



DAMMAM MUNICIPALITY PAVEMENT MANAGEMENT SYSTEM (DMPMS)

Hamad I. Al-Abdul Wahhab¹, Rezqallah H. Malkawi², Ibrahim M. Asi³, and
Jaweed Yazdani⁴

1: Professor and Chairman - Department of Civil Engineering, KFUPM

2: Pavement Research Engineer-Center for Engineering Research-Research Institute, KFUPM

3: Assistant Professor- Civil Engineering Department, The Hashemite University, Zarqa, Jordan

4: Academic Computing Services, Information Technology Center, KFUPM

Corresponding Address: KFUPM Box 1625, Dhahran 31261, Saudi Arabia

E-mail: hawahab@kfupm.edu.sa

ABSTRACT

This paper describes the development process of the pavement management system for Dammam Municipality road network. The system integrates different subsystems that included: (i) pavement features coding, (ii) visual pavement evaluation, (iii) equipment-based pavement evaluation, (iv) maintenance and repair strategy selection, (v) maintenance priority ranking, (vi) pavement condition prediction, and (vii) reporting. These subsystems were all integrated to form the Dammam Municipality Pavement Management System (DMPMS). The system is a customized computer software that is a knowledge-based Visual Basic Windows application. It has been designed to provide an easy-to-use PC product. It is a completely interactive menu-driven error-checking application, which is supplemented by a full active self-explanatory help facility. The DMPMS was tested and implemented for Dammam road network. The implementation activities included a review and evaluation of data collection procedures and a development of distress manifestation manual, preparation of the software documentation, and Dammam Municipality personnel hands-on training. It is hoped that the developed system will improve pavement performance and yield significant savings in pavement maintenance in the long term.

Keywords: Pavement, Maintenance, Performance, Distress, Dammam Municipality, Management System

() () () () :
() () () ()

1. INTRODUCTION

Cities in the Eastern Province of Saudi Arabia have witnessed a rapid industrialization and growth in every aspect, resulting in high traffic volumes. Dammam City Municipality has a large investment in road pavement network. The major objectives in the design and construction of these pavements are to provide adequate load-carrying capacity and to provide good ride quality. The most effective means of preserving a road network is the implementation of a comprehensive maintenance program.

Simple engineering judgment was the only procedure followed by Dammam Municipality engineers for pavement evaluation and maintenance prioritization. By the end of 1997, the General Directorate for Operation and Maintenance decided to adapt an objective, systematic, and scientific evaluation procedure of their pavement network and to efficiently allocate the available limited funds to maximize their benefits. Therefore, they decided to develop a pavement management system (PMS).

At the beginning of the PMS development, several discussion meetings and presentations were made among the top management and engineers of the maintenance department of Dammam Municipality in order to facilitate strong support and commitment. Moreover, a close coordination was continued throughout the PMS development steps.

In addition, several information were collected about the needs and expectations of the system. A training course on pavement evaluation and maintenance management was held for Dammam Municipality personnel as a preparation for the system development and to facilitate smooth implementation afterwards. Based on this, the following requirements were considered:

1. The system should be comprehensive and easy to implement for data collection, entry, processing, and report generation.
2. The system should be well documented with operating manuals and technical supporting information in dual languages (English and Arabic).
3. The system should be modular and upgradable for new addition of capabilities in the future.

Based on these requirements, network coding, distress data collection method, condition prediction modeling, maintenance activity selection procedure, maintenance priority ranking procedure, and other system activities were formalized and coded in the form of a computer package called "Dammam Municipality Pavement Management System" (DMPMS).

A computer program was coded and compiled using the Visual Basic language and customized as a Windows-based software. The system was calibrated, checked for all possible combinations of data, and verified by the collected data from the pilot survey. In this software package, all DMPMS activities were interconnected with self-explanatory help and error checking facilities.

2. PAVEMENT NETWORK CODING

Dammam Municipality road network is divided into seven districts or zones. Each zone is divided into areas. Roads in each area are also divided into uniform sections based on condition, operating traffic, construction history, and geometry. A pavement section is further divided into features that specify the portion of the pavement segment to be considered for condition survey. Each feature in the pavement network is given an identification code. The given pavement identification code consists of six parts: zone number of two numerical digits, area number of two numerical digits, road number of three numerical digits, section number of two numerical digits, feature number of four alpha-numerical digits, and survey year of four numerical digits. The pavement identification code is unique in the whole pavement network under evaluation. As an example, the pavement identification code (010505902ALLN1999) represents the data collected in the year 1999 for all lanes in the north direction of section 2 of road number 059 in area number 5 of zone number 1.

3. BASIC SECTION INFORMATION

The section code identifies the segment of the road network whose basic information is needed. Figure 1 shows the DMPMS section information entry form. The form has five parts, each with specific information. The first part is for the section identification that determines the location of the feature with its geometry of length, width, and area. The second part specifies the construction date and the layers' thicknesses and types. The third part gives information about the traffic volume operating on the road section under study. In addition, both the total number of surveying samples, which the section is divided into, is internally calculated from the section area, assuming a sample size of 300 m², and the number of samples to be surveyed based on project level and network level analysis are calculated as per PAVER condition survey method [Shahin and Walter, 1990]. The fourth part is to identify the location, utilization, and importance of the road section under study. This data is required for the maintenance prioritization analysis. In the last part of the form, the user can select either to exit the form, clear it, or save it, or to select to go to distress data form, equipment survey form, or special treatment form.

4. CONDITION SURVEY

The main activity in any PMS is the condition survey. The PAVER method developed by US Army Corps of Engineers was adopted in this project [Shahin and Walter, 1990]. The method is well documented for project level and network level, and widely adopted by many pavement authorities including those in Saudi Arabia.

Once the section information is entered, distress data is the most important information needed in DMPMS. The distress data can be entered by selecting the 'Distress data entry' option in Figure 1. A new screen for distress data entry shown in Figure 2 will be displayed with pavement identification (ID) information entered in the corresponding fields. The user enters the sample identification number and the system checks if any data is available for this sample number, and then it restores and shows the old data. Otherwise, a blank distress information sheet will be shown.

The sample area will be calculated automatically, but can be changed by the user. Once the distress identification number is entered, the distress name in addition to its unit of measurement as meter (m), square meter (sm), or number (n) are automatically selected from the built-in database.

When distress severity and quantity are entered, the system calculates the density of this distress and the corresponding deduct value according to PAVER method. The mouse, <TAB>, or <Enter> can be used to move from one field to another. After entering all the available distresses in the sample unit, the <Compute> button is pressed and the total deduct value (TDV) is calculated as the sum of the individual deduct values. The corrected deduct value (CDV) is calculated, the Pavement Condition Index (PCI) is determined as $(100 - CDV)$, and, finally, the rating is determined to describe the condition of the sample unit.

Additionally, the system determines if structural testing and/or skid testing are required by showing YES or NO in the corresponding fields. These are determined based on the availability of certain distress types. Structural testing is needed (YES) if alligator cracking and/or rutting are available. The skid testing is required if bleeding and/or polished aggregate are available.

The system calculates the average PCI for each pavement section from all entered samples. It also projects the available distress over the whole section by finding the density of each distress over the whole section. This is done by dividing the sum of the distress quantity in all samples by the total area of all samples, then multiplying the result by 100. This value is then multiplied by the section area to obtain the projected quantity of the distress under consideration. The distress density is divided into three levels: low for density less than 10%; medium for density below 50% and above 10%; and high for density higher than 50%. These levels are needed for the maintenance and rehabilitation (M&R) determination and maintenance priority ranking as will be discussed later.

Section Information Entry Form

Section Information Entry Survey Year: 1997

Zone No.: 06 Name: Sixth
 Area No.: 22 Name: Madinat Al-Omal
 Road No.: 002 Name: Rubee Bin Kharash
 Direction: N/S No. of Lanes: 2 Total No. of Sections: 1
 Section No.: 01 Feature No.: ALLB
 Length: (m) 173 Width: (m) 10 Area: (sm) 2127

Asphaltic Layers Thickness: (cm) 7 Base Layer Thickness: (cm) 20 Road Class: Local
 Construction Date: 01 01 1973 Subbase: Marl Subgrade: Sand

Operating Traffic: (ADT) 1000 Percentage of Trucks: 3
 Total No. of Samples: 7 Samples to be Surveyed: 2 (Network-Level) 5 (Project-Level)

Road used by VIPs? No Road passing through CBD? Yes
 Road near official/public buildings? No Road has alternative route at time of maintenance? Yes

Clear Save Exit

Distress Data Entry Equipment Survey Data Special Treatment

Figure 1. DMPMS section information entry form.

DMPMS Distress Data Entry Form

Distress Data Entry Survey Year: 1997

Zone No.: 06 Area No.: 22 Road No.: 003 Section No.: 01
 Feature No.: ALLB Sample No.: 1 No. of Samples to be Surveyed: 2 Sample Area: 300 (sm)

Dts.	Severity	Quantity	Density	Deduct Value
2	Bleeding L	30 sm	10	2.6
6	Depression M	15 sm	5	20
10	Long./Trans. Cracking H	60 m	20	48.6

Structural Testing Required: No Skid Testing Required: Yes

TDV = 71.2 CDV = 53.2 Sample PCI = 46.8 Rating = Fair

Next Sample Compute Save Exit

Figure 2. DMPMS distress data entry form.

The condition survey needs to be repeated after specific period of time to ensure close monitoring of the pavement performance, and to plan needed maintenance ahead of pavement failure. DMPMS allows the user to select or update the survey frequency, and then the system calculates, according to road class, when will the next condition survey be required for each road in the network.

5. DEVELOPING PERFORMANCE MODELS

Pavement condition prediction models are essential for a complete pavement management system. Condition prediction models are used at both the network and project levels management. At the network level, prediction models uses include condition forecasting, budget planning, inspection scheduling, and work planning. One of the most important network uses of prediction models is to conduct "what if" analysis to study the effects of various budget levels on future pavement conditions.

Performance modeling requires historical record of the objective function (performance) variation with age (time). If such record is not available, then the alternative method is to use family method. The method consists of the following steps [Shahin and Walter, 1990]:

1. Define the pavement family such as major, collector or service roads.
2. Filter the data for errors or mistakes.
3. Conduct data outlier analysis. Data within $X \pm 2\sigma$ should be included for family model development.
4. Build the family model using regression technique.

In this research, separate models were developed for the major, collector and service roads, using pavement condition data collected from various locations on Dammam City road network. The collected data was logged to specially prepared Excel sheets to calculate the PCI following the PAVER method. Data was analyzed to develop PCI-age relation for major, collector and service roads.

DMPMS uses the default values and system criteria for condition prediction to calculate the future pavement condition index, the required M&R, and the corresponding costs. This is done using the present condition prediction curves for each road class.

6. SYSTEM PARAMETERS

One of the main features of DMPMS is its flexibility since it can be customized for different pavement authorities needs. DMPMS uses system parameters, which are default values of the several factors needed for the system calculations. Prior to running the DMPMS calculations,

all parameters need to be entered and/or updated. There are seven main types of parameters: M&R type and cost, special treatments, maintenance priority ranking parameters, equipment-survey acceptable levels, survey planning, and budget planning. The cost of M&R activities, M&R selection procedure, and maintenance priority ranking are three system parameters examples detailed in the following sections.

6.1. Maintenance and repair (M&R) cost

M&R treatments are generally considered for pavement maintenance based on the type, severity, and extent of distresses. Table 1 shows typical inputted cost values for selected M&R treatments. The cost of each M&R treatment is entered and/or updated according to the local unit cost figures or according to those used by the agency for maintenance budgeting. M&R treatments, other than those listed in Table 1, are considered as special treatments and their unit costs needs to be entered separately. Examples of these special treatments are sand fill, traffic marking and signs, curbstone construction, and repair of manholes. The consideration of these treatments in DMPMS calculation is discussed later.

Table 1. Selected M&R treatment with their default unit costs

M&R No.	Description	Unit Cost (SR)*
1	Do Nothing	0.0
2	Apply Hot sand and Roll	3.5
3	Hot Seal/Seal Coat	2.0
4	Crack Sealing	0.5
5	Surface Patching	2.0
6	Deep Patching	40.0
7	Refill Shoulder	30.0
8	Slurry Seal	3.5
9	Milling and Repave	17.5
10	Base Repair and Repave	40.0
11	Thin Overlay	12.0
12	Structural Overlay	40.0

(*) The unit depends on the type of M&R treatment: linear meter (4), square meter (2, 3, 8) or cubic meter (others)

6.2. M&R selection procedure

Each pavement distress is usually corrected by one or more M&R treatments based on its severity and extent levels. Based on M&R-distress matching adopted by different pavement maintenance methods [Shahin and Walter, 1990, Asphalt Institute, 1983] and based on the locally adopted procedures [MOC, 1998], a general matrix that matches the pavement distress with a specific M&R according to the severity and extent levels was prepared and shown in Table 2.

Table 2. M&R selection matrix.

Distress	Severity Level	Density Level			Distress	Severity Level	Density Level		
		< 10%	10-50%	> 50%			< 10%	10-50%	> 50%
Alligator Cracking	LOW	1	4	4	Patching and Utility Cut Patching	LOW	1	1	1
	MEDIUM	6	6	9		MEDIUM	5	5	5
	HIGH	6	6	9		HIGH	6	6	6
Bleeding	LOW	1	1	1	Polished Aggregate	ALL	1	1	8
	MEDIUM	2	2	2					
	HIGH	2	2	2					
Block Cracking	LOW	4	4	8	Potholes	LOW	5	5	5
	MEDIUM	4	4	8		MEDIUM	5	5	5
	HIGH	8	8	8		HIGH	6	6	6
Bumps and Sags	LOW	1	1	1	Railroad Crossing	LOW	1	1	1
	MEDIUM	6	6	6		MEDIUM	5	5	5
	HIGH	6	6	6		HIGH	5	5	5
Corrugation	LOW	1	1	1	Rutting	LOW	5	5	5
	MEDIUM	6	6	10		MEDIUM	5	5	5
	HIGH	6	6	10		HIGH	6	6	6
Depression	LOW	1	1	1	Shoving	LOW	6	6	6
	MEDIUM	5	5	10		MEDIUM	6	6	6
	HIGH	6	6	10		HIGH	6	6	6
Edge Cracking	LOW	4	4	4	Slippage Cracking	LOW	4	4	4
	MEDIUM	4	4	4		MEDIUM	5	5	5
	HIGH	6	6	6		HIGH	5	5	5
Joint Reflection Cracking	LOW	4	4	4	Swell	LOW	1	1	1
	MEDIUM	4	4	4		MEDIUM	6	6	6
	HIGH	6	6	6		HIGH	6	6	6
Lane/Shoulder Drop-off	LOW	7	7	7	Weathering & Raveling	LOW	1	1	1
	MEDIUM	7	7	7		MEDIUM	1	8	8
	HIGH	7	7	7		HIGH	1	8	8
Longitudinal & Transverse Cracking	LOW	4	4	4					
	MEDIUM	4	4	4					
	HIGH	5	5	5					

Guide

1	Do Nothing	7	Refill Shoulder
2	Apply Hot sand and Roll	8	Slurry Seal
3	Hot Seal/Seal Coat	9	Milling and Repave
4	Crack Sealing	10	Base Repair and Repave
5	Surface Patching	11	Thin Overlay
6	Deep Patching	12	Structural Overlay

The system allows the user to update the M&R selection strategies for any specific distress by selecting the specific pavement distress and updating its corresponding M&R treatments. The cost of each selected M&R is calculated using the stored unit cost of each M&R (Table 1) and the projected quantities of the distresses. The severity of each distress is divided into three levels: low, medium, and high. The density is also divided into three levels; low for densities of less than 10%; medium for densities between 10 and 50%; and high for densities greater than 50%. The M&R numbers shown in Table 2 refer to those given in Table 1.

In cases where more than one M&R are selected for any section, an overriding M&R policy is internally applied, taking every pair of M&R at a time. If a higher or more comprehensive M&R comes with a lower one, the higher one overrides the lower one since it covers the latter. For example, thin overlay covers the slurry sealing if both are selected for one pavement section according to the available distresses. But thin overlay and crack sealing will both be considered since the overlay will not be applied without the crack sealing. This procedure is followed to avoid double counting of the maintenance cost and erroneous priority ranking.

In some cases, the user needs to incorporate additional information about maintenance and repair that are not distress-based, such as sand fill, lane marking, cat-eyes installation, etc. The system considers these information externally, and either adds their costs to the maintenance cost calculated according to the available distresses, or overrides the distress-based maintenance with the cost of some major treatment such as in "removing the old pavement and reconstruct a new one" alternative.

6.3. Maintenance priority ranking

The composite maintenance priority index was the method selected for pavement maintenance priority ranking procedure. This method is relatively simple and gives close to optimal results [Haas et al., 1994], and has been adopted by many PMS systems.

The composite index method considers several factors that affect the priority ranking. Each of these factors has a specific weight of importance to the priority ranking. Two types of information are needed: the priority factor value and the priority factor weight. Seven factors were considered in this project. These factors are road class, pavement condition, operating traffic, riding quality, safety condition, maintenance cost, and the overall importance of road section to community. To obtain the priority index of each pavement section in the road network, the value of each of the seven priority factors should be determined. This determination is based on location, utilization, condition, performance parameters, operating traffic, and the needed maintenance cost for that pavement section.

These factors along with their suggested weight of importance are shown in Table 3. The sum of all factor weights should be equal to 1.00. In case of any entry that results to a sum other than 1.00, an error message will be displayed. Similarly, the importance of the road to

community is determined by a set of six sub-factors. The weights of these sub-factors are shown in Table 4. The sum of these weights should be 1.00.

In maintenance priority-ranking procedure, a priority index (PI) out of 100 is calculated for every section that reflects the importance and urgency of repair to that section. PI is calculated by multiplying each priority factor value by its weight and summing the products as follows:

$$PI = \sum_{i=1}^n W_i * F_i \tag{1}$$

where:

- PI = Priority index for any section (out of 100),
- W = Priority factor weight of importance to priority ranking,
- F = Priority factor value, and
- i = Index for the selected priority factors shown in Table 3.

Table 3. Maintenance priority factors and their weights.

No.	Factor	Weight
1	Road Class	0.135
2	Pavement Condition	0.196
3	Operating Traffic	0.132
4	Riding Quality	0.124
5	Safety Condition	0.155
6	Maintenance Cost	0.106
7	Importance to Community	0.152

Table 4. Sub-factors describing importance to community and their weights.

No.	Factor	Weight
1	Road Class	0.160
2	Road Passing Through CBD	0.154
3	Road Used by Official Persons and VIPs	0.174
4	Operating Traffic	0.216
5	Available Alternative at Maintenance Time	0.136
6	Near Other Important Building	0.160

The values of priority factors need to be normalized to 100 in order to facilitate the priority index calculation by avoiding the overpowering of some factors by others. The priority factor value is either a measurable one such as pavement condition, operating traffic, measured safety as skid resistance, measured riding quality as pavement roughness, maintenance cost, or it is a qualitative one such as road class and importance to community. If the measuring equipment are not available, riding quality and safety condition, are also considered as qualitative factors that need to be quantified.

The road class value is assigned a value out of 100. If the road is arterial without alternatives at the time of maintenance, it has a high priority value of 100. If it is arterial but with alternatives, then a value of 75 is assigned to it. If the road is collector or local, values of 50 and 25 are assigned, respectively. For riding quality and safety condition, similar procedure is followed based on the availability of pavement distresses that are related to these two factors. This procedure is imbedded in the DMPMS and detailed elsewhere [Ramadhan, 1997].

The pavement condition index of a section and the measured skid resistance as skid number (out of 100) are subtracted from 100 to obtain their values for priority ranking calculation. The operating traffic value is normalized by dividing the traffic volume operating in this road section by the maximum operating traffic in the road network and multiplied by 100. Similarly, the riding quality (roughness) is normalized by dividing the measured roughness value by the maximum acceptable roughness value and multiplied by 100. In the case where the measured roughness is higher than the maximum acceptable value, a factor value of 100 is assigned.

The 'importance to community' priority factor is determined by a set of six sub-factors shown in Table 5. The values of these sub-factors depend on the location of the road section in the network. They also depend on the extent of utilization of this road section in terms of road type and operating traffic. Thus, these values can be either dichotomy (Yes/No) or numerical values. If the road is passing through a central business district (CBD), a value of 100 is

Table 5. Determination of sub-factor values for importance to community factor.

No.	Sub-Factor	Level	Factor Value
1	Road is Passing Through CBD ?	Yes	100
		No	0
2	Road is Near Official Building or used by VIPs?	Yes	100
		No	0
3	Availability of Alternative Roads during maintenance?	No	100
		Yes	0
4	Road is Near Other Important Public Centers?	Yes	100
		No	0

assigned to this sub-factor to reflect its importance; otherwise, a zero value is assigned. On the other hand, if the road, where the pavement section exists, has an alternative when it is subjected to maintenance (YES), then this road is not as important as the one that does not have an alternative (NO). Therefore, a value of 100 is assigned to the road without alternatives, and a value of zero to the other one. The other two sub-factors are road class and operating traffic, and their values are calculated as before.

8. OTHER DMPMS FEATURES

DMPMS has other features such as system security, database backup and archiving, report generation, and active help facility. These activities are briefly described below.

8.1. System backup and archiving

This option is used for storing the working database in backup files and to restore them for new application. This is needed in order to facilitate DMPMS operation only on the current data. In situations where some data are stored in different databases that need to be appended to the working database, DMPMS has a database copy feature. Moreover, DMPMS will automatically transfer old pavement section distress survey files to archive data once the new survey for the same section is inputted. Old section information can be restored, if needed.

8.2. Error-checking application

DMPMS has a powerful error-checking capability based on stored default conditions that were thoroughly checked. This makes the system easy to operate by any user with minimal experience level. The error-checking routine is essential to assure complete and correct database prior to the system calculations.

8.3. System user management

DMPMS has different security levels. These levels specify the set of activities that are applicable to each type of users. New users can be added to the system, each with a specified password. Three levels of operations are included in DMPMS: Guest level for users who are allowed to only browse the recent reports of DMPMS; Operator level for users who can use all DMPMS capabilities except updating system parameters and system management; and Administrator level for users who can utilize all DMPMS capabilities including updating system parameters and data management.

8.4. Reporting facility

DMPMS has a comprehensive reporting subsystem that is integrated with all other activities. All reports can be produced in three levels: network level, zone level, and area level, as shown in Figure 3. Once the required report is selected, a common screen is displayed for the

required report, which is then routed to Screen (as default), Printer for hard copy, or file for storing.

The reports have different purposes. Some of them are for system inventory; others are for computational outputs where actions need to be taken for implementing the results, such as the M&R recommendations. Some reports are for planning purposes, such as the survey planning and budget planning. Still, other reports are for generating new blank forms for the next scheduled condition surveys.

8.5. Help facility

In this feature of DMPMS, a comprehensive information help facility explaining all parts of DMPMS can be searched for any subject. An active self-explanatory help portion is browsed at any stage of DMPMS application. Moreover, explanatory messages are automatically browsed for erroneous actions.

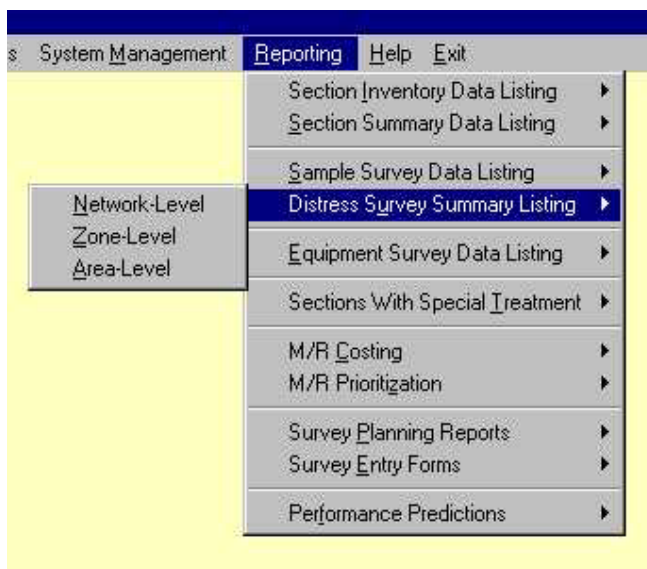


Figure 3. DMPMS report generation subsystem.

9. CALIBRATION AND VERIFICATION OF DMPMS

In order to calibrate the developed DMPMS and to verify its performance, zone number six located in area number twenty-two in Dammam City was selected as a pilot study area. The area consisted of 160 road sections. All the sections contained in the area were coded with pavement identifications. The needed information about these sections were collected as per the forms that were specially prepared for this study, and the distress surveys were carried out. To train the technician who will perform the surveys and analyze the data in the future,

personnel from the Dammam Municipality joined in the pavement condition surveys, feeding the data into the software and generation of reports. 100 sections were used for calibrating the system parameters, the remaining 60 sections were used to verify the calculations and check the output against the sound engineering analysis and engineering judgments. Manual calculations were made for some of the sections and were checked and compared thoroughly with the calculated output to insure that the system is correctly performing the required calculations.

10. EXPECTED BENEFITS

DMPMS is being implemented by the General Directorate for Operation and Maintenance of the Dammam Municipality. It is expected that the pavement network will be better maintained when the system is fully implemented. The maintenance allocated funds spending will be optimized in a long-term application since it can be estimated ahead of time. DMPMS can be easily transferred to any pavement maintenance department in Saudi Arabia and elsewhere provided that the default system parameters are wisely updated.

ACKNOWLEDGMENTS

The authors wish to acknowledge the General Directorate for Operation and Maintenance of the Dammam Municipality for funding this project, and the King Fahd University for Petroleum and Minerals for providing support to this research.

REFERENCES

1. Asphalt Institute, 1983, Asphalt Overlays for Highway and Street Rehabilitation. The Asphalt Institute Manual Series No. (MS-17), USA.
2. Haas, R. Hudson, W. R., and Zaniewski, J., 1994, Modern Pavement Management. Krieger Publishing Company, Florida, USA.
3. MOC, 1998, Highway Maintenance Manual. Ministry of Communication, Riyadh, Saudi Arabia, 1998.
4. Ramadhan, R. H., 1997. "Modeling of Pavement Condition and Maintenance Priority Ranking for Road Networks". Ph.D. dissertation. Civil Engineering Department, King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
5. Shahin, M. Y., and Walter J. A., 1990, Pavement Maintenance Management for Roads and Streets Using PAVER system. US Army Corps of Engineers, Construction Engineering Research Laboratory (USACERL), Technical Report M-90/05, USA.