASPHALTIC CONCRETE PAVEMENTS

0. Do Nothing
1. Spot Repair
2. Crack Filling
3. Seal Coat
4. Cold Recycle
5. Rut Filling
6. Surface Mill/Mill Ruts
7. Thin Overlay
8. Thick Overlay
9. Partial Mill and Overlay
10. Full Depth Mill and Overlay
11. Reconstruct

FOR PORTLAND CEMENT CONCRETE PAVEMENTS

0. Do Nothing
1. Seal Cracks
2. Thin Asphaltic Overlay
3. Partial/Full Depth Repairs
4. Repair and Grind
5. Repair, Grind and Thin Overlay
6. Spot Replace, Patch, Repair, and Thin Overlay
7. Spot Replace, Patch, Repair, and Thick Overlay
8. Repair, Patch, Crack and Seat, and Thick Overlay
9. PCC Overlay
10. Rubblize and Overlay
11. Reconstruct

FIGURE 6 Recognized treatments for asphalt and portland cement concrete pavements.

Aggregation into Project-Length Improvement Recommendations

Because most construction projects are of a length greater than 1 mi, it is necessary to combine the treatment recommendations for the pavement sections into treatment recommendations for the project-length sections (called *improvement sections*). An improvement section is made up of one or more contiguous pavement sections. All of the pavement sections within the improvement section must be of the same pavement type and approximate pavement age.

The aggregation of pavement section treatment recommendations into improvement section treatment recommendations is done by a process referred to as the *15-30-50 percent Rule.* What the 15-30-50 percent rule does is look at treatment ranges assigned to each pavement section within the improvement section and determine which treatment would undertreat no more than 15 percent of the pavement sections that it comprises, which treatment would undertreat no more than 30 percent of the pavement sections that it comprises, and which treatment would undertreat no more than 50 percent of the pavement sections that is comprises. These three levels—15, 30, and 50 percent—are also referred to as high-, nominal-, and low-level treatment strategy levels, respectively.

The 15-30-50 percent rule is sensitive to the number of pavement sections within the improvement section. Usually, the more pavement sections the less intense the treatment recommended. For example, assume that the recommended treatment for a pavement section was reconstruct. If the improvement section contained just this one pavement section, the nominal strategy treatment level would obviously be reconstruct. As more pavement sections, each with a recommendation of do nothing, are added to the improvement section, the overall recommendation would change to do nothing as soon as the initial pavement section length fell below 30 percent of the total (increasing) improvement section length. That is, less than 30 percent of the total length would be undertreated by the do nothing recommendation.

For each improvement section the low-, nominal-, and high-level treatment strategies are passed onto the final treatment selection and prioritization part of the program.

Final Treatment Selection and Prioritization

This final process involves two steps. The first step determines which of the three treatment strategies proposed should be selected as the final treatment for that project. To accomplish this the user must provide values representing the relative importance of the following five factors: the improvement in the PSI after the treatment has been applied, the improvement in the PDI after the treatment has been applied, how much the treatment will inconvenience the user, initial cost of the treatment, and the life cycle cost of the treatment. When entering the relative importance values, the user must ensure that the total of all values entered is 1.0. So if a user gives equal importance to two of the factors, the relative importance of each would be entered as 0.50. Usually, all five factors are used in some way.

During the treatment selection process a treatment is chosen for each project solely on the basis of the impact that that treatment will have on the individual project. The impact on the entire highway system is not considered when determining the treatment strategy for a single improvement section.

The second step involves taking all the projects, with the final treatment selection already made, and placing them in priority order. Again, the user must provide values representing the relative importance of the following seven factors: improvement in the PSI after the treatment has been applied, improvement in the PDI after the treatment has been applied, how much the treatment will inconvenience the user, initial cost of the treatment, life cycle cost of the treatment, "time to must" for the PDI, and "time to must" for the PSI. "Time to must" is used to define the remaining life of the pavement on the basis of either the PDI value or the PSI value. Remaining life is defined by predicting the time, by using PDI and PSI deterioration models, when a pavement will reach the critical level set for PSI and PDI. These seven factors and their relative importances are then combined into a single prioritization value. The projects are then listed from highest to lowest priority.

Once the projects have been prioritized the program will begin placing projects in either the 6-year improvement program or the 3-year maintenance program, depending on the type of treatment chosen for the section, using the budgetary constraints entered by the user. This output is then used by transportation district planning and programming personnel.

FUTURE PMDSS INITIATIVES

Deterioration Modeling

The present deterioration scheme calculates a "time to must" for PDI and PSI via a linear model. This scheme does not alter treatments in the future years. The scheme should deteriorate the individual distress factors to determine if the treatments change during the future years. To be able to accurately predict problems and treatments past the first year, a deterioration scheme that will predict distresses and their severities over time is being developed. This will give WisDOT practitioners valuable information such as how long a treatment can be postponed on a section before a higher level of treatment is recommended. This information would be used to decide between multiple projects when one must be deferred because of budgetary constraints.

Layer and Base Information

Information about a highway's cross section, along with its treatment history, is stored in the layer and base data base. These data will be used in future studies to determine optimal treatment strategies for pavements by looking at historical pavement performance.

Network-Level PMDSS

To assist statewide planners and programmers a network-level PMDSS is being developed. Because statewide program developers do not need to know about detailed problems and specific treatments, a more simplistic model is being designed for their use. The network-level model assigns a general treatment, such as high-level rehabilitation, to sections of pavement solely on the basis of what the PSI and PDI values are on that pavement. This model will be used to analyze budgetary impacts on the overall pavement performance of Wisconsin's highways and to assess the impacts of treatment strategies on the budget.