

Utilizing Geographic Information System as a Tool for Pavement Management System

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Abstract: Pavement management systems (PMS) have evidenced to become an essential and valuable tool for highway agencies in quantifying the overall pavement maintenance needs and presenting the alternative maintenance plans under budget limitations. An essential phase of the development of a PMS is to collect, manage and analyze the pavement condition data, containing various structural and functional distresses, in considerably detailed format. Recently, the infusion of the new spatial technologies such as Geographic Information System- GIS has enhanced the PMS development and implementation efforts. The purpose of this paper is to present an analysis of the use of Geographic Information Systems (GIS) as a tool for the PMS, as a first attempt in the city of Amman-Jordan.

Keywords: pavement management system, PMS, Geographic Information Systems, GIS, Jordan, Amman.

1. Introduction

Recently, the focus of transportation agencies has shifted from constructing new facilities to maintaining the existing facilities [1]. Thus transportation agencies recognized the benefits of implementing the Pavement Management System (PMS) tools to guide decision makers in finding optimum cost-effective strategies for providing, evaluating, and maintaining pavement in a serviceable conditions during a given period of time [2]. It provides an orderly method for collecting, managing, analyzing, and summarizing pavement information to support the selection and implementation of a cost-effective pavement construction, rehabilitation, and maintenance programs [3].

PMS is in a wide concept, a working program that includes all the project cycle content which starts with planning, programming, designing, building, maintaining, and rehabilitation of pavement. Pavement management concept was first introduced and implemented in the late 1960s and early 1970s to varying levels of success. It adopts methods and tools to be used to assure the best implement and allocation of existing resources in a given period of time.

In the mid-1980s, PMSs started to become popular in state and local agencies. Many local agencies such as city and county governments have begun to realize the benefits of a “decision-support” process used to help find cost-effective ways to manage their pavement network and keep their roads in serviceable condition [4, 5].

Recently, the infusion of the new spatial technologies such as Geographic Information System- GIS has enhanced the PMS development and implementation efforts. GIS is used to design PMS database that is to store, query, retrieve, and report pavement management data. Also roadway managing agencies commonly use GIS to spatially display the network and display certain network characteristics. The visualization characteristic is

usually utilized to help decision makers decide on what, where, and when any course of action should be done to the system.

GIS is also used to recognize the way in which roadway network interacts with its circumference and how the circumference conditions should affect roadway decisions. This is particularly useful in mountainous regions where landslides can be detrimental to transportation. In such areas, it serves transportation managers to visualize pavement areas and the proximity to areas susceptible to landslide. This information can be mapped to demonstrate decision makers where money should be spent to ensure that the network remains in good working order [3].

The purpose of the paper is to present an analysis of the use of Geographic Information Systems (GIS) as a tool for the PMS, as a first attempt in the city of Amman-Jordan.

2. Literature Review

A. Pavement Management System

PMS according to the Federal Highway Agencies is briefly defined as; “A set of tools or methods to assist decision makers in finding cost-effective strategies for providing, evaluating and maintaining pavements in serviceable condition” [6].

Other researcher described the PMS as the approach to optimize the implementation of highway construction and maintenance resources. Thus optimizing current pavement condition assessment application will be the first and the primly task of efficient pavement management system. [7]

PMS is anticipated to continue to be the critical component for managing and maintaining the transportation infrastructure over the world. PMSs are useful tools for highway agencies to enumerate the overall maintenance needs of pavements and to provide alternative maintenance strategies under budget limitations. The most important aspects of the development of a successful PMS are to collect, capture, manage and analyze the pavement condition data in detailed format.

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Many modifications have been developed in the field of pavement management, which lead to continue the development and improvement of computerized capabilities and analysis tools. The changes in pavement management have evolved as the types of information required by public agencies have changed [6].

B. Geographic Information System (GIS)

A GIS is a computerized data base management system for capturing, collecting, accumulating, storing, retrieving, analysing and displaying spatial data. A GIS consists of two main categories of information, geo-referenced spatial data and attribute data. Geo-referenced spatial data is defined as objects that have a location description. They involve orientation and relationship in two or three-dimensional space. Attributes have information on roadway such as street segment, number of lanes, width, pavement condition, and traffic volumes.

The application of such sophisticated visualization and analysis technique in PMS has been described in literature by many researchers [8, 9, 10, 11, 12 and 13]. The findings from these researches have proven usefulness in enhancing and supporting the PMS.

C. PMS and GIS Integration

Geographic information systems with their capability to spatially analyse road networks are believed to be one of the most appropriate tools to enhance pavement management operations, with features such as visual deployment of pavement conditions. The technological advances in computer hardware and software in these days, GIS is increasingly implemented in public authorities, also there is an increasing trend toward integration the PMS data into GIS.

Researchers studied the advantages and disadvantages for GIS, PMS integration. The advantages of such integration involve the ease of editing roadway database, the ability to visualize results, display database queries and statistics on highway network maps, and view the condition on the network by using highway sections colour coding for and access data through the graphical map interface [14].

Also, among the most important GIS-PMS utilization advantages is the applicability of GIS to each component of pavement management. The disadvantages were not taken into focus [15].

D. Paver System

Pavement system- Paver system has been widely used in many transportation fields such as airports. Paver system was developed by U.S Army Corporation of engineers during 1970s. The development of paver system not only took into consideration pavement distress data, but also destructive and non-destructive performance test results. It also involve a computer program named "Micro Paver".

Paver system utilizes Pavement Condition Index (PCI). The PCI is a numerical index that describes the pavement condition and ranges from 0 indicating failed pavement condition to 100 indicating excellent pavement conditions [16].

Standard PCI scale evaluates pavements within 7 different categories; special PCI scale uses only 3 different categories. In addition, different colours have been used by Micro Paver to characterize different situations within both standard and special scales. Concurrently, present condition, with other words pavement quality, can be depicted by using words "excellent", "very good", etc. Pavement quality and PCI comparison are shown in Figure 1.

E. Pavement Distresses

Road conditions are evaluated and rated differently by different agencies. There are many periodical surveys made by

transportation agencies for tracking and evaluating pavement conditions. These surveys are made to measure distress types and levels. Major distress types can be listed as surface defects, permanent deformation or distortion, cracking and patching [17].

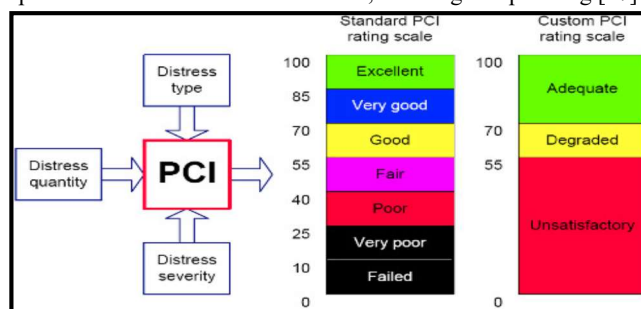


Figure 1. Pavement Condition Index - PCI [18]

3. Methodology

Amman network covers more than 900 Km of paved roadways including only flexible pavement with HMA. The determination of the network size and boundaries is the main requirement for developing a successful PMS. For this purpose the city of Amman was divided to 12 subareas, three in each direction north, south, west and east of Amman. These subareas were obtained by assuming Amman as a circular city with a diameter of 24 km. This area was subdivided into two axes and three circles where each direction was divided into three subareas as shown in Figure 2. From each subarea, the main roads were randomly selected and tested.

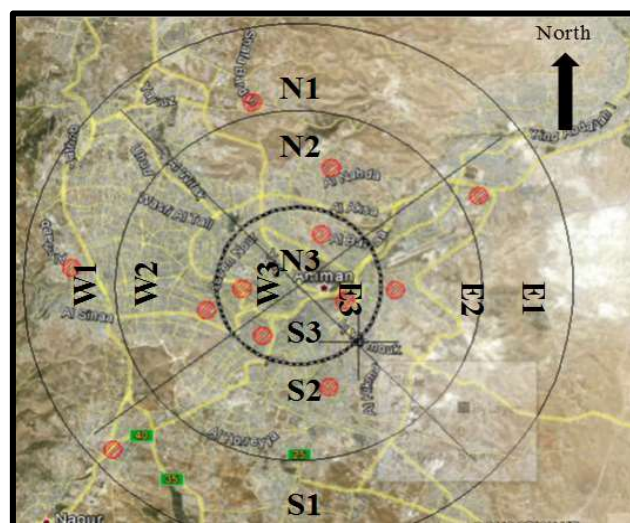


Figure 2. General Map

A section from each selected road was clearly identified on site, the section is defined as a portion from one-way direction of the road that has the same properties such as; Pavement Structure, Traffic, Pavement Type, Drainage Facilities and Shoulders, Pavement Condition and size. The selected sections are shown in Table 1. Each Section has been divided into equal sample units, number of inspected units was determined according to Table 2.

Table 1. The Selected Section for Inspection

On map	section												Speed	lanes		
	information		dimension			Unit samples										
	ID	Road name	Length	Width	Area	Total no	Area	Length	Width	# tested	Tested sample					
W1	W1-1	Ebnkhaldoon	62	5.4	334.8	2	167.4	31	5.4	1	1	40	2			
W2	W2-1	Al-kahera	220	6	1320	5	264	44	6	1	2	60	2			
W3	W3-1	Radiinnab	190	6.7	1273	8	159.125	23.75	6.7	2	1	5	40	2		
N1	N1-1	Alwatan	168	7	1176	7	168	24	7	2	6	4	40	1		
N2	N2-1	Tabarbour	175	7.3	1277.5	5	255.5	35	7.3	1	1	40	2			
N3	N3-1	Shafabadran	400	7.6	3040	15	202.67	26.67	7.6	3	14	1	11	70	2	
S1	S1-1	Haleemahsaedyyah	70.8	5.4	382.32	2	191.16	35.4	5.4	1	1	40	1			
S2	S2-1	Huryth ben ziad	180	6	1080	5	216	36	6	1	4	40	1			
S3	S3-1	Al-amiratagheed	540	10	5400	30	180	18	10	4	17	18	21	6	40	2
E1	E1-1	Shuhadaa	100	8	800	5	160	20	8	1	1	40	2			
E2	E2-1	Rihab	100	7.5	750	4	187.5	25	7.5	1	1	40	2			
E3	E3-1	Zannoubia	260	7.5	1950	10	195	26	7.5	2	1	10	60	2		

Table 2. Number of unit samples [6]

No. of Sample Units in Section	No. of Units to be Inspected
1 to 5	1
6 to 10	2
11 to 15	3
16 to 40	4
Over 40	10%

A. Data Collection and Analysis

After determining the number of the required unites to be inspected, quantitative data on the severity and extent of different pavement distresses were collected. Field surveys were conducted. The pavement surface condition data were collected in both directions. The primary direction in most cases travels from south to north and/or from west to east. The secondary direction, opposite direction, travels from north to south and/or from east to west. The distresses were identified based on the distress definitions in reference [6]. After the distress type, quantity, and severity were calculated, the distribution of each distress type and severity was calculated by dividing the quantity of the distress by the total quantity of the sample unit. Table 1 also shows a description of the sections that has been surveyed. It was found that the city of Amman is witnessing a great increase in the volume of potholes and transverse cracking which is causing noticeable disturbance and interruption to pavement maintenance schedules and activities. Table 1 shows data for the surveyed sections. It includes information on: name, dimensions, amount of tested samples, posted speed and number of lanes for each roadway.

B. PCI Calculations

Once the distress density was determined, the deduct values were determined by using the charts available in reference [6]. The deduct values are functions of distress density and severity, and range from 0 to 100 (a deduct value of 0 means the distress has no impact on the PCI calculation). The results of these calculations are shown in Table 3. It can be seen that the PCI values ranges from 5 on the eastern side of Amman (very poor pavement conditions) to 96 also in the eastern side of Amman (excellent pavement conditions). It also can be seen that the average PCI value is 56.95 which indicates fair overall pavement conditions in the city of Amman.

Table 3. PCI value

Section	Sample Unit Number				PCI for Section
	PCI for Each Sample Unit				
W1-1	1				59
	59				
W2-1	2				66
	66				
W3-1	1	5			49.5
	38	61			
N1-1	6	4			72
	84	60			
N2-1	1				35
	35				
N3-1	14	1	11		70.7
	78	84	50		
S1-1	1				75
	75				
S2-1	4				48
	48				
S3-1	6	17	18	21	50.25
	36	32	55	78	
E1-1	1				57
	57				
E2-1	1				5
	5				
E3-1	1	10			96
	96	96			

C. Geographic Presentation

To accomplish the implementation of GIS with PMS, all the collected data were in a format that can be easily transferred into GIS. Collecting the road data is typically done on a spreadsheet or database such as Microsoft Access. This spreadsheet was then exported from GIS database. The attributes considered included inventory data, distress data and traffic data. Figure 3 shows GIS model for the City of Amman based on PCI values.

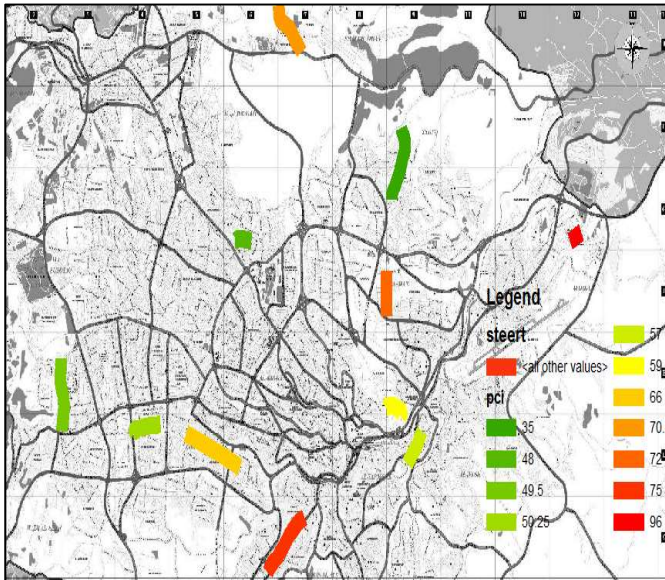


Figure 3. GIS Model

Figure 3 contains the road network in Amman coloured in blue and the PCI legend. It can be seen that the worst pavement conditions exists in the eastern side of Amman and the best pavement conditions exists in the north side of Amman.

D. Maintenance Strategy and Cost Estimation:

Maintenance prioritization was based on ranking (single year prioritization) the pavements selected is sorted in ascending order from the pavement with the least PCI (worst condition) to the highest (best condition) as shown in Table 4.

The following maintenance procedures are the only maintenance procedures used for pavement rehabilitation by greater Amman municipality (GAM). They were determined with the help of the general deterioration curve used by the GAM shown in Figure 4:

- PCI > 60% Preventive maintenance
- 60% > PCI > 20% Overlay
- 20% < PCI Reconstruction

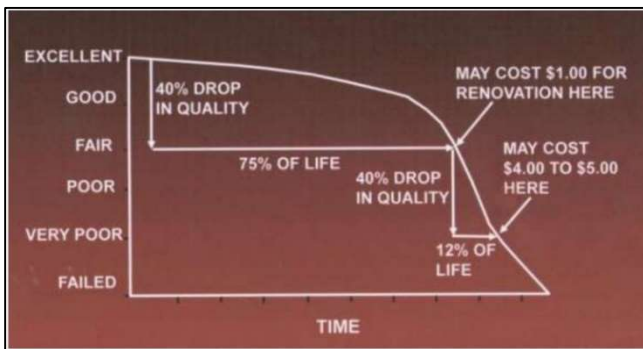


Figure 4. General Deterioration Curve [6]

The preventive maintenance is determined for each section according to the distresses types and quantities, where the injection is used for crack sealing which costs 0.3 JD/m length, other distresses are treated by patching which costs 13JD/m², overlay (5cm thick) costs 6JD/m², on the other hand reconstruction costs 20 JD/m². On the other hand there are many types of maintenance that could be used for pavement rehabilitation. However, the Greater Amman Municipality don't use such methods.

Table 4 summarizes the total cost of maintenance for each section. Because this is the first attempt to apply PMS for

Amman, there is no specific budget for road maintenance assigned by the GAM. A budget of one hundred thousand Jordan Dinners (JD 100,000) was assumed. The sections were ranked from worst condition which requires the highest rehabilitation cost to best condition which requires the lowest rehabilitation cost. The shaded region represents the sections to be addressed in the upcoming year.

Table 4. Total Maintenance Costs.

Section ID	PCI	Maintenance Strategy	Unit Cost (JD/m ²)	Section Area (m ²)	Total Cost JD
E2-1	5	reconstruction	20	750	15000
N2-1	35	Overlay(5 cm)	6	1277	7662
S2-1	48	Overlay(5 cm)	6	1080	6480
W3-1	49.5	Overlay(5 cm)	6	1273	7638
S3-1	50.25	Overlay(5 cm)	6	5400	32400
E1-1	57	Overlay(5 cm)	6	800	4800
W1-1	59	Overlay(5 cm)	6	334.8	2008.8
W2-1	66	Prevention maintenance	13	1320	17160
N3-1	70.67	Prevention maintenance	13	3040	39520
N1-1	72	Prevention maintenance	13	1176	15288
S1-1	75	Prevention maintenance	13	382.32	4970.16
E3-1	96	No maintenance needed	0	1950	0
total					152,927

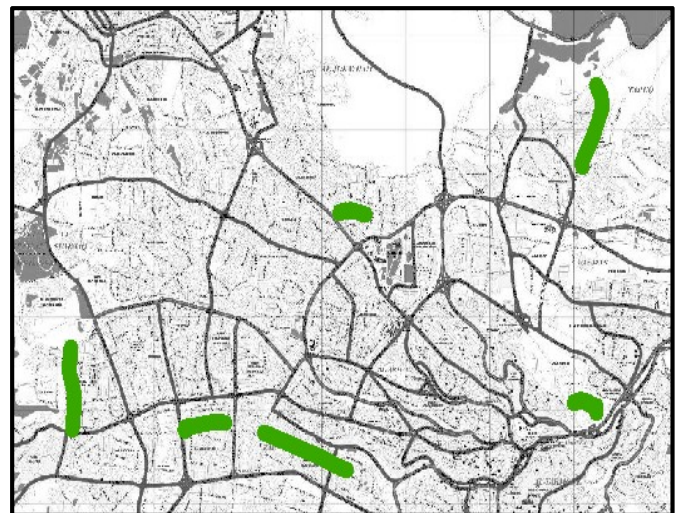


Figure 5. Maintenance and Rehabilitation.

It can be seen that the best pavement conditions exists in the north side of Amman which totally agrees with the results from Figure 3.

It should be noted that GIS models can be developed based on maintenance and rehabilitation plans for any time period (one year, two years and up to 20 years). This would allow a more efficient spending plan of the available budget. Since there was no budget appointed for this purpose, the GIS model was only developed based on the pavement condition index.

4. Conclusion

Constructing a PMS is a necessary step that most agencies around the world are taking into consideration to improve the roads rehabilitation and costs procedures. The lack of serviceable and safe pavements in our beloved city: Amman was the idea behind this research. Geographic Information Systems (GIS) based

Pavement Management System(PMS) is the future for managing infrastructure in all countries. It will enhance maintenance quality and reduce cost. The purpose of the paper is to present an analysis of the use of GIS with its spatial analysis capabilities, as a tool for the PMS, as a first attempt, in the city of Amman-Jordan.

5. Recommendations

The following recommendations are designed to establish a country wide PMS plan:

- Organize a country wide PMS Coordinating Committee, including PMS experts and representatives from The Ministry of Public Work and The Greater Amman Municipality.
- Establish reliable data collection procedures and standardize pavement rating system in Jordan.
- Set a budget and identify alternative source of funding
- Develop a country wide prioritization process.
- Document the benefits of PMS.

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