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Developing and Implementing an Integrated Pavement Monitoring and Management Approach for the Palestinian Territories

تطوير وتطبيق منهجية متكاملة لمراقبة وإدارة أنظمة الرصفات في فلسطين

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Abstract

The provision of proper transportation services would play a basic role in future development plans for the Palestinian territories. The road network, which forms the backbone of the transportation system in the Palestinian territories, suffered seriously from the constraints imposed on its development by the Israeli authorities. Since the establishment of the Palestinian authority few years ago, limited budgets were allocated to maintain the road network in the Palestinian territories. Therefore, it is necessary to develop and implement a pavement monitoring and management system aiming at identifying the prevailing conditions of the pavement structures, assessing these conditions, and defining the proper corrective measures.

The paper highlights the approach which was developed to assist Palestinian decision-makers to evaluate and define the measures to rehabilitate the damaged pavement structures of the road network in the Palestinian territories. First, the paper presents a general background related to road conditions in the Palestinian territories. This is followed by a presentation of the suggested methodology to develop an integrated tool to evaluate, maintain, and rehabilitate road pavements in the Palestinian territories. The paper presents a number of case studies performed for three different urban and rural locations in the West Bank and Gaza Strip. The paper ends with conclusions and recommendations, which include the need to apply the indicated approach as a first step to develop a comprehensive program for the establishment of a pavement management system for the Palestinian territories.

Keywords: pavement evaluation, pavement maintenance, pavement rehabilitation, pavement monitoring and management

ملخص

إن تقديم مرافق وخدمات ملائمة للمواصلات يلعب دوراً أساسياً في خطط التطوير والتنمية الفلسطينية. وتعاني شبكة الطرق، التي تشكل العمود الفقري لنظام المواصلات في الأراضي الفلسطينية، من القيود التي أعاقت تطويرها لحوالي ثلاثة عقود من الاحتلال الإسرائيلي. ومنذ إنشاء السلطة الفلسطينية مؤخراً فقد تم اعتماد

ميزانيات محدودة لصيانة الطرق في الضفة الغربية وقطاع غزة. لذا فإن من الضروري إيجاد آلية متكاملة لمراقبة أنظمة الرصفات وإدارتها من خلال معرفة أوضاع الطرق وتقييمها ومن ثم تحديد وسائل المعالجة الملائمة.

وتقوم الورقة بوضع الأسس نحو هذه المنهجية التي ستساعد أصحاب القرار في الأراضي الفلسطينية في تقييم وسائل الصيانة وتحديدها وإعادة التأهيل الملائمة. وتعرض الورقة، في البداية، خلفية كاملة حول وضع الطرق في الأراضي الفلسطينية، ثم تعرض أنماط الخلل في رصفات الطرق في الضفة الغربية وقطاع غزة. إثر ذلك تقوم الورقة، بناء على ذلك، بالتعريف بوسائل التقييم التي تم اتباعها، فضلاً عن المنهجيات المقترحة من أجل تطوير آلية متكاملة لتقييم وصيانة وإعادة إعمار رصفات الطرق في الأراضي الفلسطينية. كما تقدم الورقة عدداً من الدراسات الميدانية التي تم القيام بها بناءً على المنهجية المشار إليها، وذلك في مواقع مختلفة من الضفة الغربية وقطاع غزة. وتختم الورقة بالاستنتاجات والتوصيات والتي من أبرزها ضرورة تطبيق المنهجية المقترحة في تطوير وإنشاء برنامج شامل لإدارة أنظمة رصفات الطرق في الأراضي الفلسطينية.

1. Introduction

The total length of the road network in the Palestinian territories reached about 2040 kilometers (km), including 1862 km in the West Bank and 178 km in Gaza Strip [1]. These roads are classified into major, regional, and local roads, but do not include urban roads or agricultural roads. Most of the roads categorized as major and regional roads are two-lane paved roads. Only few segments of the major road network are four-lane divided highways. Most of the local roads which connect the Palestinian villages together and with the rest of the road network are one-lane paved roads. However, there were more than 70 km of unpaved local roads in the West Bank in 1990, which serve a total population of about 23 thousands, but there were recent efforts to pave most of these roads.

The density of roads with respect to population reached 9.7 km per 10,000 population in 1991. This indicator implies poor road network serviceability to Palestinian communities, and is less than the respective densities in all the countries in the region, except Egypt. Density of roads with respect to the total area of the Palestinian territories reached 0.35 km per square km in 1991, which implies poor road coverage and accessibility [2].

Urgent need exists to develop strategies and actions to safeguard the road network asset. This can be mainly attributed to the limited implementation of maintenance and repair of road works, and to the propagating damage in pavement structures due to the rapid increase in the number of vehicles, including heavy vehicles, which exceeded 10 percent during the last three decades [3]. As a prerequisite to maintain the road network, an appropriate approach to evaluate pavement conditions and then to assist in decision making regarding maintenance and rehabilitation strategies was developed.

Pavement evaluation provides valuable information on the current conditions of the pavement deficiencies and for consequent detailed analyses. Evaluation through various monitoring methods forms the input to predictive models regarding pavement distress, safety, and performance. Generally, the types of pavement evaluation are structural capacity evaluation, functional evaluation, safety evaluation, and distress evaluation.

Pavement distress is considered as the limiting factor in pavement damage assessment. Therefore, pavement damage is to be monitored and evaluated. The most common methodologies utilized in this regard are based on condition surveys. In pavement safety evaluation, focus is usually directed towards measuring skid resistance of pavement surfaces. Evaluation of functional pavement performance is carried out by periodic evaluation of serviceability history of the pavement. This is usually performed utilizing Road Condition Index (RCI), or Present Serviceability Index (PSI). Finally, structural evaluation of the behavior of pavements, which is defined as the immediate response of pavement to load, is performed using load-deflection testing techniques, whether related to measuring static or dynamic deflection [4].

In the process of developing a maintenance model that considers the need and requirements of the Palestinian territories, the model developed by the Organization for Economic Co-operation and Development (OECD) and the World Bank was considered as a base since this model was developed and formulated mainly for developing countries [5]. The model presented by OECD and the World Bank was intended to serve as a basic information subsystem, and was presented in two levels. The primary level provides basic information for maintenance management through a Road Condition Survey (RCS), which would be conducted over the entire network under the road authorities’ jurisdiction, preferably at an annual frequency. The second level is the Detailed Visual Inspection (DVI) of road condition, which might be done selectively for those sections appearing to need major maintenance work. The DVI is intended to identify the sections to be considered for the programming of major maintenance.

It can be seen that the above program can only give a general basic input in the process of decision on the type of maintenance required. Since the road monitoring system (model) needs to be consistent with the local requirements and resources in the Palestinian territories, this model should be adjusted to suit local conditions and preferences.

2. Methodology

The pavement management methodological approach considers the interaction and integration of the following four main activities: performing road inventory, performing road condition survey, evaluating the overall pavement conditions, and identifying proper maintenance and rehabilitation measures. This will facilitate the arrival at answers to key questions and issues related to the programming of pavement maintenance and rehabilitation works at the road network level.

Each of the major activities described above is operationalized through the identification of a specific module. These modules are described in details in the following sections.

2.1 Inventory Module

The initial stage in a pavement management system is to plan and organize the data collection efforts aiming at identifying basic information of the roads to be studied and performing the necessary preparations towards performing the road condition survey.

The roads within the study area are to be identified first. These roads have to be classified according to their function. The road network in the Palestinian territories is divided into three main categories: arterials (which include inter-urban roads), collectors, and local roads (which include village access roads). The classification depends on the function of the road whether carrying high volumes of through traffic or providing accessibility to abutting land. The classification of roads is a very important and basic input because maintenance and rehabilitation needs and criteria differ from one class to another.

Next, each road is divided into sections and each section is assigned a section number. A map of the road network is recommended to be utilized to illustrate the different road sections. Basic characteristics are to be specified for each of the road sections, including: section number, functional classification of the road, road name, district/town, number of lanes, lane width, shoulder or sidewalk type and width, and the existence of drainage structures. Traffic data are to be included such as average daily traffic and vehicle classification, if available. Special forms are used in performing road inventory. A sample form is presented in Figure 1.

Each road section is eventually divided into homogeneous sub-sections in terms of road cross-section and pavement structure. This will facilitate performing the road condition survey and the detailed visual inspection. Suggested lengths of sections and sub-sections for each of the road classes are presented in Table 1.

The collected road inventory data must be entered into a special computer data file. This will form as a basis for a more focused data collection effort for each of the road section and sub-sections, which can be easily used in updating the respective stored computer data files.

ROUTE INVENTORY SHEET

1 - Municipality __________________________ Route __________________________
2 - Route Limits ____
3 - Approximate Length __________ Kilometers; sheet _________ of ____________
4 - Functional Classification: Urban ____________ Rural ______________________
Arterial _______________ Collector ________ Business ____________________

INVENTORY ITEMS

5 - Direction of traffic flow: One-way ___________________Two-way ___________
6 - No. of traffic lanes (total) _______ Width ______________ meters
Parking Permitted: No __________One side ____________Two sides __________
7 - Median width ________________ meters. Type ___________________________
8 - Shoulder:None _______________One side ____________ Two sides __________
9 - Surface material Asphalt _______ Not surfaced ________________
10- Width ________ meters Condition __________ Edge Drop __________
11- Sidewalk & curb: None ________ One side ___________ Two sides ___________
12- Surface material: Concrete _____ Asphalt ____________ Other _______________
13- Width ______________________ meters Condition ________________________
14- Adjacent Land Use and Control of Access (AC)__________________________
Business _______ Industrial _______ Residential _______ Undeveloped _______
(CA) None _______ Driveways ___________ Intersections Only ______________
15- Street lighting: Yes _____________________ No ___________________________
16- Pavement condition (Riding Quality):
Good ________________ Fair _________________ Poor ___________________
17- Pavement Marking Adequacy (centerline, crosswalk):
Adequate _______________ Faint ______________ None existent ____________
18- Traffic Sign Adequacy (Stop, Yield, Speed limit):
Adequate ____________ Faded ____________ None existent ________________
19- Posted speed limit: Cars __________________ Trucks ________________Km/hr
20- Comments: ____
____
____
____

Figure 1: Route Inventory Sheet

Table 1: Suggested Lengths of Sections and Sub-sections for Each Road Classification.

Road classification	Suggested number of sub-sections	Length of section (m)	Length of each sub-section (m)
Arterials (Urban)	5	500	100
Collectors (Urban)	5	250	50
Locals (Urban)	5	250	50
Arterials (Inter-Urban Rural Roads)	3	1200	400
Locals (Village Access Roads)	5	300-500	60-100

For the purpose of this research, a sample of roads for each roadway classification was considered. Sample coverage was intended to include roads from each of the two regions comprising the Palestinian Territories: West Bank and Gaza Strip.

2.2 Pavement Condition Survey Module

This module deals with the identification of a pavement distress type, the extent of its existence, and the level of severity of the pavement distress for each of the roads considered. This is performed after dividing the road into sections and sub-sections.

An assessment of the general conditions of a road is to be performed first. Such assessment is performed through defining a defect index which identifies the pavement general conditions based on a five-point scale, representing five road condition categories; one corresponds to excellent and five corresponds to failed pavements. Only road distress types which distort the shape of the pavement structure are taken into consideration at this stage. Based on the results of the general assessment, sections identified to warrant further study are those with a rating of three (representing fair pavement conditions) or higher. For these road sections detailed visual inspection is to be performed. Usually these are the sections which would require maintenance or structural overlay in the near future. Special forms are used to perform the surveys. These are presented in Figures 2 and 3 for the road condition survey and the detailed visual inspection, respectively. The forms follow the World Bank Manual on road monitoring for maintenance management [5].

Road Condition Survey			Road Name:	Road Classification :
Date :	Weather : O Dry O Rainy	Carr. Way: O Dry O Drying O Wet	Section No :	Section Length :
			From :	To :
				Carriage :
			Summary (Avg. Condition)	Road Side Elements :

SUB-SECTION	1						2						3						4						5					
Roadside	L			R			L			R			L			R			L			R			L			R		
Carriageway:	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
		3	5		3	5		3	5		3	5		3	5		4	5		4	5		4	5		4	5		4	5
Prevailing damage																														

Damage Type	L		R		L		R		L		R		L		R		L		R	
Shoulder Deformation	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
Shoulder Scour	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
Side Drains (Curbs)	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
Obstacles or Debris	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
Embankment	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
Road Signs and Markings	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
		3		3		3		3		3		3		3		3		3		3

REMARKS : ____________________

Source: The World Bank and Organization for Economic Co-operation and Development, Road Monitoring for Maintenance Management, Manual for Developing Countries, Vol. 1, 1990.

Figure 2: Road Condition Summary Sheet.

Detailed Visual Inspection					Road Name:	Road Classification:
Date:		O Clear		O Dry	From:	To:
Time:	Weather:	O Rainy	Carriageway	O Drying	Section No.:	Section Length:
				O Wet	Pavement Width:	

SUB-SECTION		①						②						③						④						⑤					
Roadside		L			R			L			R			L			R			L			R			L			R		
Damage Type		L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S
Rutting	<10%	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
	10-50%	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5
	>50%	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5
Corrugation	<10%	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4
	10-50%	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5
	>50%	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
Patching	<10%	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4	1	3	4
	10-50%	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5	2	3	5
	>50%	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
Settlement	<10%	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
	10-50%	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5
	>50%	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5
Block & Transverse Cracking	<15%	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4
	15-30%	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
	>30%	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5
Longitudinal Cracking	<10%	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
	10-50%	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5	2	4	5
	>50%	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5
Alligator Cracking	<10%	1	4	5	1	4	5	1	4	5	1	4	5	1	4	5	1	4	5	1	4	5	1	4	5	1	4	5	1	4	5
	10-50%	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5
	>10%	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5	3	5	5

SUB-SECTION		①						②						③						④						⑤					
Roadside		L			R			L			R			L			R			L			R			L			R		
Damage Type		L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S	L	M	S
Potholes	<5 (No/100m)	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
	5 - 15	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
	>15	4	5	5	4	5	5	4	5	5	4	5	5	4	5	5	4	5	5	4	5	5	4	5	5	4	5	5	4	5	5
Shoving	<5%	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
	5-50%	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4	2	3	4
	>50%	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5	3	4	5
Raveling	<10%	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4	1	2	4
	10-50%	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5	1	3	5
	>50%	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5	2	5	5
Bleeding	<5%	1	x	x	1	x	x	1	x	x	1	x	x	1	x	x	1	x	x	1	x	x	1	x	x	1	x	x	1	x	x
	5-50%	2	x	x	2	x	x	2	x	x	2	x	x	2	x	x	2	x	x	2	x	x	2	x	x	2	x	x	2	x	x
	>50%	3	x	x	3	x	x	3	x	x	3	x	x	3	x	x	3	x	x	3	x	x	3	x	x	3	x	x	3	x	x

L-Low, M- Medium, S- Severe

REMARKS : ____________________

Source: The World Bank and Organization for Economic Co-operation and Development, Road Monitoring for Maintenance Management, Manual for Developing Countries, Vol. 1, 1990.

Identification of the distress type is to be performed in the detailed visual inspection stage. Five levels of detail are presented in such a survey. Distresses related to the asphaltic pavements are considered. The module can be extended to accommodate rigid pavements and aggregate-surfaced low cost pavements.

The following asphaltic pavement distress types are considered in the detailed visual inspection survey: rutting, corrugations, settlement, block and transverse cracking, longitudinal cracking, alligator cracking, potholes, patching, raveling, shoving, and bleeding.

The extent of the existence of a distress type is then to be estimated. Three different ranges are identified to express levels of area affected. These are: less than 10 percent, 10-50 percent, and greater than 50 percent, except for transverse cracking, where the number per length of sub-section criterion, and potholes distress, where the number per length of sub-section and depth of pothole criteria are identified. This is combined with the identification of three levels of severity for a sub-section: low, medium, and severe. Finally, a value on a scale of one to five can be identified for the road sub-section for the specific distress type; one being the least severe while five being the most. The selection of the proper scale value for a road sub-section is dependent on the detailed visual inspection and evaluation based on extent of the existence of a distress type and level of severity. The form presented in Figure 3 is used to perform this task.

2.3 Pavement Evaluation Module

In this module, an overall evaluation of the pavement sub-section in question is performed. Such evaluation is based on the results of the road condition survey module, described above. The concept here is to come up with an index which best describes the overall conditions of the pavement sub-section.

A Pavement Condition Index (PCI) is defined here as an index describing the overall conditions of the pavement. The index is identified for a specific pavement based on the weighted sum of the distress points for the sub-section. The total distress points indicate the condition of the sub-section where a lower sum of distress points indicate a better pavement condition. The accuracy of the calculated PCI depends to a large extent on the road condition and detailed visual inspection surveys. The PCI is determined by subtracting the total distress points from 121 as illustrated in the following model presented in Equation (1) and as explained below.

$$PCI = 121 - [(3)X_1 + (2)X_2 + (1)X_3] \quad (1)$$

where:

X_1 is the sum of alligator, pothole, and rutting points of detailed visual inspection distress severity scale;

X_2 is the sum of corrugation, patching, settlement, and transverse cracking points of detailed visual inspection distress severity scale; and

X_3 is the sum of bleeding, longitudinal cracking, shoving, and raveling points of detailed visual inspection distress severity scale.

The deductions are weighted following the type of distress. Distress types like alligator cracks, potholes, and rutting are given higher weights than other types like longitudinal cracks and bleeding. This is due to their impacts on the performance and serviceability of the road. Failures are here divided into three categories. The first category includes alligator cracks, potholes, and rutting. This group is given a weight of 150 percent with respect to the basic and intermediate group. This second basic and intermediate group in turn, includes corrugation, patching, settlement, and transverse cracking. This category is given no preferential weight. The third category includes bleeding and longitudinal cracks. This category is given a reduction in weight of 50 percent compared to the second group. These weights are assigned based on local experience related to the role of a specific defect on the overall pavement condition. These weights are translated into the values of 3, 2 and 1 for the first, second and third distress category, respectively, which indicate, for example, that the relative effect of the distress of the first category with respect to the second category is 3/2 (i.e., 150 percent).

To illustrate the use of the model, suppose a road sub-section has the best rating for all the pavement distress types. This means that each of the 11 distress categories will be assigned a value of 1 out of scale of 5. The first category, which includes three distress types: alligator cracks, potholes, and rutting, would contribute to the PCI a value of 3 x (1+1+1) = 9, based on the above equation. The second category, which includes four distress types, would contribute to the PCI a value of 2 x (1+1+1+1) = 8. Finally, The third category, which includes four distress types also, would contribute to the PCI a value of 1 x (1+1+1+1) = 4. Therefore, and based on the above equation, the representative PCI for the road sub-section will be 121- (9+8+4) = 100. Therefore, an excellent pavement has a PCI value of 100 while a very deteriorated pavement has a minimal value of PCI.

Other studies had used a similar concept where a Pavement Condition Index (PCI) was developed (see, for example, Shahin, and Kohn [6] and Tavakoli, Lapin, and Figueroa [7]. The PCI is used to determine the course of action to take for the section.

As mentioned above, the PCI can be defined as the weighted sum of the distress points for the pavement sub-section. This allows to weigh the various types of pavement distresses differently. The analyst should have a rationale behind the weight assigned for a given distress type.

2.4 Identification of Maintenance Measures Module

In this module, identification of a proper maintenance activity is to be recommended based on the previously evaluated PCI. Three types of evaluations were considered in this model, based on the classification of the roadways studied which includes: Arterial Roads (Urban and Inter-Urban Rural Roads), Collector Urban Roads, and Local Roads (Urban and Village Access Roads).

For each of the roadway classifications, a preference factor is introduced into the PCI equation by which the cumulating distresses are evaluated in accordance with the pavement evaluation module. This factor is mainly dependent on a preference for maintenance of higher order roadways. That is, Inter-Urban Rural Arterial Roads have higher preference than

Urban Arterial and Collector Roads, which in turn, have more preference than Urban Local and Village Access Roads. This has been done by assigning a preference factor value of 1.15 for Inter-Urban Rural Arterial Roads, 1.10 for Urban Arterial and Collector Roads, and 1.00 for Urban Local and Village Access Roads.

Considering both failure categories and classification preference, the model indicated above in Equation (1) is modified to reflect the classification preference. This modification is presented in Equation (2).

$$PCI = 121 - K [(3)X_1 + (2)X_2 + (1)X_3] \quad (2)$$

where:

K is the preference factor for roadway classification as presented before; and

$\mathbf{X_1}$, $\mathbf{X_2}$, $\mathbf{X_3}$ are as presented in Equation (1).

Considering the outcome of the PCI model based on the above preferences, and based on experience, a range of PCI values were set to evaluate the type of maintenance actions to be taken. Those actions were limited to do-nothing, routine maintenance, major maintenance (resurfacing and/or overlay), and reconstruction. These ranges are presented in Table 2. It should be indicated that the road class effect is already considered through the selected preference factor, K.

Table 2: Ranges of PCI Suggested for Proper Actions.

Action	PCI
Do-nothing	82-100
Routine maintenance	72-82
Major maintenance	55-70
Reconstruction	55<

3. Data Collection

As a pilot study, data were collected for about 50 km of roads in the Palestinian territories. These roads include 28.2 km of Inter-Urban Rural

Arterial Roads, 9.9 km of Urban Arterial and Collector Roads, and 13.5 Urban Local and Village Access Roads. Figure 4 illustrates the distribution of studied roads. The roads lie in Nablus, Jenin, and Gaza regions. Relevant needed road inventory data, as illustrated in the road inventory module, were collected for each of the roads considered. Such data were input into the proper computer database files.

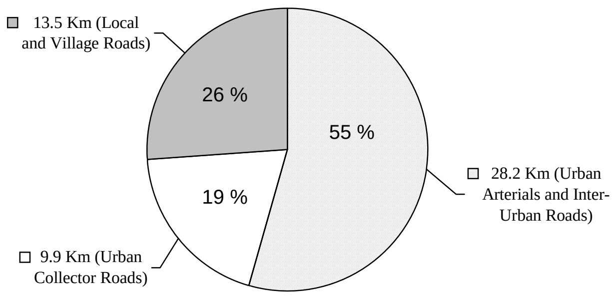

Figure 4: Sample size for the various roadway classification (Km).

Next, pavement condition surveys were performed for each of the roads, which were divided into proper sections and sub-sections. Roads which were found to have a general evaluation for road pavement of fair or worse needed further studies through performing detailed visual inspection. For this study case, it was found that the majority of roads had pavements that were categorized as fair or worse, thus arriving at the decision to perform detailed visual inspection for such roads. Results of such studies are presented in the next section.

4. Application of the Approach and Discussion of Results

The application of the methodological approach as presented earlier is illustrated here. For each of the road classes considered, the general results are discussed below. Figure 5 shows the average defect index values for each of the road classes across all the regions. In general, alligator cracking, longitudinal cracking, block and transverse cracking, and potholes were the most common pavement distress types for almost all the road classes. However, rutting appeared to be a problem on some sections of the local roads.

For the illustrated results below, only average PCI values are presented. These are based on detailed PCI calculations for each subsection of each road. For a specific road, and depending on the existence and extent of each of the distress types, proper maintenance measures are suggested for each sub-section.

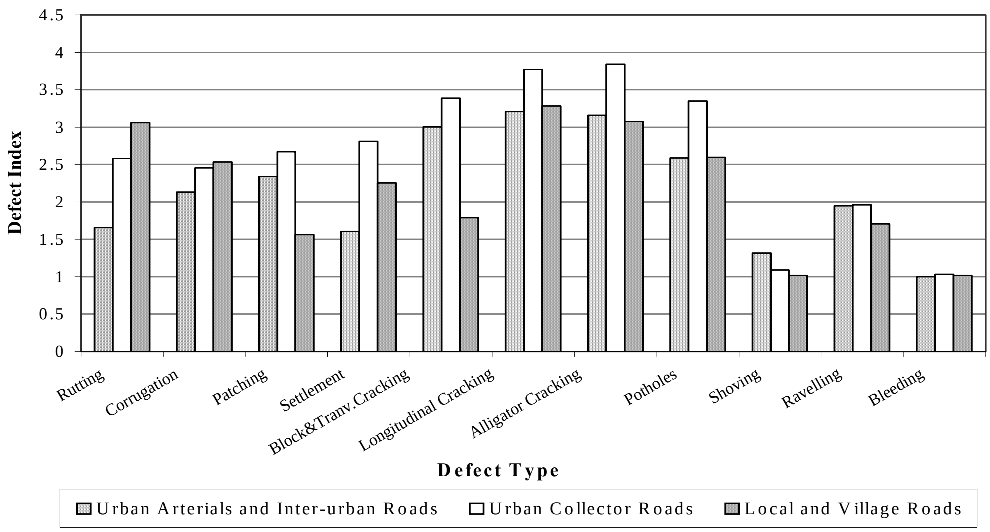

Figure 5: Average Extent of Defect for Studied Sites.

For Urban and Inter-Urban Rural Arterial Roads, the extent of distress types for the sites studied is presented in Figure 6. Regarding the Inter-Urban Rural Arterial Roads, block and transverse cracking, alligator cracking, longitudinal cracking and potholes are, in general, the most severe pavement defects, where an average distress index of at least 2.5 was observed, except for potholes, in Jenin. For these types of distress, roads in Gaza exhibited higher index values indicating the existence of more severe pavement problems. Bleeding is shown to be the distress type with the least impact, where a defect value of one was assigned. Applying the overall pavement evaluation module, it is shown that an average PCI for Inter-Urban Rural Arterial Roads in Jenin District resulted in a value of 67, while that for Gaza District resulted in a value of 65. This illustrates that such roads require major maintenance.

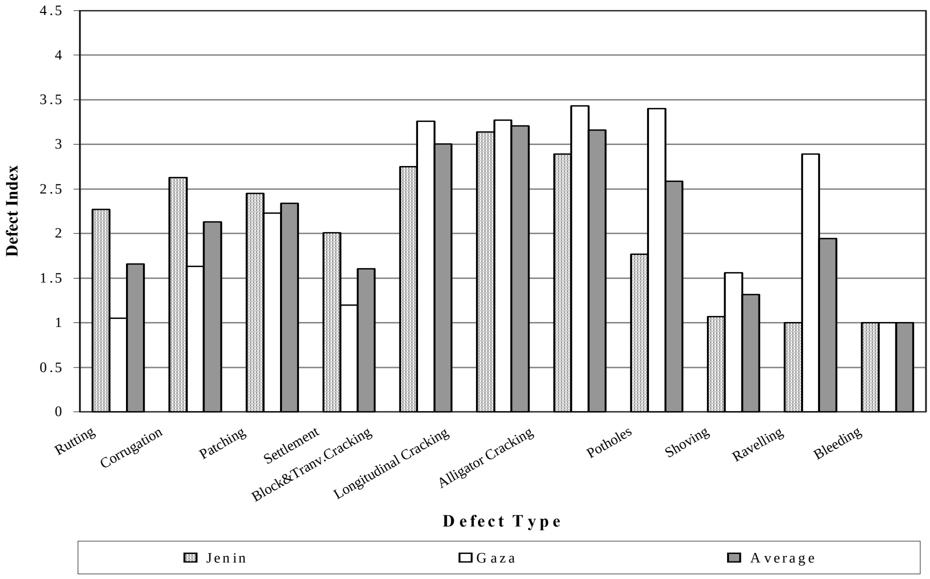

Figure 6: Extent of Defect for Studied Sites (Urban Arterials and Inter-Urban Roads).

Application of the Identification of Maintenance Measures Module for the Urban Collector Roads considered was also conducted. Figure 7 illustrates that the various types of cracking were the dominant failure mode in all the regions, while rutting was a major concern in Nablus District. Such application illustrated that for Jenin and Gaza Districts, PCI resulted in values of 58 and 61, respectively, showing that there was a need for major maintenance work. On the other hand, the results of application of the module to Nablus District roads showed a PCI value of 46 indicating a need for road reconstruction activities on roads which have similar conditions.

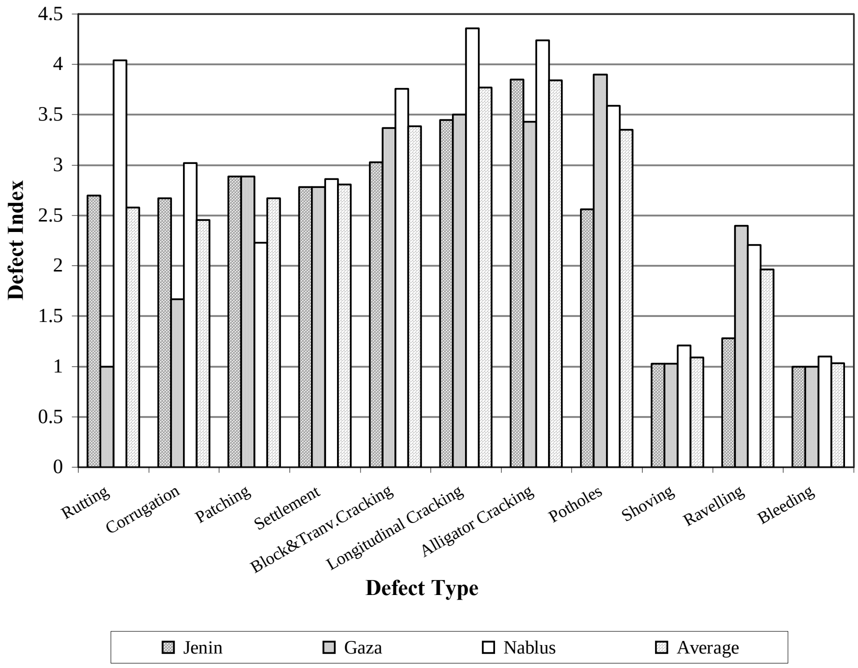

Figure 7: Extent of Defect for the Different Sites (Urban Collector Roads).

As for Urban Local and Village Access Roads, the extent of defects for each of the regions is illustrated in Figure 8. Longitudinal and alligator cracking, along with rutting, appeared to be the most severe pavement distress types. Such roads which were constructed long time ago and left without proper maintenance, are found to be underdesigned in terms of thickness, and therefore even limited repetitions of heavy axle loads can cause such ruts. The average PCI values for the studied roads in Jenin and Nablus Districts were calculated to be 68 and 75, respectively. This indicates that major maintenance activities are needed for the studied roads.

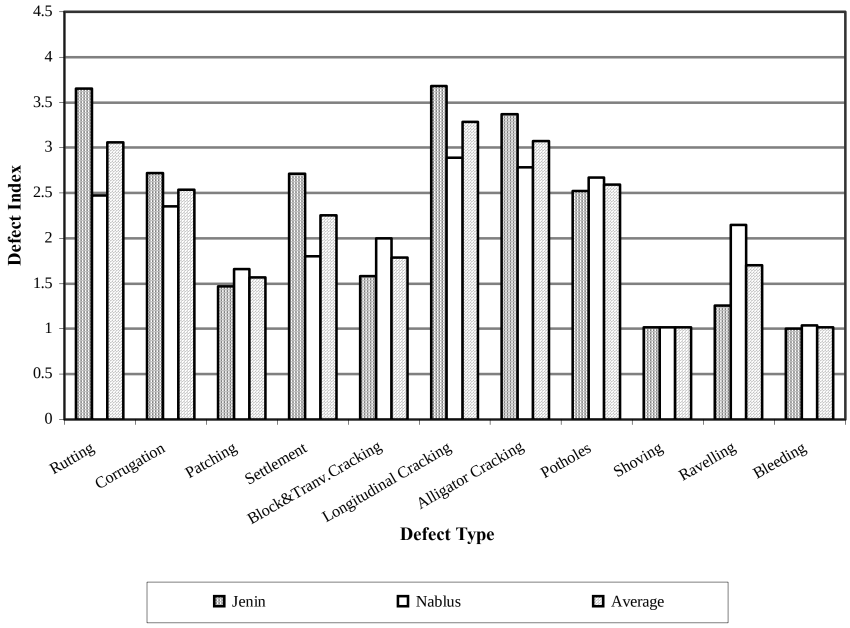

Figure 8: Extent of Defect for the Different Sites (Local and Village Roads).

5. Conclusions and Recommendations

Based on the presented pavement monitoring and management methodology, and based on the illustrated case studies, the following are concluded:

1. The current status of Palestinian roadway network showed an urgent need for an emergency program for road pavement rehabilitation, maintenance, and reconstruction. The results of the study for the sample of 50 km in the Palestinian territories indicated, in general, that the majority of these roads possessed high road distress indices and consequently low PCI values, irrespective of the classification of the road.

2. The lack of maintenance over the past three decades created severely distressed pavements which require comprehensive reconstruction programs.
3. The current maintenance practices are not based on scientific systematic methods. Appropriate methods should be developed and adopted to assist in the decision-making process related to upgrading the pavement structures of the roadway network.
4. Although the methodology partially utilized, in some of its modules, available procedures such as those for pavement condition survey and detailed visual inspection, the presented developed model proved to be valid as an integrated tool to evaluate, maintain, and rehabilitate roadway pavement structures on the network level.

Major recommendations include the following:

1. Further studies should be implemented to test and analyze the use of scientific evaluation of pavement structures such as roughness, deflection, skid resistance, ... etc.
2. Cost-based maintenance models should be developed to best utilize the limited financial resources.
3. Geographic Information Systems tools are suggested to be utilized in developed a nationwide pavement management system for the Palestinian roadway network.
4. A national agency (such as the Ministry of Public Works) is recommended to adopt a comprehensive program to keep roadway structures in acceptable conditions. As an initial step, the suggested model is recommended to be implemented by such a national authority.

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