EFFECT OF ROAD SHOULDER CHARACTERISTICS ON PAVEMENT CONDITION

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ABSTRACT

This study included a survey of 275 road sections representing the two major road classes (primary and secondary) in Jordan. The pavement condition at each section was evaluated, the shoulder width was measured, the shoulder drop-off, deterioration, slope and build-up were assessed. The effect of shoulder characteristics on pavement condition was studied and illustrated in models and figures. Results of the road survey indicated that the pavement condition in Jordan is "Very Good" and the shoulders condition is "Fair". It is concluded from the study that shoulder characteristics have a significant influence on pavement condition depending on road class and shoulder type. Shoulder width, slope and build-up are the most significant factors.

INTRODUCTION

Road shoulder is a supplementary feature to road pavement. The shoulder is that portion of the roadway contiguous with the traveled way that is primarily used as a refuge area by parked vehicles. The shoulder has two main functions [1][2][3]: Firstly: safety function, where it caters for emergency stops of broke down cars and gives a sense of openness that helps considerably toward driving ease and freedom from concern to lateral clearance. Secondly: structural function, where hard shoulders provide a lateral support to pavement structure.

The purpose of this study is to investigate the Jordanian road network condition in particular, and to study the effect of road shoulder characteristics on pavement condition in general. Both goals will be achieved through analysis of data obtained from road survey conducted in Jordan. Some informational statistics about Jordan' s administrative districts are shown in Table 1.

DATA COLLECTION

The conducted road survey included 275 road sections which were selected to cover all the administrative districts which represent the dominant climatic and terrain conditions. In order to satisfy the second goal of the study, and to reflect the nature of traffic and maintenance conditions; the road sections were selected to represent the two major road classes in the country namely: primary and secondary roads. The primary roads are highways joining the country with other neighboring countries or joining cities of country wide importance like provincial centers. They are normally 4–lane divided highways with Annual Average Daily Traffic (AADT) over 3000 vehicles. The secondary roads are passing through roads joining towns and villages with cities in the same district. The road is 2–lane undivided highway with AADT between 1000 and 3000 vehicles.

EVALUATION PROCEDURE

Each road section was individually investigated for the following:

1-<u>Pavement Condition</u>: pavement distress measurements of representative samples were measured according to the method described in the PAVER manual [5][6][7]. The PAVER system uses the Pavement Condition Index (PCI). The PCI is a scale from zero to 100 where zero denotes a failed pavement and 100 denotes an excellent one as shown in Table 2.

Table 2. PCI Scale and Pavement Condition Subjective Rating.

PCI	0-10	20-50	25-40	40-55	55-70	70-85	85-100
Rating	Failed	V. Poor	Poor	Fair	Good	V. Good	Excellent

The procedure for calculating the PCI value of a certain pavement section is discussed in details in references 5 and 6. It basically consists of the following steps:

Step 1: each sample unit (25 m long) is inspected and distress types, severity levels, and densities are recorded..

Step 2: for each type, density and severity level of distresses within a sample unit, a deduction value is determined from the appropriate deduct curve see Figure 1.

Step 3: the total deduct value (TDV) is determined by adding all deduct values for each distress conditions observed for each unit inspected.

Step 4: a corrected deduct value (CDV) is determined from correction curves (Figure 1). The CDV is based on the TDV and the number of distress conditions observed with the individual deduct values over five points

Step 5: the PCI for each sample unit inspected is calculated as PCI=100 - CDV .

Step 6: the PCI of the entire section is computed by averaging the PCI's from all sample units inspected.

Step 7: The pavement condition of the inspected section is subjectively rated according to Table (2) above. An example of sample calculation of PCI is shown in Figure 1.

2-<u>Shoulder Rating</u>: road shoulder sections were subjectively rated following the method used by the Ministry of Public Works and Housing of Jordan (MPWH) [8]. In this method a panel of 5 raters representing the road users evaluated the same section independently based on a numerical scale ranging from 1 to 5, where 1 denotes a bad shoulder and 5 denotes an excellent one as shown in Table (3) below.

Table 3. Subjective Rating Scale of Road Shoulder.

SHR	1	2	3	4	5
Ratting	Bad	Poor	Fair	Good	Excellent

The average of the numbers given by the raters was registered as the Shoulder Rate (SHR). The following is a full description of the used numerical scale:

5-Excellent: Some shoulder are flush with the edge of the pavement (no settlement). The shoulder has well graded surface which drains water off shoulder area into drainage courses.

4-Good: Some minor settlement of gravel or earth shoulders (less than 20 mm in depth) requiring refilling or leveling. Minor potholes in stabilized surface requiring repairs. Cleaning of debris on shoulder surface is necessary.

3-Fair: Settlement at pavement edge (20 to 50 mm in depth) requiring re-grading of earth or gravel shoulder surface. Some potholes in stabilized shoulder requiring patching. Surface treatment of stabilized or paved shoulder is not required.

2-Poor: Extensive settlement at pavement edge (more than 50 mm in depth) and deep holes in the shoulder surface in the graveled shoulders. Re-grading of the shoulder is required by adding new material. Pothole patching and surface treatment in stabilized or paved shoulders are needed.

1-Bad: Sever and deep settlement of earth or gravel surface at the pavement edge (more than 80 mm in depth). Extensive re-grading and adding of additional material is needed. Deep potholes refilling and surface treatment of stabilized or paved shoulders are essential.

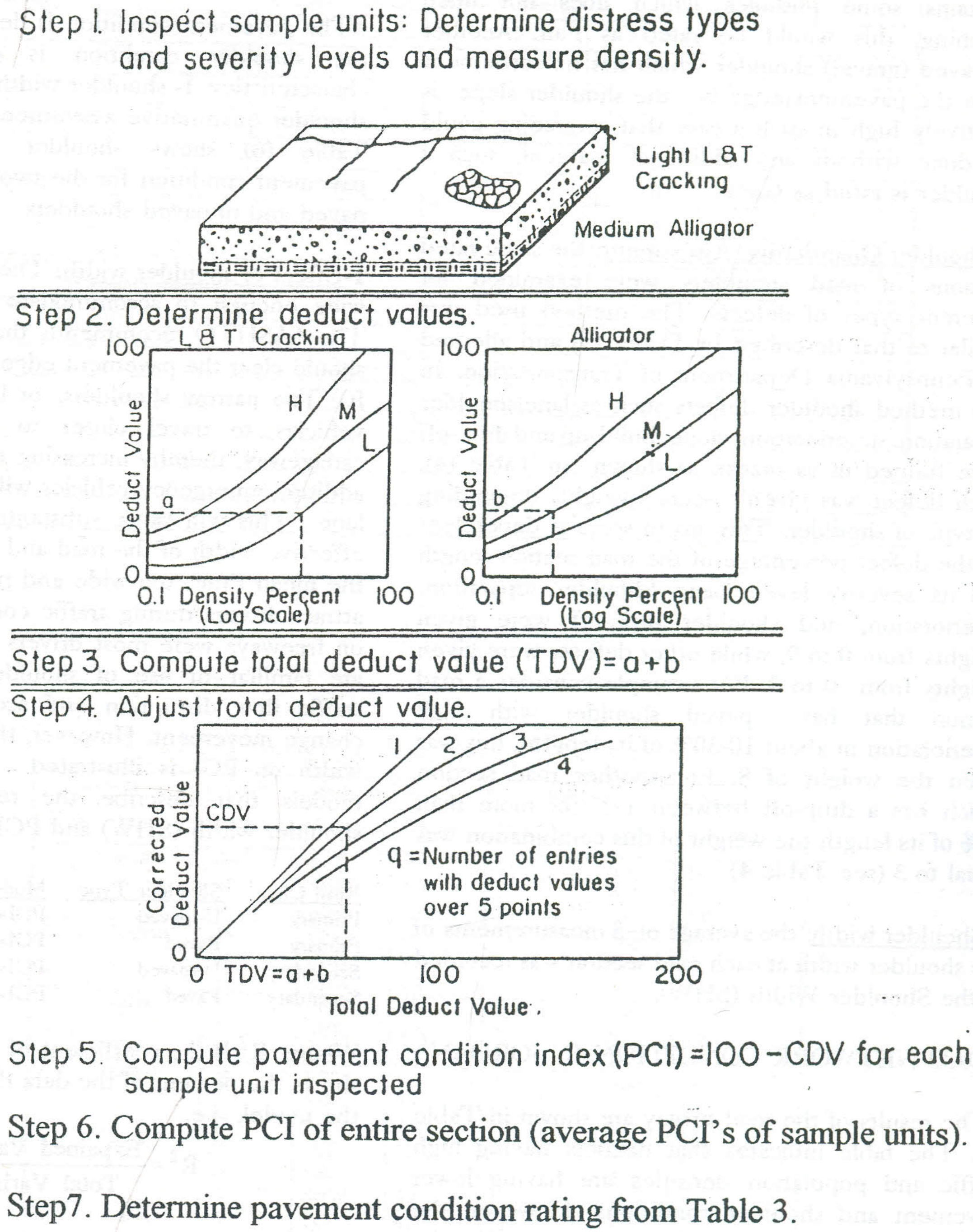

Figure 1. Steps for calculating pavement condition index (PCI) [source Reference 6].

For example consider a paved shoulder with 40-mm settlement from the pavement edge, and contains some potholes which does not need patching, this would be rated as Fair. Another unpaved (gravel) shoulder which has no settlement from the pavement edge but the shoulder slope is relatively high in such a case that re-grading could be done without any additional material, such a shoulder is rated as Good.

3-Shoulder Quantitative Assessment: the same rated sections of road shoulders were examined for different types of defects. The method used was similar to that described by Daher [9] and adopted by Pennsylvania Department of Transportation. In this method shoulder defects such as lane/shoulder separation, deterioration, slope, build-up and drop-off were formed in as matrix as shown in Table (4). Each defect was given a score (weight) depending on type of shoulder. The given score is dependent on the defect percentage of the road section length and its severity level. Lane /shoulder separation, deterioration, and shoulder drop-off were given weights from 0 to 9, while other defects were given weights from 0 to 3. For example consider a road section that has paved shoulder with high deterioration in about 10-30% of its length , this was given the weight of 8. For another road section which has a drop-off between 1-2" for more than 30% of its length the weight of this combination was equal to 3 (see Table 4).

4-Shoulder width: the average of 5 measurements of the shoulder width at each road section was recorded as the Shoulder Width (SHW).

ROAD NETWORK CONDITION IN JORDAN

The results of the road survey are shown in Table (5). The table indicates that districts having high traffic and population densities are having lower pavement and shoulder conditions. However, the average of PCI for all road sections was found to be 84%, while the average of SHR for all shoulders was found to be 3. Considering the rating criteria shown in Tables (2) and (3), the pavement and the shoulder condition in the country could be rated as (Very Good) and (Fair) respectively.

EFFECT OF SHOULDER CONDITION ON PAVEMENT CONDITION

The pavement condition is described by PCI and the shoulder condition is described by the characteristics: 1- shoulder width. 2-shoulder rate. 3-shoulder quantitative assessment of surface defects. Table (6) shows shoulder characteristics and pavement condition for the two road classes having paved and unpaved shoulders.

1-Effect of shoulder width: The shoulder should be wide enough to accommodate a stopped vehicle. The AASHTO recommends that a stopped vehicle should clear the pavement edge by at least 60 cm (2 ft). Too narrow shoulders, or lack of them causes vehicles to travel closer to the center of the cariageway, thereby increasing the medial traffic. In addition emergency vehicles will stop on the driving lane . This will cause substantial reduction in the effective width of the road and reduces capacity. In the mean time too wide and paved shoulders may attract drivers during traffic congestion particularly on freeways were most drivers are commuters who are familiar of use of shoulder. This will cause traffic flow disruption and accidents due to lane change movement. However, the effect of shoulder width on PCI is illustrated in Figure (2). The models that describe the relationship between shoulder width (SHW) and PCI are as follows:

Road Class	Shoulder Type	Model	R^2
Primary	Unpaved	PCI=55.37+0.60 SHW	0.05
Primary	Paved	PCI=76.59+1.75 SHW	0.18
Secondary	Unpaved	PCI=74.62+0.68 SHW	0.06
Secondary	Paved	PCI=73.20+3.70 SHW	0.05

Where R^2 is the coefficient of determination which shows the percent of the data that are explained by the model, i.e.

$$R^2 = \frac{\text{Expained Variation}}{\text{Total Variation}}$$

It should be noted that the straight line regression model was found to be the best fit among the other possible curvilinear models, where the R^2 of this type of model are the highest.

Table 4. Criteria For Quantitative Assessment of Road Shoulder Condition.

Defect	Percent of Road Section Length				Severity
	None	< 10%	10-30%	> 30%	
Paved Shoulders					
Lane / shoulder separation		7	8	9	> in. Width
		4	5	6	¼ - 1 in.
	0	1	2	3	> ¼ in.
Deterioration		7	8	9	High
		4	5	6	Moderate
	0	1	2	3	Low
Slope	0	1	2	3	Does not drain
Drop-off		7	8	9	> 4 in. Depth
		4	5	6	2 - 4 in.
	0	1	2	3	1 - 2 in.
Unpaved Shoulders					
Drop-off		7	8	9	> 4 in. Depth
		4	5	6	2 - 4 in.
	0	1	2	3	1 - 2 in.
Build-up	0	1	2	3	High
Slope	0	1	2	3	Does not drain

Table 5. Pavement and shoulder survey statistics.

District Code	District Name	No. of Sections	Variable Type	Mean Value	Range Min	Range Max	Standard Deviation
1	Irbid	66	PCI[1]	78	24	100	22
		66	SHR[2]	3.7	2	5	1
		63	SHW[3]	6.8	1	14	2.5
2	Mafraq	38	PCI	82	14	100	27
		38	SHR	3.8	2	5	1.1
		38	SHW	4.8	4	9	1.2
3	Zarka	23	PCI	88	45	100	17
		23	SHR	3.8	3	5	0.7
		23	SHW	4.8	2	14	2.3
4	Balka	24	PCI	85	25	100	18
		22	SHR	3.9	2	5	1.1
		22	SHW	4.8	2	7	1.6
5	Amman	24	PCI	77	9	100	25
		22	SHR	3.7	1	5	1.5
		22	SHW	6.1	2	12	2.2
6	Karak	38	PCI	87	53	100	12
		38	SHR	3.6	2	5	1.2
		38	SHW	5.5	2	9	2.1
7	Tafila	15	PCI	87	59	100	12
		13	SHR	4.4	3	15	0.8
		13	SHW	6.8	4	9	2.2
8	Ma'an	20	PCI	95	69	100	9
		20	SHR	4.8	4	5	0.4
		20	SHW	8.1	6	10	1.5

Table 6. Pavement and shoulder evaluation statistics.

Highway Class	Variable Type	No. of Sections	Mean Value	Range Min	Range Max	Standard Deviation
Primary	PCI	210	82	9.4	100	22
	SHR	209	4	1	5	1.2
	SHW	209	6.5	1	12	2.1
Secondary	PCI	65	85	24.8	100	16
	SHR	59	3.4	1	5	1.0
	SHW	59	5.3	1	12	2.4
Paved Shoulder	PCI	182	89	16	100	16
	SHR	182	4.5	2	5	0.8
	SHW	182	6.7	2	12	2.0
Unpaved Shoulder	PCI	77	70	9.4	100	25
	SHR	77	2.5	1	4	0.8
	SHW	77	4.6	1	8	1.6

The above models and Figure (2) indicate that: as shoulder width increases, the pavement condition index increases. This effect is more pronounced if the shoulder is paved where drivers find an alternative place to stop or drive on such shoulders and thus decreasing the impact on the highway pavement.

2- Effect of shoulder rate : The relationship between shoulder rate (SHR) and PCI is illustrated in Figure (3). The regression models that best describe this relationship was found to be linear as follows:

Road Class	Shoulder Type	Model	R^2
Primary	Unpaved	PCI=45.01+9.69 SHW	0.21
Primary	Paved	PCI=28.24+12.94 SHW	0.28
Secondary	Unpaved	PCI=78.07+3.40 SHW	0.06
Secondary	Paved	PCI=73.78+6.01 SHW	0.08

The above models and Figure (3) indicate also that as the shoulder condition improves, the pavement condition improves specially in the case of primary roads regardless of shoulder type. This may be due to the fact that long distance trips are more likely to occur on primary roads and so forth the shoulder is more usable for alternative driving and rest stops.

3-Effect of shoulder characteristics: It was concluded [10] that the quantitative assessment of shoulder surface condition is more indicative of shoulder condition than the qualitative assessment (rating). Shoulder characteristics data are too big to be included in this study. They are available on request from the author. Regression analysis of the effect of shoulder characteristics on PCI were found to be linear as follows:

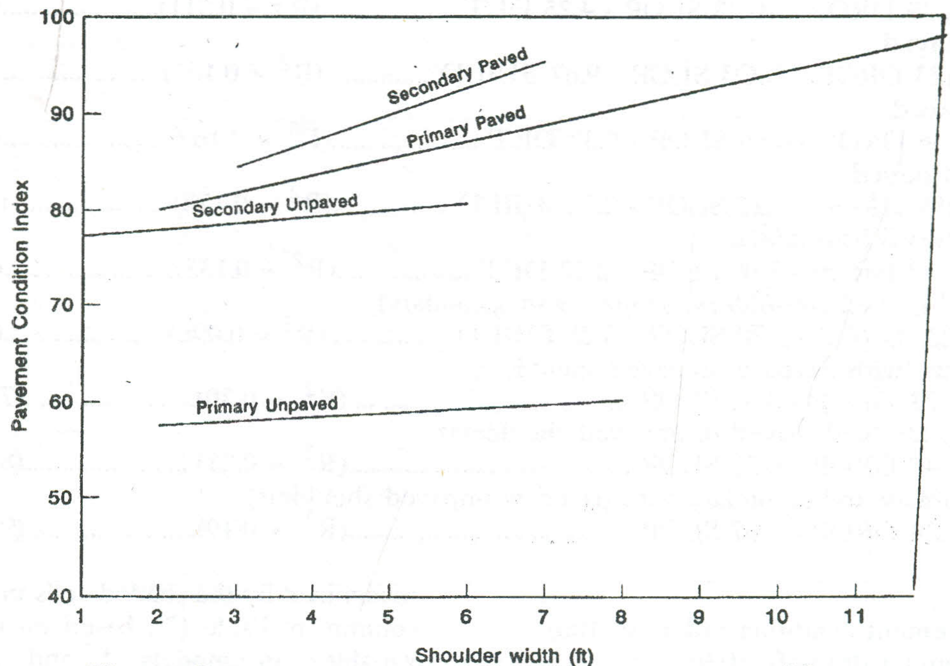

Figure 2. Effect of Shoulder width on pavement condition.

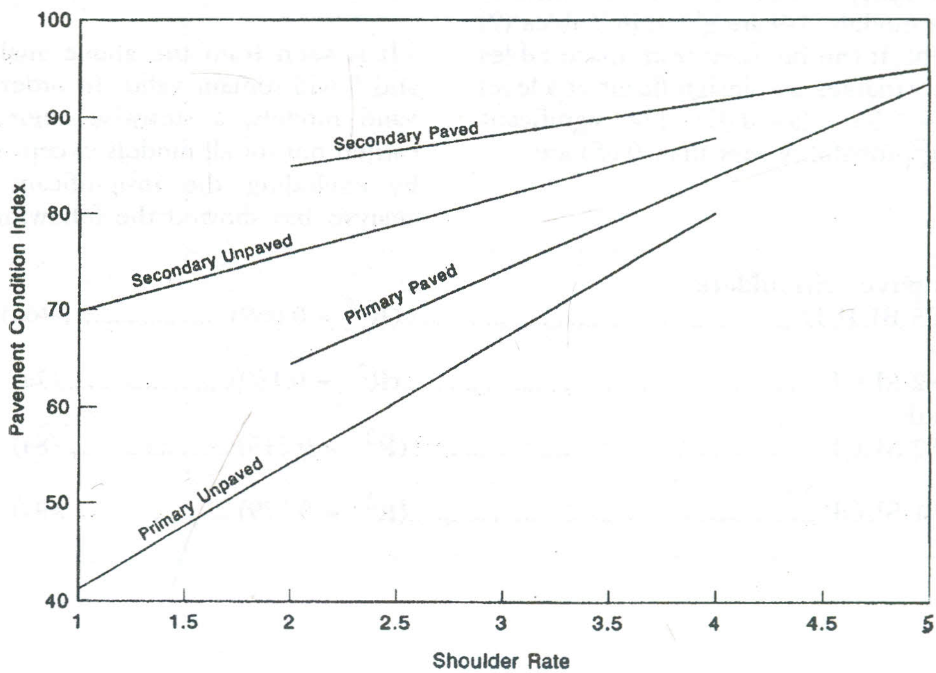

Figure 3. Effect of shoulder condition on pavement condition.

Primary Paved
PCI= 92.25 - 2.29 DROP - 10.73 SLOP - 4.25 DET ....($R^2 = 0.211$)........................(1)
Primary Unpaved
PCI= 74.87 - 123 DROP - 0.03 SLOP - 9.67 BUILD ....($R^2 = 0.167$) ....(2)
Secondary Paved
PCI= 95.26 -1.46 DROP - 4.66 SLOP - 0.37 DET ....($R^2 = 0.169$) ....(3)
Secondary Unpaved
PCI= 91.81 - 189 DROP - 5.25 SLOP - 2.72 BUILD ....($R^2 = 0.178$).......................(4)
Roads with Paved Shoulders
PCI= 92.14 - 1.92 DROP - 7.09 SLOP - 2.22 DET ....($R^2 = 0.135$).......................(5)
Roads with Unpaved Shoulders (primary and secondary)
PCI= 90.87 -123 DROP - 2.70 SLOP - 5.25 BUILD ....($R^2 = 0.096$).......................(6)
Primary Roads (with paved or unpaved shoulders)
PCI= 88.84 - 1.77 DROP - 8.52 SLOP ....($R^2 = 0.20$).......................(7)
Secondary Roads (with paved or unpaved shoulders)
PCI= 93.27 - 1.40 DROP - 6.52 SLOP ....($R^2 = 0.21$).......................(8)
All Roads (primary and secondary with paved or unpaved shoulders)
PCI= 89.42 - 1.34 DROP - 7.67 SLOP ....($R^2 = 0.19$).......................(9)

where:
PCI = Pavement condition index (0-100)
DROP = Shoulder drop-off (0-9)
SLOP = Shoulder slope (0-3)
DET = Shoulder deterioration (0-9)
BUILD = Shoulder build-up (0-3)

The statistical analysis and analysis of variance (ANOVA) of the models 1-9 are given in Tables (7) and 8 respectively. It can be seen from these tables that some of the variables are insignificant at a level of significance = 0.95 (a= 0.05). The significant variables (having probability less than 0.05) are recognized by the shaded cells under the probability column in Table (7). based on this criteria, all the variables in models 1 and 5 are considered significant, none of the variables in models 2,3 and 4 is significant and only one variable per each of the models 6-9 is considered significant.

MODELS DEVELOPMENT

It is seen from the above analysis that models 1 and 5 will remain valid. In order to obtaining other valid models, a stepwise regression analysis was carried out for all models except models 1 and 5 and by excluding the insignificant variables, a new analysis has showed the following models:

Roads with Unpaved Shoulders
PCI= 74.66 - 5.05 BUILD ....($R^2 = 0.069$) ....(6a)
Primary Roads
PCI= 88.36 - 8.82 SLOP ....($R^2 = 0.189$).......................(7a)
Secondary Roads
PCI= 91.66 - 6.52 SLOP ....($R^2 = 0.215$).......................(8a)
All Roads
PCI= 88.89 - 7.91 SLOP ....($R^2 = 0.179$).......................(9a)

Table 7. Statistical characteristics of the regression models in equation 1-9.

Model No.	Variable Name	Regression Coef.	Standard Error	T-Value	Probability
1 Primary paved	Drop-off	-2.29	1.08	2.11	0.0364
	Slope	-10.73	2.39	-4.48	1.4E-5
	Det.	-4.25	1.1	-3.85	0.0002
	constant	92.25	1.32	69.8	2E-118
2 Primary Unpaved	Drop-of	-1.23	2.47	-0.498	0.621
	Slope	-0.037	2.78	0.013	0.989
	Build-up	-9.67	3.33	-2.903	0.0056
	Constant	74.86	6.84	10.93	1.6E-14
3 Secondary Paved	Drop-off	-1.46	1.05	-1.38	0.1813
	Slope	-4.66	2.64	-1.767	0.0926
	Det.	-0.37	1.23	0.303	0.764
	constant	95.26	3.03	31.36	1.7E-18
4 Secondary Unpaved	Drop-of	-1.89	1.81	-1.04	0.3093
	Slope	-5.25	3.11	-1.68	0.1063
	Build-up	-2.72	2.74	-0.99	0.3319
	Constant	91.81	7.62	12.03	3.7E-11
5 Paved Shoulders	Drop-off	-1.92	0.84	-2.28	0.023
	Slope	-7.09	1.93	-3.72	0.0003
	Det.	-2.22	0.90	-2.45	0.015
	constant	92.14	1.26	72.95	2E-134
6 Unpaved Shoulders	Drop-of	-1.23	1.64	-0.74	0.4579
	Slope	-2.7	2.18	-1.23	0.2193
	Build-up	-5.24	2.33	-2.25	0.0274
	Constant	80.87	5.42	14.92	7.2E-25
7 Primary Roads	Drop-off	-1.77	1.09	-1.62	0.1065
	Slope	-8.52	1.27	-6.67	2.3E-10
	Constant	88.84	1.58	56.18	7E-124
8 Secondary Roads	Drop-off	-1.4	0.97	-1.44	0.1543
	Slope	-6.53	1.77	-3.66	0.00062
	Constant	93.27	3.14	29.61	4.5E-32
9 All Roads	Drop-off	-1.34	0.78	-1.70	0.0898
	Slope	-7.76	1.06	-7.23	5.4E-12
	Constant	89.42	1.42	62.77	2E-157

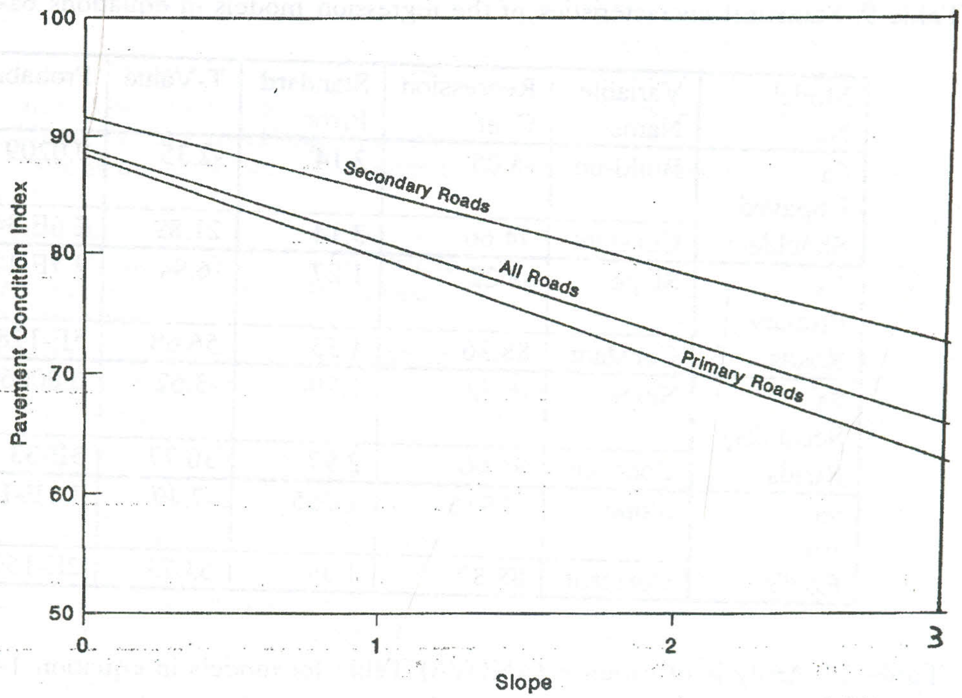

Figure 4. Effect of shoulder slope on pavement condition.

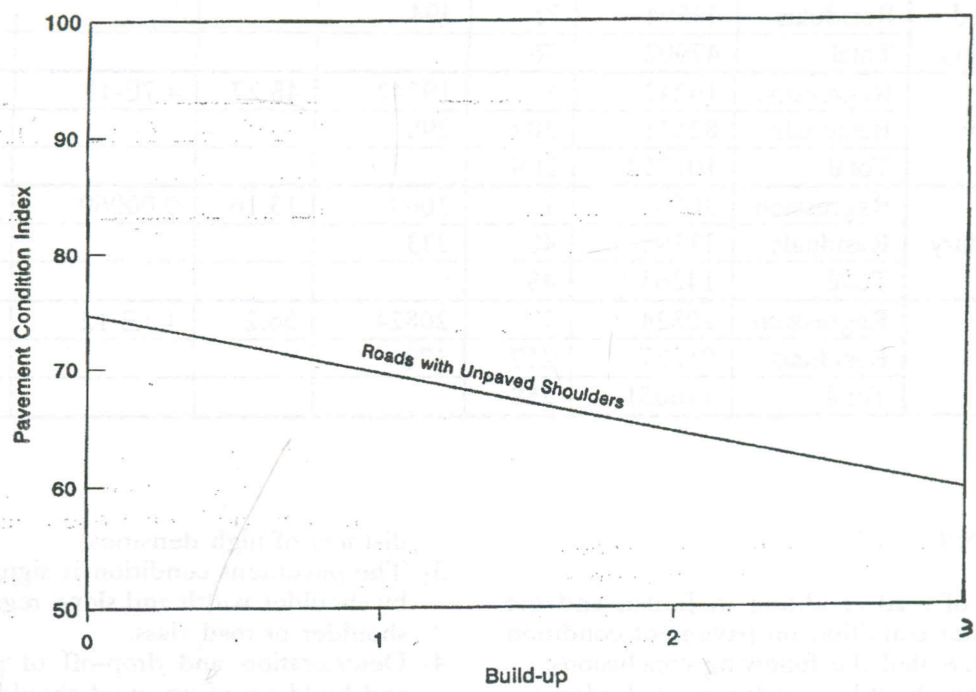

Figure 5. Effect of shoulder build-up on pavement condition.

Table 9. Statistical characteristics of the regression models in equations 6a-9a.

Model No.	Variable Name	Regression Coef.	Standard Error	T-Value	Probability
6a Unpaved Shoulders	Build-up	-5.05	2.14	-2.35	0.0209
	Constant	74.66	3.14	21.89	2.6E-34
7a Primary Roads	Slope	-8.22	1.27	-6.94	4.7E-11
	Constant	88.36	1.55	56.68	5E-128
8a Secondary Roads	Slope	-6.52	1.79	-3.62	0.00069
	Constant	91.66	2.97	30.77	3E-33
9a All Roads	Slope	-7.915	1.055	-7.49	1.1E-12
	Constant	88.89	1.39	63.73	2E-159

Table 10. Analysis of variance (ANOVA) Table for models in equation 1-9.

Model No.	Source of Variation	Sum of Squares	D.F	Mean Square	F-Value	Significant F	R^2
6a	Regression	3308	1	3308	5.56	0.0209	0.069
Unpaved	Residuals	44594	75	594			
Shoulders	Total	47902	76				
7a	Regression	19242	1	19242	48.27	4.7E-11	0.189
Primary	Residuals	82511	207	298			
Roads	Total	101753	208				
8a	Regression	3069	1	3069	13.16	0.00069	0.215
Secondary	Residuals	11196	48	233			
roads	Total	14265	49				
9a	Regression	20824	1	20824	56.2	1.1E-12	0.179
All	Residuals	95227	257	370			
Roads	Total	116051	258				

CONCLUSIONS

The analysis of road condition in Jordan and the effect of shoulder condition on pavement condition analysis have revealed the following conclusions:

1- The road and shoulder conditions in Jordan are rated as " Very Good " and " Fair" respectively.
2- Roads in districts of low population and traffic densities are in a better condition than those in districts of high densities.
3- The pavement condition is significantly affected by shoulder width and slope regardless of type of shoulder or road class.
4- Deterioration and drop-off of paved shoulders, and build up of unpaved shoulders are the most significant characteristics affecting the pavement condition.

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