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Research Article

Development of pavement maintenance management system for an urban areas based upon multiple linear regression analysis

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ABSTRACT

The Road Network, a crucial national asset, requires high maintenance investments to ensure longevity and optimal functioning. In the context of Amman city in Jordan, most roads were constructed before the year 2000, which makes most of them at the end of their service life. To address this challenge, we developed a Pavement Maintenance Management System (PMMS) utilising GIS, Micro PAVER, and SPSS software, providing intuitive assessment tools for decision-makers. Focusing on the urban Nasir district in Amman city as a representative case study, our study used Performance Scoring Rating (PSR), Pavement Surface Index (PSI), and Pavement Condition Index (PCI) to evaluate the street network. Benefiting from the GPS technology, conduct a detailed assessment of five streets to assess the distress types, severity levels, and section lengths. Multiple linear regressions were employed to create nine distinct prediction models containing various PSR, PSI, and PCI variables. These models enable estimating and measuring pavement conditions at any street section, even when limited data is available. After testing the developed models, minimal estimation errors and high acceptance levels were found, reinforcing decision-maker reliability.

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INTRODUCTION

Amman, the capital of the Hashemite Kingdom of Jordan, is rich with a combination of old city and modern infrastructure. It is in a hilly area between the desert and the fertile Jordan Valley. The city is administered by The Greater Amman Municipality (GAM), which covers 22 districts [1]. The total length of roads in Amman city is 1044 km, which consists of 564 km of rural roads, 203 km of secondary roads and 277 km of highways. The estimated population of Amman will be around 4.6 million in 2021, which constitutes 42 per cent of Jordan's population [2].

Roads need to be maintained and reformed; once new pavements are constructed, environmental and traffic stress causes them to deteriorate. Traffic loads and the variability of materials used play a crucial role in the rate of deterioration [3]. The pavement maintenance management system (PMMS) inspects and ratings the pavement condition in a specific area [4].

Current threats to the current practice for managing road maintenance in Amman Municipality can be summarised as follows:

1) Rapid traffic growth of vehicle possession in Amman city exceeding the design capacity of that roads
2) Arbitrary and uncontrolled vehicle overloading leads to faster deterioration of the road network.
3) There is a continuous need to improve the implementation of maintenance behaviour and the PMMS.
4) Municipalities' limited equipment, materials, and funds maintenance resources.
5) There is a need to use highly technical inspection tools to find the low level of serviceability of roads to be maintained.
6) Weak coordination between municipalities and companies of water and sanitation, electricity, and telecommunication regarding infrastructure installation.
7) A long period of infrastructure installation weakens road pavement and pavement layers.

Future Threats: From 2009 to 2020, there has been a consistent increase in the number of vehicles possessed in Jordan; the number exceeded 1.7 million vehicles; the rate of increase varied each year, with the highest percentage change occurring in 2009 at 9.9% and the lowest in 2018 at 2.8%. The trend shows a general upward trajectory in vehicle ownership, albeit with some fluctuations. The steady growth in the number of vehicles possessed implies a corresponding impact on various aspects of society and infrastructure. It puts pressure on transportation systems, roads, and parking facilities. [2]. These statistics can project the future growth of cars in Jordan and lead to more traffic, one of the main factors affecting pavement performance [3].

Statistics show that the number of vehicles in Amman is increasing steadily, which puts municipalities under a higher challenge to maintain, sustain, and develop the road network and ensure the safe and comfortable movement of people and goods in Amman [5].

Because management systems have become crucial in many fields, much research has been done on this constantly evolving subject. A significant addition to the discussion is provided by [6], who elaborates in his insightful article on the recent advancements in the standardisation of management systems and offers a thorough history of their development.

New technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), work schedules, and follow-up and field reports should have an integrated system to be used by decision-makers to perform maintaining activities roads network efficiently, economically and within the timeframe [7]. In the management process, planning, scheduling, operating, controlling, and giving feedback on a detailed and specified framework are the ways to achieve the project goals efficiently, economically, and within the timeframe [8]. Pavement Maintenance Management System (PMMS) should practice management process activities to achieve a good and well-maintained road network [9].

Geographic Information System (GIS) and its relational database are exclusive ways to locate features that are part of or located along a particular road. Integrated infrastructure can help municipalities minimise road deficiencies as a part of the infrastructure system [10]. The Ministry of Public Works and Housing uses a five-level evaluation system. [11] presented two new conditions and modified the description to the five current levels to become more accurate and comprehensive in describing pavement conditions. Effective highway management necessitates the management of numerous data sets, including traffic volume data, roadway data, and data from the road edge and roadside. Like all significant infrastructure clients, highway administration authorities are pressured to use such platforms for better data management [12]. Transportation is critical to the economic well-being of every nation in today's modern society. Road transport is the most common and widely used among the various modes of transport. It facilitates 90% of the movement of people, agricultural products, goods, livestock, and critical mobile services such as clinics, libraries, and banks [13]. Road failure, deterioration, ageing, overuse, and mismanagement are threats any municipality encounters in maintaining and preserving the road network [14].

The objectives of the research are 1) the Creation of a maintenance system database with a particular attribute table for the requirement of maintenance activities., and 2) the Development of a statistical prediction model based on the Present Serviceability Index (PSI), Present Serviceability Rating (PSR), and Pavement Condition Index (PCI).

A Pavement Maintenance Management System (PMMS) is a Systematic approach involving inspection, cost analysis, prioritization, and resource management to extend the pavement service life within certain budget constraints [4]. The main characteristic of a sound PMS system is the ability to implement data collection, entry, processing and report generation and the ability to be upgraded for new capabilities in the future. Dammam municipality has developed PMMS, Maintenance priority factors are suggested with weight for each factor for a better selection process [15]. [16]aimed to develop Pavement Maintenence Management System (PMMS) utilising PAVER software to create an integrated database of Pavement conditions and integrate it with a GIS-base maps database, and found that despite the large number of research conducted in the field of M&R, this is still a lack of a systematic, unified strategy for prediction and maintenance procedures, some challenges were found such as the unavailability of historical maintenance records in Jordan were reported. Another study aimed to develop a (PMMS) using the HDM-4 model for four urban road sections in India. The study computes (M&R) and conducts a comparative analysis of scheduled and condition-responsive M&R strategies [17]. Due to the critical role of Pavement Asset Management Systems (PAMS) in optimizing budget allocation for maintaining deteriorating pavement assets, [18] conducted a review paper summarizing the latest data collection, analytical techniques, decision-making tools, and processing methods associated with pavement condition management.

Pavement Maintenance Management System is a part of the infrastructure management system. [19] An infrastructure management system is "The operational package that enables the systematic, coordinated planning and programming of investments or expenditures, design, construction, maintenance, rehabilitation, renovation, operation, and in-service evaluation of physical facilities". One of the essential aspects of the PMMS is directly related to the system itself, where incorporating the reporting features in the system is where GIS software is necessary to view the current and future condition of roads. Micro Paver and GIS are critical elements to employ the PMMS capabilities fully. [15]. Using the expert system over conventional computerised models could offer significant advantages. Expert systems are very efficient in solving complex maintenance problems using their extensive knowledge and human reasoning in analytical ways [20].

The Handbook for Highway Engineering illustrates highway maintenance as "actions taken to retain all the highway elements in a safe and usable condition"[21]. To provide better assessment for decision makers to perform maintenance tasks more economically, effectively, and with higher quality and promptly, the need for a Pavement Maintenance Management System appears. According to Al-Hallaq, the definition of the pavement maintenance management system is "A Scientific tool for managing the pavements to make the best possible use of resources available or to maximise the benefit for society"[15].

Furthermore, [22] developed a visual evaluation of asphalt concrete pavement surface condition to suggest the required maintenance action to keep asphalt concrete pavement. Sarsam quantified the pavement condition into pavement condition rating (PCR), which rated pavement according to the distress severity, from 100 to zero (best to worst). The main goal of the PMMS developed is to keep pavement conditions in the upper (PCR) range to keep rehabilitation costs at a minimum. "Locating sites that have to be maintained and determining upon the kind of maintenance and methods of treatment had become more accurate and more feasible than before, which led to a reduction in financial costs reflecting in its turn development and improvement of road networks in the Kingdom" [23]. From another aspect, [24] evaluated the Jordanian experience in managing urban road maintenance using a questionnaire for the nine major municipalities in Jordan. This includes Amman, Irbid and Zarqa.

Maintenance tasks are not a one-day job. Today's pavement conditions project the future pavement conditions, as past pavement conditions affected the condition of today's condition, making it an essential function of the pavement management system to predict future pavement conditions. Micro PAVER pavement maintenance management systems are designed to optimise the maintenance and rehabilitation (M&R) costs; [25] developed a questionnaire-based database according to network division, dividing the network into zones, branches, sections, and sample units. The report used the Pavement Condition Index (PCI) to establish Maintenance and Rehabilitation (M&R). while [23] states, "A PMMS is required to make the system more flexible to adjust the work plan and schedule to reflect the changing condition." A Pavement Maintenance Management System using Micro Paver software was developed. The researcher developed the system using the Pavement Condition Index (PCI) as an evaluation tool. The Micro Paver software predicts future physical conditions and creates Maintenance and Repair (M&R) using minimum future repairing costs [26]. Due to funding restrictions worldwide, there is a need to incentivise developing an effective budget allocation process to maintain pavement, as it is easier to know the pavement condition than create an on-time budget PMMS to overcome the budget constraints [27].

[28] She studied pavement maintenance management systems for urban roads in Madurai. In this study, a preliminary survey is conducted to collect preliminary information about the road from Thanakankulam to Thiruparankundram; the analysis process will be carried out using the HDM-4 tool to determine the pavement condition index and its strategies. HDM-4 framework has been chosen and utilised in this examination because of the more extensive International Acceptance. The HDM-4 framework has been used to improve pavement, and the board programs for the National Highway have been arranged in the nation.

Study Area

Al-Nasir district was carefully chosen to represent the whole Amman districts for multiple reasons; where Al-Nasir district is one of the oldest districts in Amman

Figure 1. Al-Nasir district.

city, is an old district and is situated in a hilly area (Yoder and Witczak , 1976).

Five different streets were chosen to represent the urban streets in urban areas of Amman city. Those streets lay in other close locations with varying population sizes, traffic volumes, physical conditions, land-use purposes, and street segments (Figure 1).

METHODOLOGY

Data inventory can be divided into two data sets; Greater Amman Municipality provides the first, and the other data set is to be inspected in the field. This foremost data set includes the following: Streets ID, Streets Segment 166 ID, Name of the Street, Average daily traffic (ADT), Street installation year, Street classification, Street length, 167 width, and number of lanes.

Data Collection and Analysis

Pavement condition survey

To perform the pavement condition survey, three main steps should be followed which are:

1) ASTM standards for the airfield and roads D6433-09 for the Asphalt road defined the sample unit with a standard size range, where the sample size range is 2500 square feet ± 1000 ft. (225 + 90m^2)—the first step in performing the 177 inspection survey to divide the pavement sections into smaller samples [29].

Each section is 1000 m long and 8 m wide, and the total area of 8000 is subdivided into sample units 240, which are 30 meters long and 8 meters wide. For the case study chosen, the number of subdivisions for the first street, for example, is forty-six.

2) Due to resource and budget limitations, a sampling plan was developed to reasonably estimate the PCI value for a particular given street by determining the inspection of only portions of the sample units in the pavement section. However, the first step to perform the inspection by sampling is to develop the minimum acceptable number of sample units (n) that must be surveyed to have a confidence level of 95% of the PCI of the whole section. The statistical 185 sample size can be calculated according to the ASTM standards for the airfield and roads D6433-09 [29] using the following formula (equation 1), where rounded to the following high whole number. Equals

$$= \frac{Ns^2}{(\frac{e^2}{4})(N-1)} + S^2 \quad (1)$$

Where:

e = acceptable error in estimating the PCI for section 192 e = ±5 PCI points according to (ASTM D 6433, 2018).

s = standard deviation of the PCI from one sample unit to another within the section when performing the initial 194 inspection. The standard deviation is assumed to be ±10 for flexible pavements [17].

N = total number of sample units in each section.

For the first street and by applying equation 3.1, where the number of subdivisions is 46 and assuming the acceptable 197 error in estimating is 5 per cent, and the standard deviation is considered to be 10, then

$$n = \frac{46 * 10^2}{(\frac{5^2}{4})(46-1)} + 10^2$$

$$n = 13$$

Table 1. Number of subdivision of street according to length and minimum number of sample units

Street ID	Length	Number of subdivisions	Minimum number of sample units
1	1400	46	13
2	2200	72	14
3	1650	54	13
4	1400	46	13
5	1400	46	13

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
33	34	35	36	37	38	39	40	41	42	43	44	45	46		

Figure 2: Spacing Interval for the First Street.

However, applying the previous equation and using the number of subdivisions has found a minimum number of sample units required. Table 1 shows each street with several subdivisions according to the length of the streets and 203, the minimum number of sample units necessary for each section.

For street number one, the total number of sample units in the section is 46, and the number of sample units to be inspected is 13. The sample units to be surveyed will be sections 3, 7, 10, 14, 17, 21, 24, 28, 31, 35, 38, 42, and 46.

Based on the data above, the spacing interval for street number one will be shown in Figure 2.

Pavement inspection procedure

A simple procedure was followed to inspect the pavement for the study area, followed by the detailed condition procedure. The process was to walk through the selected sample units using the GPS Handheld Lieca Zeno 5 to measure

lengths. However, fill out the data sheet with the needed information such as date, location, branch, section, sample size, distress type, and severity level. The pavement inspection was conducted by walking over the sample units to measure each distress type's quantity and severity level and write down the data in the inspection sheet.

Field observation of the geometrıc data

The study was conducted in Al-Nasir District in Amman Greater Municipality as a representative sample; the study was conducted on five different streets in an urban area with other characteristics. The experiment included the first street (1400) meters long and with (40) meter pavement width and two way three lane street separated by a median, while the second, third, fourth, and fifth streets are not separated by a median, with a length of (2200, 1650, 1400, 1400) meter respectively, and with width of (20, 30, 16, 16) respectively, number of lanes for the second street is one lane per direction, the third with two lanes, while the fourth and the fifth with one lane as well.

Statıstıcal Analysis

The Statistical Package for Social Sciences (SPSS) software (IBM SPSS Statistics 22) was used to analyse the collected data. One of the simplest uses of SPSS is general regression between two columns of data or more to find the correlation between two or more data sets. This type of data requires to be entered into the data view table. After two or more data sets enter the software, the regression will be made to find the best-fit model for the data set as an independent and dependent data source. However, the best-fit model will be made and general a whole report that contains various report components that will be explained briefly as:

The best fitting line extracted from the data set was used to form regression models between dependent variables Yi on one side and independent variables Xi on the other side. The multiple linear regression model was used, where the relationship between independent and dependent variables will follow the form of (equation 2)

$$Yi = ß0 + ß1X1 + ß2X2 + \dots + ß n X n \qquad (2)$$

Where:
Y = dependent variable or the response variable
ß0 = intercept term
ß1, ß2, ßn = regression coefficients
X1, X2, Xn= independent variables or predictors

Nine different models are presented for better handling evaluation methods. However, each variable is correlated to the other two variables in three models, where the first two

Table 2. Shows the street details

ID	Street Name	Street Length(m)	Street Width(m)	Lanes in each direction	Median
1	Saleh Hamlan	1400	40	3	Yes
2	Mo'awyeh Bin Abi Sofyan	2200	20	1	No
3	Al Saydah Hajar	1650	30	2	No
4	Al Saydah Zaynab	1400	16	1	No
5	Al Nasir	1400	16	1	No

Table 3. First street dependent and independent variables for all sections

Section	PSR	PSR corrected	PSI	PCI
1	A3	3	2.84	52
2	A3	3	2.76	60
3	A4	4	3.28	70
4	A4	4	3.7	70
5	A4	4	4.05	68
6	A4	4	4.6	74
7	A3	3	2.73	61
8	A3-	2.7	1.12	33
9	A3-	2.7	2.14	31
10	A3-	2.7	2.17	41
11	A3	3	2.29	59
12	A3	3	2.38	52
13	A3	3	2.36	56

PSR as Dependent Variable
Y1 = Present Serviceability Rating
X1 = Present Serviceability Index
X2 = Pavement Condition Index
PSI as Dependent Variable
Y2 = Present Serviceability Index
X3 = Present Serviceability Rating
X4 = Pavement Condition Index
PCI as Dependent Variable
Y3 = Pavement Condition Index
X5 = Present Serviceability Rating
X6 = Present Serviceability Index

models represent one variable correlated into one variable, and the third model is when one variable is correlated to the other two.

Dependent Variables & Indendent Variables

The dependent and independent variables were presented in Table 3 for PSR, PSI, and PCI. However, SPSS software was used to predict PSR in terms of PSI and/or PCI, PSI in terms of PSR and/or PCI, and PCI in terms of PSR and/or PSI. The findings were as follows:

RESULTS AND DISCUSSION

Present Serviceability Rating (PSR)

One of the earliest pavement conditions was the present serviceability rating (PSR) developed at the AASHTO road test centre. It was developed by the AASHTO [30] road test by having raters riding in an automobile to evaluate the pavement condition value that indicated the level of service.

However, for the case of this study, the panel consisted of ten raters experienced in the pavement evaluation process, and the rating was given on a very typical day to eliminate the effect of weather on vehicle jams. Even though PSR rating is not used frequently because of the high cost of the rating panel and the development of numerical indexes that can evaluate the current pavement condition based on the value of pavement smoothness, rutting, cracking and patching. However, the Federal Highway Administration (FHWA) and many agencies across the globe, including MPWH and GAM, are still required to submit PSR data for nationwide road health monitoring or when an outsourced contractor erects the road. PSR ranges vary from 0 up to 5 based on the description of rideability, physical distress, and rehabilitation needs.

However, the Federal Highway Administration (FHWA) and many agencies worldwide still must submit PSR data for nationwide road health monitoring or when an outsourced contractor erects the road. PSR ranges vary from 0 up to 5 based on the description of rideability, physical distress, and rehabilitation needs. Figure 3 shows the diagrammatic illustration of the first street.

Figure 3 shows the first street PSR evaluation, where the value of the PSR rating is shown on the map on each part of the lane. However, most of the lane sections are in the A3 range. A4 is found almost in the middle of the street, and the A2 part is almost at the edge of the street. The rest of the PSR maps are found in Appendix B.

Present Serviceability Index (PSI)

Engineers wanted to measure the Present serviceability rating objectively. Because of the high cost of the panel

Figure 3. Diagrammatic illustration of the first street.

to evaluate roads, a relationship was developed between the mean PSR rated by the panel with objective measurements such as rutting, roughness, and cracking. The new index was called the Present Serviceability Index, which was based on pavement smoothness, rutting cracking and patching values. The resulting relationship for PSI for flexible pavements is shown in Equation 3.

$$\mathrm{PSI} = 5.03 - 1.9\log(1+\mathrm{SV}) - 0.01\sqrt{C+P} - 1.38^{RD^2} \quad (3)$$

Where

PSI = the present serviceability index, which is a statistical estimate of the mean of the present serviceability ratings given by the panel,

SV = Slope variance over the section from Profilometer (slope variance was an early roughness measurement)

RD = mean rut depth (in.).

C = cracking (ft / 1000 ft2) (flexible), P = patching (ft2 / 1000 ft2).

The equation allowed the determining of the serviceability condition directly from objective measurements. Even though the measurement of RD, SV, C and P was not cheap, it is less expensive than the PSR based on a panel to evaluate every street.

By applying equation 3 for sample No. 13 in the second street, the Slope variance for that sample is 15, and the

The rutting depth is 0.8 in., the cracking was 32 meters, and the patching is 19 sqm. The results will be shown below.

$$\mathrm{PSI} = 5.03 - 1.9\log(1+\mathrm{SV}) - 0.01\sqrt{C+P} - 1.38^{RD^2}$$

$$\mathrm{PSI} = 5.03 - 1.9\log(1+15) - 0.01\sqrt{32*\frac{3.28084}{2.5} + 19*\frac{10.764}{2.5}} - 1.38^{0.8^2}$$

$$\mathrm{PSI} = 2.29$$

After the whole street's PSI value was calculated, the street number can be classified as fair according to the PSI value of the overall road. Table 4 shows the PSI value for inspected samples of the first street.

Pavement Condition Index (PCI)

Pavement Condition Index (PCI) is an evaluation process developed in accordance with ASTM D 5340, the Standard Test Method for Pavement Condition Index Survey [29].

After the whole condition survey had been conducted for each sample unit, the PCI was calculated for each sample unit using the Micro Paver software. The software uses the distress data and the age of the street and then calculates the 327 current PCI value using the deduced value and the age of the street. The software then calculates the overall PCI value of 328 for the whole street.

After evaluating the street, street number one pavement was found to be in overall "Fair" condition, with an average of 330 PCI (56). Table 5 shows the PCI value for all inspected samples of street number one.

Table 4. Current PSI values for first street

Sample number	Current PSI value	Current condition
1	2.7	Poor
2	2.23	Poor
3	3.14	Fair
4	2.67	Poor
5	3.13	Fair
6	2.91	Poor
7	3.14	Fair
8	3.36	Fair
9	3.34	Fair
10	3.1	Fair
11	3.16	Fair
12	2.58	Poor
13	2.29	Poor
14	1.38	Very Poor

Table 5. Current PCI value for the first street

Sample number	Current PCI value	Current condition
1	52	Poor
2	60	Fair
3	70	Satisfactory
4	70	Satisfactory
5	68	Fair
6	74	Satisfactory
7	61	Fair
8	33	Very poor
9	31	Very poor
10	41	Poor
11	59	Fair
12	52	Fair
13	56	Fair

Table 6 illustrates the Overall Pavement Condition Index (PCI) values before and after implementing a Maintenance and Rehabilitation (M&R) plan over five years. The Average PCI Before and After values consistently improve pavement conditions, with significant increases in PCI from Year 1 to Year 4. The data indicates an enhancement in the average PCI over the specified timeframe, showing a positive impact of the M&R plan on the overall pavement quality.

Study Results of the Present Serviceability Rating Model

The study results of the Present Serviceability Rating using the SPSS Software are as follows;

Table 6. Overall PCI value before and after M&R plan for five years

Year	Average PCI Before	Average PCI After
Year 1	54.15	62.68
Year 2	60.99	70.59
Year 3	68.54	77.36
Year 4	75.24	90.44
Year 5	87.78	87.78
Year 6	84.95	84.95

Source (Micro PAVER)

Study Results of the Present Serviceability Index Model

The study results of the Present Serviceability Rating using the SPSS Software are as follows:

Study Results of the Pavement Condition Index Model

The study results of the Present Serviceability Rating using the SPSS Software are as follows;

Summary Management Prediction Models

One of the oldest methods of evaluating pavement was PSR, which uses a panel of raters using an automobile to evaluate the pavement condition; researchers in AASHTO developed the PSI model to minimise the cost of the panel and to measure the pavement condition more objectively. However, PSI should represent the panel rating or the PSR value. After developing the PSI rating index that depends on pavement smoothness, rutting, cracking, and patching, a new index called the pavement condition index (PCI) was developed. PCI depends on nineteen distress types, the severity level of each distress, and the distress type's measurement.

However, Table 10 shows the summary management prediction models and the SPSS model summary data. Nine different models are presented for better handling evaluation methods. However, each variable is correlated to the other two variables in three models, where the first two models represent one variable correlated into one variable,

Table 7. Present serviceability rating management model

Model no.	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	$Y1 = 1.374 + 0.596\, X1$ (Equation 4)	0.783	0.613	0.607	0.3432
2	$Y1 = 1.339 + 0.032\, X2$ (Equation 5)	0.858	0.737	0.733	0.2832
3	$Y1 = 1.169 + 0.219\, X1 + 0.023\, X2$ (Equation 6)	0.877	0.769	0.761	0.2675

Where Y1 = Present Serviceability Rating
X1 = Present Serviceability Index
X2 = Pavement Condition Index

Table 8. Present Serviceability Index management model

Model No.	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
4	$Y2 = 0.775 + 0.038\, X4$ (Equation 7)	0.783	0.613	0.607	0.45155
5	$Y2= 0.309 + 1.030\, X3$ (Equation 8)	0.783	0.613	0.607	0.45116
6	$Y2 = 0.031 + 0.556\, X3 + 0.02\, X4$ (Equation 9)	0.812	0.660	0.649	0.42656

Where Y2 = Present Serviceability Index
X3 = Present Serviceability Rating
X4 = Pavement Condition Index

Table 9. Pavement condition index management model

Model No.	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
7	$Y3 = 8.717 + 16.068\, X6$ (Equation 10)	0.783	0.613	0.607	9.269
8	$Y3 = 16.615 + 23.154\, X5$ (Equation 11)	0.858	0.737	0.733	7.642
9	$Y3 = 14.801 + 5.869\, X6 + 17.12\, X5$ (Equation 12)	0.877	0.788	0.761	7.226

Where Y3 = Pavement Condition Index
X5 = Present Serviceability Rating
X6 = Present Serviceability Index

Table 10. Summary management prediction models

Model No.	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	$Y1 = 1.374 + 0.596\ X1$	0.783	0.613	0.607	0.3432
2	$Y1 = 1.339 + 0.032\ X2$	0.858	0.737	0.733	0.2832
3	$Y1 = 1.169 + 0.219$ X1 $+ 0.023\ X2$	0.877	0.769	0.761	0.2675
4	$Y2 = 0.775 + 0.038\ X4$	0.783	0.613	0.607	0.45155
5	$Y2 = 0.309 + 1.030\ X3$	0.783	0.613	0.607	0.45116
6	$Y2 = 0.031 + 0.556\ X3 + 0.02\ X4$	0.812	0.660	0.649	0.42656
7	$Y3 = 8.717 + 16.068\ X6$	0.783	0.613	0.607	9.269
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9	$Y3 = 14.801 + 5.869\ X6 + 17.12\ X5$	0.877	0.788	0.761	7.226

and the third model is when one variable is correlated to the other two.

In the first model, PSR is correlated with PSI. The R Square is 0.613, which means that the model explains 61.3% of the variations in real life, so the model is good. However, the standard error estimate is 0.3432, which is very low and shows the model's effectiveness. The second model, PSR, is correlated with PCI. The R Square is 0.737, meaning the model explains 73.7% of the variations in real life, so the model can be considered reasonable. However, the standard error in the estimate is 0.2832, which is also very low and shows the model's effectiveness.

From another point of view, the third model describes the correlation between PSR and both PSI and PCI. The R Square is 0.769, which means that the model explains 76.9% of the variations in real life, which is higher than the first two models. However, the standard error in estimation was 0.2675, which is also lower than the first two models, which makes it much more reliable. The fourth model describes the correlation between PSI and PCI. However, R Square is 0.613, which means the model explains 61.3% of the variations in real life. Moreover, the standard error in estimation is 0.45155, which means a low error and a high level of effectiveness.

The fifth shows the correlation between PSI and PSR, where the R Square is 0.613, which means that the model explains 61.3% of the variation in real life. However, 0.45116 is the standard error in estimation. This model is clearly stronger in relation to the fourth model.

Furthermore, the Sixth model shows the correlation between PSI from one point and PSR and PCI from another point. The R Square is 0.660, meaning the model explains 66.0% of the variation in real life. However, the standard error in estimation is 0.42656, which was lower than the above two models, which means lower error and higher effectiveness model.

The seventh model shows the correlation between PCI and PSI. The R Square is 0.613, meaning this model explains 61.3% of the real-life variation. However, 9.269 is the standard error in estimation, which means the effectiveness of this model is lower than before. The eighth model describes the correlation between PCI and PSR, where the R Square is 0.737, higher than in the seventh model. However, this means that the model explains 73.7% of the variation in

Table 11. Typical validation data from the first street

Model no.	Model	Observed value	Predicted value	Difference	%
1	$PSR = 1.374 + 0.596\ PSI$	3	3.07	0.067	1.3%
2	$PSR = 1.339 + 0.032\ PCI$	3	3.05	0.054	1.1%
3	$PSR = 1.169 + 0.219\ PSI + 0.023\ PCI$	4	3.50	0.503	10.1%
4	$PSI = 0.775 + 0.038\ PCI$	2.73	2.39	0.345	6.9%
5	$PSI = 0.309 + 1.030\ PSR$	3.7	3.81	0.111	2.2%
6	$PSI = 0.031 + 0.556\ PSR + 0.02\ PCI$	3.7	3.74	0.035	0.7%
7	$PCI = 8.717 + 16.068\ PSI$	59	52.58	6.417	6.4%
8	$PCI = 16.615 + 23.154\ PSR$	52	45.90	6.099	6.1%
9	$PCI = 14.801 + 5.869\ PSI + 17.12\ PSR$	56	43.98	12.017	12.0%

real life. Moreover, 7.642 is the standard error in estimation, which is lower than the seventh standard error.

The final model shows the correlation between PCI from one side and both PSI and PSR. The R Square is 0.788, higher than the seventh and the eighth models. Moreover, the model explains 78.8% of the variation in real life. However, 7.226 is the standard estimation error, making it lower than the above two models. In conclusion of those nine models, the model is stronger and has less estimation error when the three variables are closer together. The third, sixth, and ninth models are the strongest; however, all other models are accepted with an acceptable model summary.

Typical Validation Data for the First Street

A typical sample was used to validate the models, where the differences between the observed and predicted data were calculated. Table 11 shows the typical validation data from the first street.

Table 11 shows differences from the random validation sample, where the highest percentage of the difference found was 12 per cent, and the lowest was 0.7 per cent. These results show a high level of acceptance with a low level of estimation error.

RECOMMENDATIONS

It is recommended that GAM and MPWH develop initial training courses in the PMMS and provide technical assistance when needed [31]. The training courses should provide systematic rules for everyone involved in the pavement management system. However, such a system should follow the same rules and procedures for the staff involved for effective decision-making. It is recommended that GAM and MPWH build a database for all Amman roads that includes all the historical data to conclude the flexible pavement roads. It is recommended for GAM and MPHW to provide the management team with technology instruments such as digital electronic level to evaluate the distress in the pavement as well as its severity, which could eliminate the human errors of using personal observations.

It is recommended for GAM and MPWH to evaluate the roads using both PCI and PSI methods that can be measured according to the distress inspection data and the PSR method when necessary (Ismail , Ismail, and Atiq, 2009). It is recommended that GAM and MPWH update the correlation between PSR, PSI, and PCI from the inspection data from the database created [22]. It is recommended to perform Network-level inspection for pavement conditions instead of branch and section levels. The inspection should include surveys for five years circle. This could help better track pavement behaviour and deterioration curves, which helps better predict future pavement conditions

Future development of the PMMS system is to consider the limited budget for maintenance and rehabilitation plans, which directly relates to the level of maintenance that can be achieved (US Army Corps of Engineers, 2014). Future development should consider pavement evaluation based on the type of road, such as highways, collectors, etc. In addition, include the entire road network of Amman city. It is recommended to evaluate the roads based on the importance of the road; characteristics can be defined based on the location of the road, types of buildings on it, and population density on the road [25]. It is recommended to use the reports available on the PAVER software and take advantage of the software's tools and capabilities. It is recommended to use the analytic capabilities of ArcGIS software and take advantage of the vast tools and reports that can be generated in the software

It is recommended to use the modelling capabilities in SPSS software and analyse the correlation between the variables throughout time. Future studies are needed to compare the different optimisation PMMS software to evaluate the advantages and disadvantages, pricing, the inputs required for each one, the accuracy, and the available report generation. Future studies are needed to study the effects of the weather on the evaluating process and the abilities of distress evaluation. Future studies are needed to study the effects of skid resistance on pavement conditions on traffic safety and how accidents could change the deterioration rates. Future studies are needed to study the effects of population expansion and the relation between the population and the pavement condition. Future studies are needed to study the effects of inflation on the budgets available to maintain pavement and how a change in inflation rates could change the cost of performing maintenance activities.

CONCLUSION

This study introduces a novel approach to pavement management in Jordan by integrating Micro PAVER software, ArcGIS, and SPSS, showcasing their effectiveness in inventory development, condition evaluation, and predictive analysis while adhering to budgetary constraints. The research delves into a detailed examination of prediction models, identifying correlations among variables like PSR, PSI, and PCI. This comprehensive exploration contributes to pavement management systems, offering a subtle understanding of their practical implementation and predictive modelling.

Current practices and traditional Pavement Maintenance Management System (PMMS) employed by GAM and MPWH often fall short in keeping up with maintenance activities to meet road user expectations. The introduced PMMS is a systematic approach to flexibility that empowers decision-makers to adapt work plans and schedules for any unforeseen changes. The assessment conducted in this research showed that 64% of the sections evaluated across the five streets were categorised as "Poor," and 36% as "Fair," resulting in an overall Pavement Condition Index (PCI) value of 54.13, which reflected as "Poor" rating. Immediate maintenance intervention is essential to prevent costly remidical future measures.

The Pavement Surface Index (PSI) for the five streets is found to be 2.85, which is classified as "Poor." This indicates that urgent maintenance is recommended to prevent further deterioration in the pavement conditions and avoid higher maintenance costs. Five-year projection plans using Micro PAVER software show a PCI decrease of PCI value to 49 with a noteworthy 5% decrease. However, when implementing recommended Maintenance and Rehabilitations (M&R) demonstrates a notable increase of the PCI to 84.95 over the same period which shows a remarkable 36 % PCI increment. Despite a 1.26 million JDs investment, the research underscores Micro PAVER's effectiveness in enhancing Jordan's pavement management system, excelling in inventory development, condition evaluation, predictive analysis, and M&R plan formulation within budget constraints. Furthermore, Integrating ArcGIS, a Geographic Information System, is vital for referencing, representing network sections, and creating informative maps based on pavement conditions and road classification.

Nine pavement condition evaluation prediction models were conducted on multiple linear regression analysis and nine different prediction models of PSR, PSI, and PCI in terms of two variables were developed, examining correlations among PSR, PSI, and PCI, shedding light on their effectiveness in explaining real-life variations. Notably, the third, sixth, and ninth models are the strongest, demonstrating higher R Square values and lower standard errors in estimation.

In conclusion, our study establishes that a PMMS founded on the synergistic integration of Micro PAVER and ArcGIS facilitates informed decision-making and empowers decision-makers to make cost-effective choices based on their expertise. SPSS played an essential role in developing prediction models to predict the Pavement condition while having limited data available. This collaborative approach marks a significant stride towards managing flexible pavement conditions dynamically and responsively.

List of notations (examples below)

e acceptable error in estimating the PCI for the section
s the standard deviation of the PCI from one sample unit to another within the section
N total number of sample units in each section
Y1 Present Serviceability Rating
X1 is Present Serviceability Index
X2 is Pavement Condition Index
Y2 is Present Serviceability Index
X3 is Present Serviceability Rating
X4 is Pavement Condition Index
Y3 is Pavement Condition Index
X5 is Present Serviceability Rating
X6 is Present Serviceability Index
PSI is the present serviceability index
SV is Slope variance over the section from Profilometer
RD is mean rut depth (in.).
C is cracking (ft / 1000 ft2) (flexible)
P is patching (ft2 / 1000 ft2).

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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