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Evaluation of Pavement Condition of the Primary Roads in Jordan Using SHRP Procedure

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ABSTRACT

The main objectives of this research were to evaluate the pavement condition of the primary roads in Jordan using the Strategic Highway Research Program (SHRP) procedure and to investigate the effects of pavement age and traffic loading on pavement performance. One of the most important products of SHRP was the Pavement Condition Rating (PCR) on a scale between 0 and 100 and it was calculated based on the existing distresses and pavement roughness. An integrated data base was developed for the selected pavement sections, including information on pavement identification, pavement condition, pavement age, traffic volumes and traffic loading. The results of pavement evaluation showed that most of the pavement sections were in fair condition. Based on the suggested Maintenance and Rehabilitation (M & R) strategies for the rural roads in Jordan, it was found that about 40% of the evaluated pavement sections were in need of major maintenance and reconstruction. Regression analysis was used to develop sound pavement performance models. The effects of pavement age and traffic loading on PCR in these models were found statistically significant at α – level < 0.01 with relatively high R^2 value (0.841). Also, the analysis indicated that most of the primary roads in Jordan failed prematurely and require major M & R before the end of their design lives because of heavy traffic loading.

KEYWORDS: Pavement condition, SHRP, Performance models, Traffic loading, Primary roads.

INTRODUCTION

Most of the highway agencies around the world developed Pavement Management Systems (PMSs) in order to evaluate pavement condition and consequently estimate Maintenance and Rehabilitation (M &R) needs. Several subjective and objective procedures were developed to evaluate pavement serviceability and/or condition. One of the most common subjective procedures is the Present Serviceability Rating (PSR) on a scale between 0 and 5, which was developed at the AASHO Road Test in the late 1950s (Hass and Hudson, 1978). This procedure depends on the riding comfort of a group of different road users. The Pavement Condition Index (PCI) on a scale between 0 and 100 is the most widely used objective procedure, which was developed by the United States Corps of Engineers in the mid-1980s (Shahin and Walther, 1984). The PCI is calculated based on the existing pavement distresses, their severity levels and quantities. Both procedures do not consider jointly the effects of pavement distresses and riding comfort (pavement roughness) on pavement condition. Nowadays, in order to manage the huge road networks, pavement distress and roughness surveys are conducted by highly instrumented vehicles driven at standard travel speeds. Questions regarding the accuracy and consistency of the automated methods with the existing manual survey protocols are still under verification and discussion. Underwood et al. (2010) reported the findings of a study to evaluate automated distress surveys. They stated that the coordination between the vendor and highway agency is the most important factor that allows for the proper utilization of automated surveys. For best results, highway agencies should conduct an initial test to calibrate the automated pavement distress results.

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In 1987, the U.S.A. launched the Strategic Highway Research Program (SHRP) which focused on five areas: asphalt, Long-term Pavement Performance (LTPP), concrete and structures, winter maintenance and highway operations (Marie and McDonnell, 2002). The LTPP as one of the main areas of SHRP is considered the largest and most comprehensive pavement performance project in history. During the project's 20-year life, data on pavement condition, pavement materials, subgrade soils, traffic volume and loading, climate and maintenance practices has been collected in the United States and 15 countries by different highway agencies (Clarke et al., 1992).

Although SHRP ended as planned in 1992, the LTPP project continued under the leadership of the Federal Highway Administration (FHWA). One of the most important products of SHRP was the Distress Identification Manual for the LTPP (Miller and Bellinger, 2003). The developed manual provides guidelines for describing linear cracks, alligator cracks, rutting, potholes, patching and pavement roughness. The Pavement Condition Rating (PCR) on a scale between 0 and 100 is calculated based on the severities and extents of existing distresses and on pavement roughness measured by the International Roughness Index (IRI).

Ponniah et al. (2001) suggested recommendations to improve the existing PCR procedure by integrating the pavement structural capacity in the evaluation process. Goulias et al. (1992) conducted a research to study the effects of pavement distresses, pavement age and traffic loading on pavement performance. The results showed that the propagation of pavement distresses mainly depends on the pavement age and the traffic loading is significant only when predicting the propagation of load-related distresses. Perera and Kohn (2001) used the available data in the LTPP Information Management System (IMS) to study the effects of design and rehabilitation parameters, climatic conditions, traffic levels, material properties and pavement distresses on pavement smoothness measured by the IRI. The statistical analysis indicated that the progression of pavement roughness over time of the overlaid pavements depends on the pre-overlay IRI and on the overlay thickness. In addition, Abed (2020) developed a model to predict the Pavement Condition Index (PCI) from the International Roughness Index (IRI). Results of the developed model showed that quadratic model provides a sufficient PCI prediction based on IRI data only.

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

Jordan is considered an important transit country within the Middle East region, by facilitating the movements of passengers and goods through its borders to the neighboring countries. Road transport is the most advanced means of transportation in Jordan. According to the 2018 annual statistical report of the Ministry of Public Works and Housing (MPWH), Jordan has 8719 km of a well-developed rural road network distributed among three road classes; 3334 km primary roads, 2176 km secondary roads and 4301 km village roads (MPWH, 2018).

The MPWH of Jordan developed a Maintenance Management System (MMS) for the rural road network in the late 1980s. The MMS used subjective rating procedure to evaluate the pavement serviceability and estimate the maintenance needs. Obaidat and Al-Suleiman (1996) proposed an information technology framework to improve the existing MMS. Al-Suleiman and Nusier (1998) evaluated the MMS and found that the pavement evaluation process is not continuous and that maintenance engineers and technical staff are not well trained.

The substantial increase in traffic volume and loading significantly affected the pavement deterioration and service lives of the primary roads in Jordan. Consequently, several studies were conducted to evaluate the pavement condition and performance of these roads using subjective and objective procedures. Khedaywi et al. (1987) evaluated the effects of materials and construction practices on pavement condition in terms of PSR. The investigation covered only the pavement failure reasons of the rural roads in Irbid Governorate (North of Jordan). They concluded that poor quality of construction was the major cause of pavement failure.

Al-Suleiman et al. (1992) developed pavement performance models for the primary roads in Jordan and the PCI was used as a measure of pavement condition. The effects of pavement age, traffic loading and climatic region on pavement performance were found statistically significant. The performance models were employed to propose an M & R strategy which can be used by the MPWH to estimate M & R needs and consequently assign the related funds and priorities. Al-Aazzam (1993) conducted a study to identify the effect of each distress type on the pavement performance of primary roads in Jordan. The PCI was used as a measure of pavement condition. Regression techniques were used to describe the statistical relationships between each distress and pavement performance. The models showed that pavement distress propagation was significantly affected by both pavement age and traffic loading.

Al-Khateeb and Khadour (2020), evaluated the effect of heavy-axle loads on pavement serviceability of primary roads in Jordan. 35 pavement sections with various traffic loads were selected and the PSR was used to estimate pavement serviceability or riding quality. Load-related structural distresses such as fatigue cracking and rutting were measured and roughness was determined by measuring the slope variance (SV). They developed statistical models to represent the relationship between the PSR and heavy-traffic variables. These models cannot be considered sound and comprehensive, because they are based on a limited number of pavement sections. Al-Rousan et al. (2010) measured the pavement roughness in terms of IRI for all primary and secondary roads in Jordan using a laser roughmeter. They found that about one third of the primary and secondary roads were in fair, poor and bad conditions, indicating that serious actions and M & R plans should be taken to improve the pavement condition of the road network in Jordan. It is worth stating that M & R plans also require accurate inspection of pavement distresses, in addition to pavement roughness.

The first objective of this research was to apply the SHRP procedure in evaluating pavement condition of the primary roads in Jordan, taking into consideration jointly pavement distresses and roughness. SHRP procedure depends on two indices; Surface Condition Rating (SCR) and Roughness Condition Index (RCI). SCR measures distresses, their extents and severities, while RCI measures riding comfort or quality. The second objective was to study the effects of pavement age and traffic loading on pavement performance.

DEVELOPMENT OF DATABASE

The database is considered the key element in any research effort and a corner stone of any successful Pavement Management System (PMS). To fulfill the research objectives, a comprehensive and integrated database for the pavements of primary roads in Jordan was developed. The developed database included information on pavement identification, pavement characteristics, construction and M &R history, traffic volume, traffic loading and pavement condition. The MPWH is the responsible authority to plan, design, construct, maintain and operate the rural roads in Jordan. Jordan consists of twelve governorates. The MPWH has an office in each governorate to supervise the implementation of construction and maintenance activities. Other activities such as planning and design are conducted by the central office in the Capital (Amman City).

Selection of Pavement Sections

A pavement section is defined as a portion or a stretch of a road with similar characteristics. The pavement sections in this research were selected to represent most of the primary roads and governorates in Jordan. Also, these sections should have variations in pavement condition, construction and maintenance history and traffic volume and loading, in order to develop sound pavement performance models.

The contract documents, maintenance and rehabilitation records and traffic counting records in the MPWH were reviewed and the following basic data was extracted for each pavement section:

a- Road number and name.
b- Road length.
c- Year of construction.
d- Year of major M & R (last resurfacing or overlay).
e- Average Daily Traffic (ADT) in vehicles per day (vpd).
f- Percentage of Trucks (PT).
g- Equivalent Axle Load Factor (EALF).

Table 1 shows the distribution of 272 pavement sections among 10 governorates. As shown in this table, the number of pavement sections varied from governorate to another depending on the lengths of primary roads and strategic location. About one third of the selected pavement sections were in Amman Governorate which is located almost in the middle of the country and has 40% of its population.

Pavement Condition Evaluation

The distress identification manual developed by the FHWA was used to evaluate the selected pavement sections in this research. The Pavement Condition Rating (PCR) of a pavement section is determined by carrying out the following steps (Miller and Bellinger, 2003):

Step 1: The pavement section was first chosen with a length equal to 30 m and its geometric data was recorded. The inspection was performed on the outside lane, because it carries most of the heavy traffic.

Step 2: The distress types were identified and their severity levels and quantities were recorded on the inspection sheet.

Table 1. The selected primary roads and distribution of pavement sections

Road No.	Road Name	Governorate	No. of Sections
35	Irbid/ Jarash/ Suwaileh/ Madaba/ Al-Aqaba	Amman Jarash Irbid	42 12 10
20	Al-Mafraq/ Jarash	Jarash	2
10	Iraqi boundary/ Al-Ruwaished/ Al-Safawi/ Al-Mafraq/ Irbid	Al-Mafraq Irbid	20 4
25	Syrian boundary/ Nuimeh/ Al-Zarqa	Irbid Al-Zarqa Amman	2 14 6
40	Al-Azraq/ Al-Muwaqar/ Marj Al-Hamam	Amman Al-Balqa	20 8
65	North Shuna/ South Shuna/ Al-Hameh	Al-Balqa Irbid	13 11
15	Syrian boundary/ Al-Mafraq/ Al-Zarqa/ Al-Qatraneh/ Al-Aqaba	Amman Al-Mafraq Al-Karak Al-Tafilah Ma'an Al-Aqaba	14 10 16 10 22 16
30	South boundary/ Al-Azraq/ Al-Zarqa/Suwaileh	Amman Al-Mafraq	10 10
Total			272

Step 3: The indices for the existing distresses were computed using the following formulae:

Alligator Crack Index

$$AC\ Index = 100 - 40\ \frac{\%LOW}{70} + \frac{\%MED}{30} + \frac{\%HI}{10} \ldots \quad (1)$$

where:

% LOW = Percent of total area, low severity.

% MED = Percent of total area, medium severity.

% HI = Percent of total area, high severity.

Percent of total area = area of alligator crack in square meters/(30 m x lane width).

Longitudinal Crack Index

$$LC\ Index = 100 - 40\ \frac{\%LOW}{350} + \frac{\%Med}{200} + \frac{\%HI}{75} \ \ldots (2)$$

where:

% LOW = Percent of interval length, low severity.
% MED = Percent of interval length, medium severity.
% HI = Percent of interval length, high severity.
Percent of interval length = length of longitudinal crack/ 30 m.

Transverse Crack Index

$$TC\ Index = 100 - 20\ \frac{LOW}{15.1} + \frac{Med}{7.5} + 40\ x\ \frac{HI}{1.9} \quad \ldots (3)$$

where:
LOW = Number of cracks in interval, low severity.
MED = Number of cracks in interval, medium severity.
HI = Number of cracks in interval, high severity.
Number of cracks = total length of transverse cracks/ lane width.

Patching/ Potholes Index

$$PATCH\ Index = 100 - 40\ x\ (\%PATCHING/\ 80) \quad (4)$$

where:
% PATCHING = Percent of total area.
Percent of total area = area of patching or potholes/ (30 m x lane width).

Rutting Index

$$RUT\ Index = 100 - 40\ \frac{\%LOW}{160} + \frac{\%Med}{80} + \frac{\%Hi}{40} \ldots (5)$$

where:
% LOW = Percent of low-severity measured ruts in both wheel paths.
% MED = Percent of medium-severity measured ruts in both wheel paths.
% HI = Percent of high-severity measured ruts in both wheel paths.
10 rut depth measurements are taken per 30 m for each of the two wheel paths.

Step 4: The Surface Condition Rating (SCR) was computed using the following formula:

$$SCR = 100 - [(100 - AC\ Index) + (100 - LC\ Index) + (100 - TC\ Index) + (100 - PATCH\ Index) + (100 - RUT\ Index)] \ldots (6)$$

Step 5: The Roughness Condition Index (RCI) was computed using the following formula:

$$RCI = 32\ (5\ \ (2.718^{-\ 0.0041\ *\ AVG\ IRI}) \quad \ldots (7)$$

where:
AVG IRI = The average International Roughness Index (IRI) in mm/m.

In order to estimate the average IRI of each pavement section, the PSR procedure was used. A group of five persons performed the PSR inspection, by traveling in one vehicle at the speed limit. Every person rated the same pavement section and recorded his evaluation separately on a scale between 0 and 5. The PSR of each pavement section is the average of the five recorded values. The regression model developed by Al-Omari and Darter (1992), as shown in Equation 8, was used to estimate the average IRI in mm/m.

$$PSR = 5\ e^{-\ 0.24\ IRI} \quad \ldots\ldots\ldots\ldots (8)$$

Step 6: The SCR and RCI were used to determine the Pavement Condition Rating (PCR) using the following formula:

$$PCR = 0.60\ (SCR) + 0.40\ (RCI) \quad \ldots\ldots (9)$$

DESCRIPTIVE STATISTICAL ANALYSIS

The description of the main variables included in the statistical analysis is summarized below:

a- PCR = Pavement Condition Rating (0 – < 60 Poor, 60 - < 85 Fair, 85 - < 94 Good and 94 - 100 Excellent). It was computed based on the SCR and RCI, as shown in Equation 9.
b- Age = Pavement age since construction or last major M & R in years (resurfacing or overlay).
c- ESAL = Annual Equivalent Single Axle Loads = ADT X PT X EALF X 365.
d- ∑ESAL: Accumulated Equivalent Single Axle Loads since construction or last major M & R. The average annual growth rate of traffic on primary roads was found equal to 5 %. This percentage and pavement ages of the selected pavement sections were used in the computation of ∑ESAL.

Table 2 shows the mean, standard deviation and range of these variables regardless of governorate. As shown in this table, the PCR varied from 0.7 to 100 with a mean of 72.485 and a standard deviation of 30.341, indicating that most of the pavement sections were in Fair condition. Although, the mean pavement age was relatively small (6.331 years), the variations in pavement condition were found large. This may be because of the big variations in traffic loading. The ∑ESAL ranged from 114,612 to 42,421,334, as shown in Table 2. Table 3 shows the statistical characteristics of the PCR variable classified by the selected governorates. As shown in this table, the highest mean value of PCR was found in Al-Aqaba governorate (91.81), followed by Irbid governorate (84.13). This can be traced to two facts; most of the primary roads in Irbid governorate carry lightweight traffic and the range of pavement age in Al-Aqabq governorate was found small (1 to 8 years), while most of the pavement sections in other governorates were found in Poor to Fair condition, reflecting the effects of heavy traffic loading on the Desert Highway which passes through most of these governorates. Based on the suggested M & R strategies for the rural roads in Jordan by Al-Suleiman et al. (1992), it was found that 50%, 11%, 11%, 15% and 13% of the evaluated pavement sections were in need of routine maintenance, surface treatment, thin overlay, structural overlay and reconstruction of surface and/or base layers, respectively.

Table 2. Statistical characteristics of the considered variables

Variable	Mean	Standard Deviation	Minimum	Maximum
PCR	72.49	30.34	0.73	100
SCR	70.65	31.720	0.264	100
RCI	75.36	29.68	1.00	100
Age (Years)	6.331	5.362	1	20
ADT (vpd)	8155	6172.8	919	30056
∑ESAL	5632579	7572051	114612	42421334

Table 3. Statistical **characteristics** of the PCR variable classified by governorates

Governorate	Minimum	Maximum	Mean	Standard Deviation
Amman	3.94	100	46.02	27.187
Al-Balqaa	5.60	100	74.20	27.414
Jarash	30.35	100	79.56	25.445
Irbid	1.04	100	84.13	26.399
Al-Zarqa	6.40	98.61	56.59	33.386
Al-Mafraq	0.73	100	72.50	32.326
Ma'an	0.87	100	57.50	35.431
Al-Karak	1.14	100	64.82	29.557
Al-Tafilah	3.93	100	41.91	32.671
Al-Aqaba	75.00	100	91.81	10.436

DEVELOPMENT OF PAVEMENT PERFORMANCE MODELS

One of the main objectives of this research was to develop pavement performance models for the primary roads in Jordan. Pavement performance represents the structural and functional failures over time or pavement deterioration at different stages of pavement service life. The performance models are used to predict pavement condition at different values of pavement age and traffic loading. Pavement performance models are greatly helpful in deciding the suitable M & R strategies for a specific pavement section.

A correlation matrix was established among the different variables, as shown in Table 4. The correlation matrix is very useful to determine the independent variables which have the most significant correlations with the dependent variable. As shown in this table, the correlation coefficients among all variables were found significant at α-level < 0.01. The correlation coefficients between PCR as the dependent variable and Age and ∑ESAL as the independent variables were found to be equal to – 0.859 and – 0.582, respectively.

Scatter plots were used to determine the ranges and the general trends of the considered variables and the required statistical transformations. Figures 1 and 2 show the scatter plots between PCR and age and PCR and ∑ESAL, respectively. After establishing the correlation matrix and scatter plots, the needed transformation and regression analysis were performed in order to develop sound, reliable and predictable pavement performance models. The Statistical Package for Social Sciences (SPSS) software was used in all phases of models' developments. The following steps were considered in determining which regression model represents the collected data better (Neter et al., 1985).

Table 4. Correlation matrix among the considered variables

	PCR	Age	∑ESAL	RCI	SCR
PCR	1	-0.859**	-0.582**	0.966**	0.987**
		0.000	0.000	0.000	0.000
Age	-0.859**	1	0.649**	-0.815**	-0.857**
	0.000		0.000	0.000	0.000
∑ESAL	-0.582**	0.649**	1	-0.567**	-0.571**
	0.000	0.000		0.000	0.000
RCI	0.966**	-0.815**	-0.567**	1	0.912**
	0.000	0.000	0.000		0.000
SCR	0.987**	-0.857**	-0.571**	0.912**	1
	0.000	0.000	0.000	0.000	

** Correlation is significant at 0.01 level.

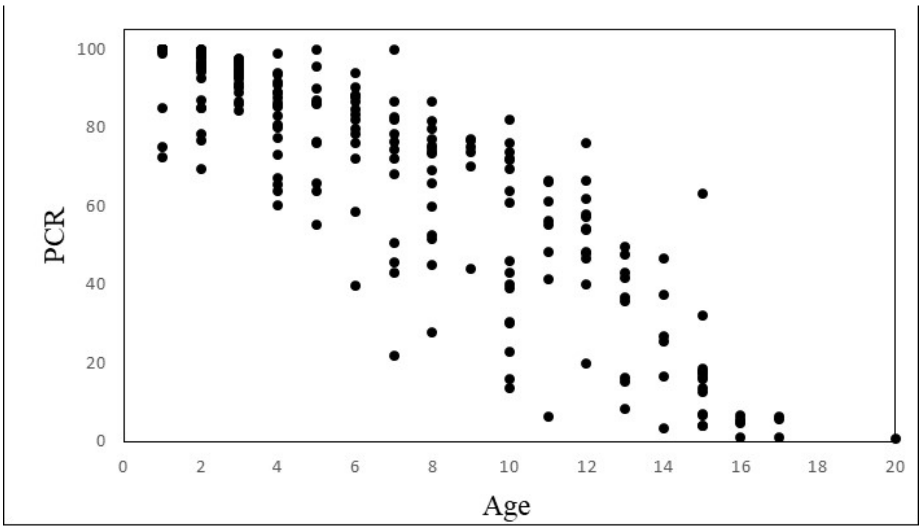

Figure (1): Scatter plot between PCR and pavement age

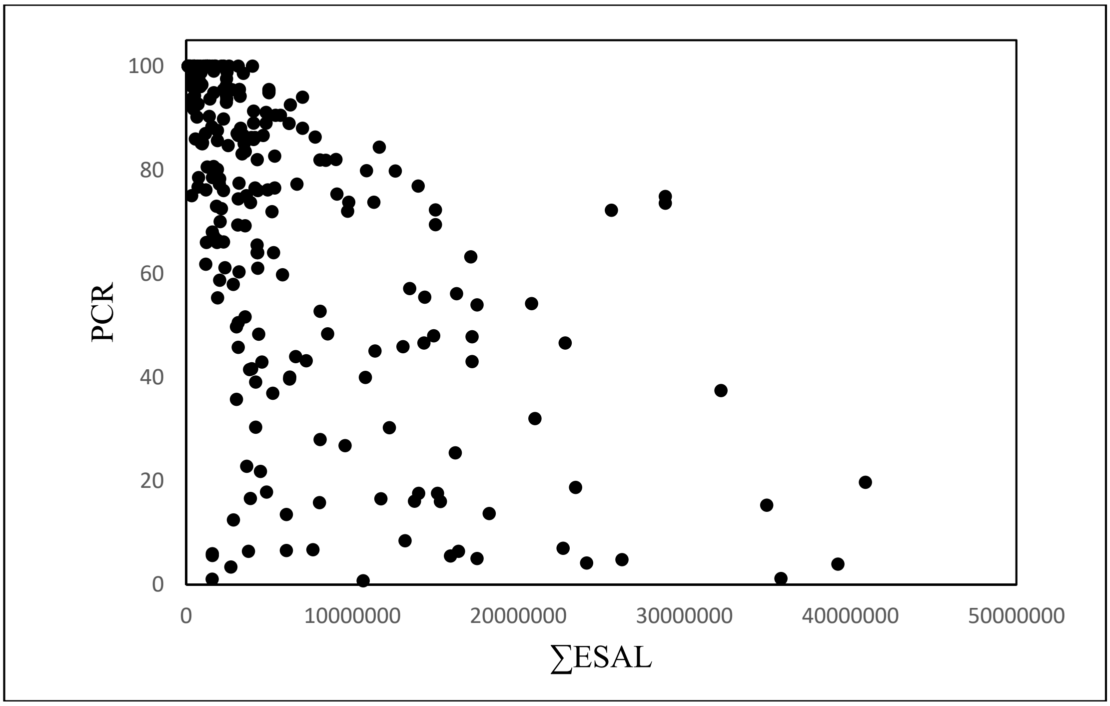

Figure (2): Scatter plot between PCR and $\sum ESAL$

a- The general goodness of fit represented by the coefficient of multiple determination (R^2) and adjusted R^2.
b- The general linearity test for the models through the application of the general F-test.
c- The significance of individual coefficients of the model through the t- or F-test.
d- Residual analysis is used for normality and variance tests.

The following sub-sections present different pavement performance models which are helpful for decision makers and road maintenance engineers in planning and scheduling the M & R operations. More information about the statistical analysis and development of pavement performance models is presented elsewhere (Abu Daoud, 2014).

Effect of Pavement Age on PCR

The scatter plot of PCR *versus* pavement age showed clearly that the statistical relationship is not linear. Polynomial and power functions were applied to develop the suitable regression model. The R^2 values for the polynomial and power regression models were found to be equal to 0.820 and 0.823, respectively. In order to guarantee the general trend of decreasing PCR with pavement age, the power function was adopted to predict the pavement condition, because it has the following advantages:

a- At any pavement age, the PCR cannot be greater than 100 or less than zero.
b- The function has a PCR equal to 100 at age equal to zero.
c- The PCR strictly decreases as the age increases.

The developed power regression model is shown in Equation 10 and the statistical characteristics of this model are summarized in Table 5, with an R^2 value of 0.823.

$$PCR = 100 - 0.282 * Age^{2.102} \qquad \text{………… (10)}$$

Effect of Traffic Loading on PCR

The Jordanian regulations for weights of vehicles permit a load of 13 tons on a single axle with dual tires. However, the actual axle load exceeds the allowed limit. It is well known that the excessive loads are considered the main cause of pavement deterioration. The accumulated Equivalent Single Axle loads (∑ESAL) on a specific pavement section represents the level of traffic loading. Pavement performance of heavily trafficked roads is more affected by (∑ESAL) than aging or environmental factors.

Table 5. Statistical characteristics of the model in Equation 10

Model Summary

R	**R^2**	**Adjusted R^2**	**Std. Error of Estimate**
0.907	0.823	0.819	0.283

ANOVA

	Sum of Squares	**DF**	**Mean Square**	**F**	**α - level**
Regression	182905.88	1	182905.88	195.340	0.000
Residual	39336.99	271	145.15		
Total	222242.87	272			

Regression Coefficients

	Unstandardized Coefficients		**Standardized Coefficients**	**t**	**α - level**
	Coefficient	**Std. Error**	**Beta**		
Constant	100	0.030		69.797	0.000
$Age^{2.102}$	0.282	0.041	- 0.648	-13.976	0.000

The scatter plot of the PCR *versus* ∑ESAL showed uncertainty about the linearity of the relationship. Several transformations were tried and the logarithmic (Log) transformation on the ∑ESAL was found the best. The best regression model is shown in Equation 11 and the statistical characteristics of this model are summarized in Table 6, with an R^2 value of 0.536. However, the model can be used when the ∑ESAL value is between the minimum and maximum values shown in Table 2.

$$PCR = -289.452 + 146.904\, Log(\sum ESAL) - 13.878\, (Log(\sum ESAL))^2 \ldots \quad (11)$$

Table 6. Statistical characteristics of the model in Equation 11

Model Summary

R	**R^2**	**Adjusted R^2**	**Std. Error of Estimate**
0.732	0.536	0.532	16.354

ANOVA

	Sum of Squares	**DF**	**Mean Square**	**F**	**α - level**
Regression	75679.813	2	37839.907	141.490	0.000
Residual	65522.412	270	267.438		
Total	141202.225	272			

Regression Coefficients

	Unstandardized Coefficients		**Standardized Coefficients**	**t**	**α - level**
	Coefficient	**Std. Error**	**Beta**		
Log (∑ESAL)	146.904	30.988	3.554	4.741	0.000
$((Log (\sum ESAL))^2$	-13.878	2.448	-4.250	-5.670	0.000
Constant	-289.452	97.606		-2.966	.003

Effect of Pavement Age and Traffic Loading on PCR

Tables 5 and 6 show that the separate effects of pavement age and ∑ESAL on PCR were found to be significant at **α-level < 0.01**. The joint effect of both variables on PCR is presented in the pavement performance model shown in Equation 12 and the statistical characteristics of this model are summarized in Table 7. However, the model can be used when the ∑ESAL value is between the minimum and maximum values shown in Table 2.

$$PCR = 134.607 - 0.239\,Age^{2.102} - 6.587\,Log\,(\sum ESAL) \ldots\ldots \quad (12)$$

Introducing the ∑ESAL variable to the model in Equation 10 improved the R^2 value from 0.823 to 0.841. This small increase in R^2 can be explained by the fact that pavement age represents the accumulated effect of load-and non-load related distresses, while ∑ESAL represents only the accumulated effect of load related distresses. The model in Equation 12 was used to estimate the PCR under different values of pavement age and three levels of traffic loading; the minimum, mean and maximum ∑ESAL. Taking into consideration that the pavements of primary roads need major M & R (structural overlay) when PCR < 60, It can be concluded that the evaluated pavements require this action after 10.5, 11 and 12.5 years for the maximum, mean and minimum levels of accumulated traffic loading, respectively. Figure 3 shows the scatter plot of expected PCR values based on Equation 12.

Table 7. Statistical characteristics of the model in Equation 12

Model Summary

R	R^2	Adjusted R^2	Std. Error of Estimate
0.917	0.841	0.840	11.218

ANOVA

	Sum of Squares	DF	Mean Square	F	α - level
Regression	162322.941	2	81161.471	644.893	0.000
Residual	30582.172	270	113.27		
Total	192905.113	272			

Regression Coefficients

	Unstandardized Coefficients		Standardized Coefficients		
	Coefficient	Std. Error	Beta	t	α - level
Constant	134.607	10.069		13.369	0.000
$Age^{2.102}$	- 0.239	0.010	- 0.823	- 24.484	0.000
Log (∑ESAL)	- 6.587	1.634	- 0.136	- 4.031	0.000

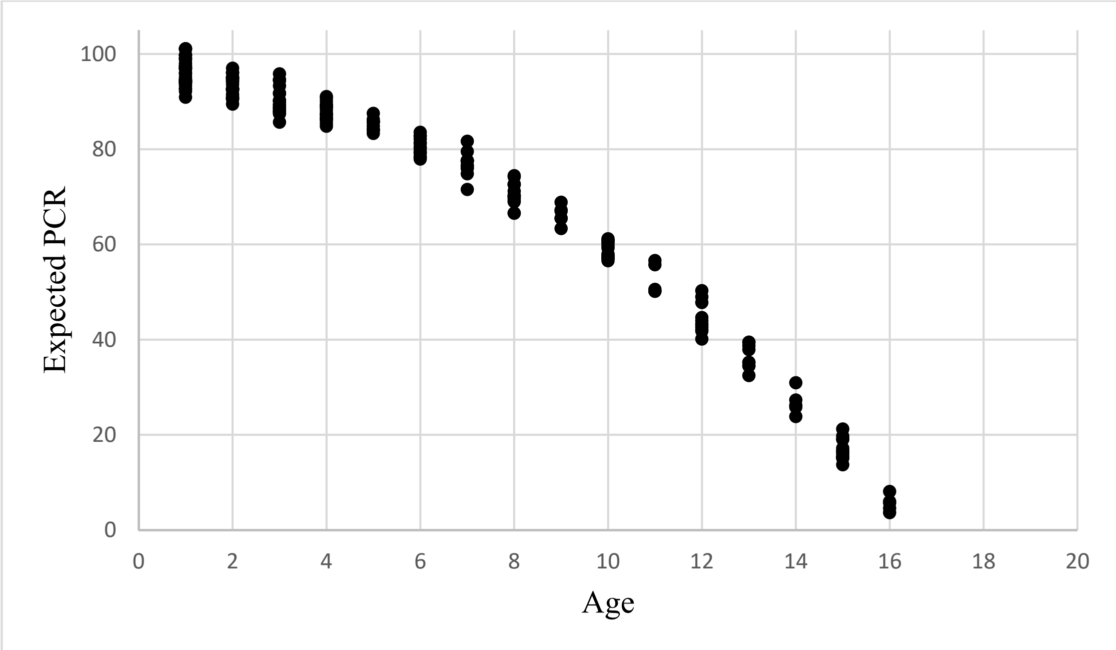

Figure (3): Scatter plot between the expected PCR and pavement age

CONCLUSIONS AND RECOMMENDATIONS

This research was conducted to evaluate the pavement condition of the primary roads in Jordan using the Strategic Highway Research Program (SHRP) procedure and to investigate the effects of pavement and traffic loading on pavement performance. The SHRP was launched in the U.S.A. in 1987 and focused on five areas: asphalt, Long-term Pavement Performance (LTPP), concrete and structures, winter maintenance and highway operations. The LTPP as one of the main areas of SHRP is considered the largest and most comprehensive pavement performance project in history.

Although SHRP ended as planned in 1992, the LTPP project continued under the leadership of the Federal Highway Administration (FHWA). One of the most important products of SHRP was the Pavement Condition Rating (PCR) on a scale between 0 and 100. The PCR is an objective evaluation procedure and the values of PCR are calculated based on the severities and extents of existing distresses and on pavement roughness measured by the International Roughness Index (IRI).

In order to achieve the objectives of this research effort, 272 pavement sections were selected from the primary road network in Jordan representing most of the administrative governorates. An integrated and comprehensive database including information on pavement identification, pavement age, traffic volume and loading and pavement condition was developed.

The results of pavement evaluation showed that most of the pavement sections were in fair condition. Although the mean pavement age was relatively small (6.3 years), the variations in pavement condition were found large. This may be because of the huge variations in traffic loading, the Accumulated Equivalent Single Axle Load (∑ESAL) ranged from about 100 thousand to 42 million. Based on the suggested M & R strategies for the rural roads in Jordan, it was found that 50%, 11%, 11%, 15% and 13% of the evaluated pavement sections were in need of routine maintenance, surface treatment, thin overlay, structural overlay and reconstruction of surface and/or base layers, respectively.

Regression analysis techniques were employed to investigate the separate and joint effects of pavement age and traffic loading on pavement performance. The scatter plots of the collected data showed that the relationships between the PCR as dependent variable and pavement age and ∑ESAL as independent variables are not linear. Therefore, suitable transformations were applied on the independent variables to develop sound and predictable pavement performance models. The effects of pavement age and ∑ESAL on PCR were found significant at α – level < 0.01.

Introducing the ∑ESAL variable into the pavement performance model with only pavement age variable improved the R^2 value from 0.823 to 0.841. This small increase in R^2 can be explained by the fact that pavement age represents the accumulated effect of load-and non-load-related distresses, while ∑ESAL represents only the accumulated effect of load-related distresses. The developed model was used to estimate the PCR under different values of pavement age and three levels of traffic loading; the minimum, mean and maximum ∑ESAL. Taking into consideration that the pavements of primary roads need major M & R (structural overlay) when PCR < 60, It can be concluded that the evaluated pavements require this action after 10.5, 11 and 12.5 years for the maximum, mean and minimum levels of ∑ESAL, respectively. This indicates that the pavements of all primary roads in Jordan need major M & R before the end of their design lives, assumed to be equal to 20 years.

Based on the findings of this study, it is recommended for the Ministry of Public Works and Housing (MPWH) in Jordan to use the SHRP procedure in evaluating the pavement condition of the rural roads. The developed pavement performance models can be employed to predict pavement condition and consequently estimate the M & R needs. Also, it is recommended to investigate the separate effect of load-related distresses on pavement performance. Destructive and Non-Destructive Testing (NDT) evaluation in addition to visual inspection are important in this investigation.

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REFERENCES

Abed, M. (2020) “Development of regression models for predicting pavement condition index from the international roughness index”. Journal of Engineering, 26 (12), 81-94.

Abu Daoud, O.N. (2014). “Pavement distresses evaluation of the primary roads network in Jordan using the strategic highway research program (SHRP) procedure”. MSc Thesis, Civil Engineering Department, Jordan University of Science and Technology, Irbid, Jordan.

Al-Azzam, J. (1993). “Evaluation of pavement distresses of rural roads in Jordan”. MSc Thesis, Civil Engineering Department, Jordan University of Science and Technology, Irbid, Jordan.

Al-Khateeb, G., and Khadour N. (2020). “Distress-based PSI models for asphalt pavements of rural highways”. Jordan Journal of Civil Engineering, 14 (2), 281-293.

Al-Omari, B., and Darter, M. (1992). “Relationships between international roughness index and present serviceability rating”. Transportation Research Record, 1435, 130-136.

Al-Rousan, T., Asi, I., and Abu-Baker, A. (2010). “Roughness evaluation of Jordan highway network”. Proceedings of the 24th ARRB Conference, October 28-30, Melbourne, Australia.

Al-Suleiman, T.I., Kheder, M.S., and Al-Masaeid, H.R. (1992). “Development of pavement performance models for rural roads”. Journal of Road and Transport Research, ARRB, 4 (1), 88-101.

Al-Suleiman, T.I., Obaidat. M.T., and Nuseir, R.M. (1998). “Evaluation of road maintenance system in Jordan”. Journal of Indian Highways, 10(26), 49-56.

Clarke, D.B., Harris, S.B., Heitzman, A.C., and Margiotta, R.A. (1992). “SHRP long-term pavement performance and information management system”. Transportation Research Record, 1260, 33-41.

Goulias, D.G., Castedo, H., and Hudson W.R. (1992). “Pavement distress surveys in the strategic highway research program's long- term pavement performance study”. Transportation Research Record, 1260, 4-13.

Hass, R., and Hudson, W. (1978). “Pavement management systems”. 1st Edition, McGraw Hill.

Khedaywi, T.S., Tons, E., and Bindra, S. (1987). “Road network, materials and evaluation in Jordan”. Transportation Research Record, 1106, 188-195.

Miller, J.S., and Bellinger, W.Y. (2003). "Pavement distress identification manual for the long-term pavement performance program". Federal Highway Administration (FHWA), U.S. Department of Transportation, FHWA-HRT-13-031.

MPWH. (2018). "Lengths of rural roads distributed among the governorates". The Annual Statistical Report, Amman, Jordan.

Neter, J., Wasserman, W., and Kutner, M. (1985). "Applied linear statistical models". 2nd Edition, Richard D. Irwin, Inc.

Obaidat, M.T., and Al-Sulieman, T.I. (1996). "A proposed information technology framework to improve road maintenance management systems". International Journal of Construction Information Technology, 2(4), 85-93.

Perera, R.W., and Kohn S.D. (2001). "LTPP data analysis: Factors affecting pavement smoothness". Transportation Research Board, National Research Council, Final Report, NCHRP Web Document 40.

Ponniah, J., Sharma, B., and Kazmierowski, T. (2001). "A critical review of an existing pavement condition rating system". Proceedings of the 5th International Conference on Managing Pavements, August 20-22, Kiev, Ukraine.

Shahin, M.Y., and Walther, J.A. (1990). "Pavement maintenance management for roads and streets using PAVER System". Technical Report M-90/05, U.S. Army Corps of Engineers.

Underwood, B.S., Kim, Y.R., and Corley-Lay, J. (2010). "Assessment of use of automated distress survey methods for network-level pavement management". Journal of Performance of Constructed Facilities, ASCE, 3 (25), 250-258.