Guidelines for a Pavement Management System and Rehabilitation Plan for Village Access Roads in the West Bank, Palestine

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Guidelines for a Pavement Management System and Rehabilitation Plan for Village Access Roads in the West Bank, Palestine

Sameer Abu-Eisheh and Khaled Abaza*

ABSTRACT

The scope of this study has focused on the establishment of guidelines for developing an Integrated Pavement Management System (IPMS) and recommending a Pavement Rehabilitation Plan (PRP). The recommended pavement rehabilitation plans include routine and preventive maintenance, plain overlay, skin patch, and complete reconstruction. Data on some thirty kilometers of local village roads in the northern part of the West Bank are utilized in the study. The proposed IPMS system depends on the methodology for pavement monitoring for maintenance management recommended by the World Bank for developing countries. It calls for implementing a Detailed Visual Inspection (DVI) in a focused evaluation of pavement distress. A Pavement Condition Rating (PCR) has been used in rating the overall pavement condition. The presented case study of the local village roads in the West Bank used the results of the PCR, where 59% of the total length of roads was found to be in bad or poor conditions, in recommending appropriate pavement rehabilitation plans. It was found that the most appropriate pavement rehabilitation plans include surface overlay or reconstruction, with an average ratio of reconstruction to resurfacing cost of 1.81. Pavement rehabilitation prediction models were estimated predicting the ESAL applications as a function of the ADT; and the overlay thickness as a function of the PCR, the ESAL applications, and the subgrade CBR; where the models' correlation coefficients exceeded 90% and the parameters' t-statistics exceeded 3.3. The study has also elaborated on life-cycle analysis and identified the rehabilitation alternative that would maximize pavement life-cycle performance and minimize pavement life-cycle cost.


1. Background

Low-volume roads can generally be classified as minor rural and urban roads serving local communities. It is the responsibility of the local authorities to operate and maintain such roads within their jurisdictions. Because of the functional operation of these roads, serving low traffic volumes, they tend to be neglected in terms of rehabilitation and maintenance. Also, small local governments usually operate on limited budgets and lack the technical staff necessary to perform the required pavement evaluation and recommend appropriate repair strategies. In developing countries, these limitations are even much more severe. Palestine is one developing country with a special set of conditions and limitations that make it a good candidate to be considered in a pilot study for the establishment of a pavement management system and the development of pavement rehabilitation plans.

The vast majority of village access roads connecting the Palestinian villages together or with major rural highways were built prior to the Israeli occupation in 1967. These roads are generally classified as minor rural roads serving relatively low-volume local traffic. Some of these roads were established during the British mandate of Palestine, while a considerable portion of these roads was constructed later during the Jordanian rule. These roads were initially constructed as Macadam roads following old footpaths with relatively tortured alignment.
due to the prevailing mountainous terrain and limited resources. Since the Israeli occupation of West Bank, these roads were intentionally neglected and received very little or no maintenance (Abu-Eisheh et al., 1990). After the establishment of the Palestinian National Authority, as a result of Oslo agreements in 1993, rehabilitation efforts in rebuilding the country’s infrastructure have given priority to rehabilitate these badly deteriorated roads.

This paper presents first the objectives of the study which was motivated by the need to develop a roadway monitoring and evaluation system for local village access roads in the Palestinian territories. Next, the methodological approach adopted in the study is discussed, which includes performing roadway condition survey and pavement detailed visual inspection, and developing the appropriate pavement rehabilitation plans. The paper presents a case study, which covers parts of the roadway network in the West Bank. Some relevant considerations related to the cost effectiveness and pavement life-cycle analysis are then outlined. Finally, recommendations for future research are presented.

2. Objectives of the Study

The goal of this study is to develop and implement a pavement monitoring and evaluation system for local village access roads in the Palestinian territories. Specific objectives of the study include:

- The investigation of available pavement condition monitoring and evaluation techniques; and the adaptation of a low-cost and easy-to-implement methodology suitable for low-volume roads.
- Selection of appropriate pavement rehabilitation plans for use to remedy deteriorated local roads pavements.
- The evaluation of the pavement life-cycle cost effectiveness and performance trends of the selected pavement rehabilitation options.
- The establishment of guidelines for the development of an Integrated Pavement Management System (IPMS).

3. Methodology

The proposed IPMS depends on the methodology for road monitoring for maintenance management recommended by the World Bank for developing countries (Organization of Economic Co-operation and Development and the World Bank, 1990). A pavement management system (PMS) is generally comprised of several components starting with the establishment of an inventory of the roadway network (Tavakoli et al., 1992). This phase should classify pavements according to type, lane width, number of lanes, pavement layer materials and thicknesses, maintenance and rehabilitation history, and traffic volumes and loads.

The second major component of a PMS is to conduct a condition assessment survey of the pavement structural section based on visual inspection of various pavement defects, and to perform other related pavement testing, if resources permit. Such tests include the ride quality test to rate the roughness of the pavement surface (a measure related to the pavement longitudinal profile), the deflection test that measures the vertical displacement underneath the flexible pavement as an indication of its strength, and the skid test to determine the pavement skid resistance.

The third main component is setting up a computerized database that would synthesize all collected data, including traffic data, for the entire roadway network. This database can then be used in evaluating pavement deterioration rates, establishing repair plans, constructing pavement rehabilitation prediction models, and setting priorities based on limited budgets. The database will also serve a long-term goal to study pavement performance and evaluate the performance of various implemented repair plans. Figure 1 provides a flowchart showing the basic components and the logic sequence involved in the implementation of a PMS (Abaza and Ashur, 1999). The portion of the flowchart enclosed by the dashed line indicates the components that have been considered in the initial phase of this project. The other components are to be considered in the final phase which requires development of an Integrated Pavement Management System (IPMS) which will be discussed further in the recommendations section.

3.1 Performing Roadway Condition Survey and Detailed Visual Inspection

In accomplishing the first objective, the procedure outlined in the World Bank manual has been used (Organization of Economic Co-operation and Development and the World Bank, 1990). It calls for conducting a Road Condition Survey (RCS) to assess the general condition of the roadway network. The end result is the identification of roadway sections, which are considered in a critically deteriorating condition and
require immediate maintenance. The sections that fail the RCS test would then be qualified for the next phase of evaluation known as Detailed Visual Inspection (DVI). The DVI procedure will assess in detail the severity and extent of various types of pavement defects that are prevailing over a pavement structural section.

The purpose of the DVI evaluation is to assess and document the type, extent and severity of pavement distress. Pavement distress is generally described in terms of several recognized pavement defects. These defects mainly include, as related to asphalt concrete pavement, traverse and longitudinal cracking, alligator and block cracking, edge cracking, pavement stripping and raveling, settlement and rutting, and patching and potholes.

This phase of pavement inspection needs to be carried out by a qualified panel of trained staff. Once the staff is trained, then carrying out the inspection is considered relatively a routine work, straightforward, and cost effective. Each roadway section evaluated in the RCS procedure and failed needs to be divided into subsections usually about 100 meters long each. Then, the technical panel would assign individual ratings on a scale of 1 (i.e., excellent) to 5 (i.e., bad) describing the extent and severity of all prevailing pavement defects. In this study, it was helpful to walk the pavement, as defects may not be easily visible from a car. Then, an average of all ratings was calculated resulting in an overall condition rating for each subsection. A weighted average can also be considered in estimating the overall rating for a particular subsection (Abazah and Abu-Eisheh, 2001).

The obtained average rating is referred to as the Pavement Condition Rating (PCR) value. This PCR value is based on a five-point scale, conforming with the World Bank monitoring manual (Organization of Economic Co-operation and Development and the World Bank, 1990). The PCR may also be partially based on other quantitative measures of pavement distress and deficiencies such as the previously mentioned tests for ride quality, deflection, and skid resistance. These measures require expensive instrumentation that are not readily available to local authorities. Therefore, in conducting a low-cost inspection, only visual evaluation and estimation of pavement defects are recommended.

Figure 2 provides a flowchart depicting the basic steps involved in the roadway condition evaluation and the recommended pavement rehabilitation plans (PRPs).

3.2 Developing Pavement Rehabilitation Plans

The obtained PCR value for each pavement subsection can then be utilized to group the subsections into homogeneous roadway sections, which would lead to the recommendation of the appropriate PRPs. It must be clear that while such PCR value gives a good indication of the overall pavement condition, other considerations based upon the experience and judgment of the specialized technical staff shall ultimately play a major role in reaching a final conclusion and in recommending the most feasible rehabilitation plan. However, tentative guidelines may be established that would relate the PCR to various applicable PRPs. One such a guideline system is suggested in Table (1). The table also shows a recommended rate of application in years for the various PRPs based on experience and general practice especially as incorporated in many widely used PMSs.

Comparing the data in Table (1) to the recommendations made in the study as presented in a later section, with regard to the PRPs plans as related to the PCR, close agreements were found within ±0.5 PCR. Generally, the recommended PRPs for the studied roads are asphalt overlay with localized reconstruction, skin patch with localized reconstruction, or complete reconstruction. This is because the majority of investigated roads was neglected, and was allowed to reach an advanced stage of deterioration, in which major rehabilitation work is the only feasible course of action. The basic question to be answered in recommending an overlay or reconstruction is the adequacy of the existing pavement in terms of the remaining strength (soundness).

A pavement section that lacks the minimum level of strength cannot provide adequate structural support of an additional overlay. In this case, reconstruction would be the only feasible option. Occasionally, only portions of an existing pavement section lack the minimum strength; thus, localized reconstruction would be considered. Depending on the size of the failed pavement portions, expressed as a percentage of the total pavement surface area, localized reconstruction may be recommended, along with an overlay, if it is economically feasible. Practically, it may be economical if the percentage does not exceed the 20-25% range of scattered failure locations. Otherwise, reconstruction should be recommended. On a large scale project, a detailed economical study should be performed to validate the above.
3.2.1 Routine and Preventive Maintenance

Routine maintenance includes crack sealing and minor patching. Localized reconstruction, another form of routine maintenance, is done to correct a failure in one or more of the pavement layers by removing the affected area and replacing it with new layer materials built with satisfactory construction specifications and standards. Preventive Maintenance is recommended for pavements in good condition as a precaution measure to delay further deterioration. It has been well documented in the literature that preventive and routine maintenance improve the pavement service life and decrease life-cycle cost. It usually consists of applying either a thin asphalt overlay or repeated applications of seal/slurry coat with the intention of providing a service life of 5 years (California Department of Transportation, 1995). The majority of the roads studied were found to be in an advanced stage of deterioration, which makes preventive maintenance ineffective and would be recommended as part of a long-term comprehensive maintenance program.

3.2.2 Asphaltic Concrete Overlay

Resurfacing consists essentially of providing an asphalt concrete overlay with a certain thickness considering a design period of 10 years. There are two methods of overlay design. The first method depends on deflection measurements of pavement. Pavement deflection is usually measured using especially designed expensive instruments such as the Dynaflect or Deflectometer. Deflection measurements, traffic data, and existing structural section properties are then used to calculate the required overlay thickness in what is known as backward solution of the multi-layer elastic theory method. The elastic method has been simplified by some professional organizations, such as the American Asphalt Institute, using design charts (Yoder and Witczak, 1975).

The second method of overlay design depends on using Equivacency Conversion Factors (ECFs) recommended by the Asphalt Institute (Yoder and Witczak, 1975). These ECFs account for the degree of distress present in the existing pavement structure. For example, 1.0 cm of an existing stable asphalt concrete is equivalent to 0.5-0.7 cm of a new asphalt concrete pavement. The ECF has been directly related to PCR, such that a 2.0 PCR is equivalent to 0.7 ECF and a 3.5 PCR is equivalent to 0.4 ECF. Essentially, this method requires designing a new asphalt concrete layer using the same thicknesses and properties of the existing base and subbase layers. Then, the new asphalt layer is reduced by an amount obtained from multiplying the appropriate equivalent conversion factor by the existing asphalt layer thickness. For low-volume roads, the overlay thickness is generally less than 5 cm, therefore, it is rounded to a practical thickness of 5 cm.

3.2.3 Skin Patch

Skin patch is another form of major rehabilitation and is typically applied to pavements in poor conditions. It requires milling portion of the existing asphaltic layer and replacing it with a new asphaltic concrete overlay. Skin patch is considered more effective than plain overlay as it helps reduce crack depth and width, but it is more costly. The thickness of overlay associated with Skin patch can be reduced using an appropriate equivalency ratio. For example, 1.0 cm of overlay with skin patch is equivalent to 1.5 cm of plain overlay (California Department of Transportation, 1995). Skin patch sometimes is the only option when the existing surface level needs not be raised to maintain vertical clearances and other existing roadway elements.

3.2.4 Major Reconstruction

Major reconstruction is defined as providing a newly designed pavement structural section based on a 20-year design period. The structural section is to consist of a maximum of three layers: asphaltic concrete layer, a granular aggregate base layer and a sub-base layer. The AASHTO method of flexible pavement design has been used. Cost factors considered other than the cost of constructing a new section are the cost of removing existing pavement, and hauling and disposing it. The decision was economically made not to remove existing pavement, but instead to build over it. The work would proceed with correcting localized pavement failures, applying a tack coat film, adding a leveling aggregate layer, and then placing the new structural section.

4. Case Study: Local Village Roads in Northern West Bank

This research has utilized the data collected for a road rehabilitation project administered by the Palestinian Economic Council for Development And Reconstruction (PEC DAR). About 30 kilometers of local village access roads with asphaltic concrete pavements have been analyzed. They comprise a total of thirteen local roads leading to villages in the northern districts of Nablus,
Tulkarem, and Jenin. The outcome of the pavement and traffic surveys and the recommended pavement rehabilitation plans is outlined below. In addition, examples of prediction models related to pavement rehabilitation are presented.

4.1 Road and Pavement Surveys

A Road Condition Survey (RCS) followed by Detailed Visual Inspection (DVI) of pavement defects were performed. An overall average rating of Pavement Condition Rating (PCR) for each roadway was obtained from individual PCR assigned to roadway subsections of 100 meter long each. A summary of the pavement conditions for the surveyed roads is presented in Figure 3. It shows that 59% of the total length of roads has either bad or poor pavements. Only 1% of the total length of road pavements is rated as excellent. The remaining 40% represent pavements in good or fair conditions.

Appropriate traffic counts were conducted, as presented in Table (2), which were utilized in the estimation of the 80 kN Equivalent Single Axle Load (ESAL) applications for each road considering 20-year design life for reconstruction and 10-year design life for overlay resurfacing. Appropriate laboratory testing of existing pavement materials such as subgrade and aggregate base was also conducted. Table (2) also shows the minimum requirements for design procedures, which include PCR, traffic data, and CBR for subgrade. The table indicates that the PCR ranged from 1.83 to 4.78 with the general trend showing a high PCR (indicating bad condition) due to the long years of negligence and lack of maintenance.

4.2 Recommended Pavement Rehabilitation Plans and Associated Costs

Based on the PCR and the guidelines suggested in Table (1), pavement rehabilitation has been recommended to include overlay and/or major reconstruction. Table (2) shows the recommended PRPs along with the estimated unit cost for each roadway. Major reconstruction has been recommended for a PCR of 3.5 and greater while overlay for PCR between 2.0 and 3.5. Recommended overlay thickness ranges from 5 to 10 cm with corresponding unit cost ranging from $5.80 to $10.70 per square meter. Major reconstruction calls for constructing two or three layers with corresponding unit cost ranging from $10.80 to $18.80 per square meter. The surface layer is asphalt concrete with aggregate course layer as a base layer. The subbase layer can either be crushed aggregates or large stones (i.e., Macadam layer). The ratio of reconstruction cost (RC) to the overlay cost (OC) has been also calculated to be about 1.81 on the average as demonstrated in Table (2).

4.3 Pavement Rehabilitation Prediction Models

The collected pavement data can be utilized later to generate relevant prediction models to be used in the proposed IPMS. These models are intended to estimate certain pavement rehabilitation parameters such as the 80 kN ESAL, PCR, and Overlay Thickness (OT) from related variables using statistical regression. Two examples of such prediction models have been derived and provided in Table (2). The first one predicts the ten-year design 80 kN ESAL applications as a function of the Average Daily Traffic (ADT). The second one predicts the Overlay Thickness (OT) as a function of the Pavement Condition Rating (PCR), ten-year 80 kN ESAL applications (ESAL\textsubscript{10}), and subgrade CBR value (CBR\textsubscript{a}). The first regression model is statistically significant at 99.5% confidence level (student t-value = 7.09) with 90.6% correlation coefficient (R), and the standard error of the ESAL\textsubscript{10} estimate is 0.61 thousand. The second regression model is statistically significant at 97.5% with 97.4% correlation coefficient. The resulting student t-statistic values associated with the three independent variable coefficients are 3.38, 5.92, and 3.31, and the standard error of the OT estimate is 0.071 cm. The two presented regression models are derived using the data provided in Table (2). These models will be updated once additional data points become available.

5. Pavement Life-Cycle Analysis

This section outlines the methodology used in performing a pavement life-cycle analysis, pavement performance and cost are both considered. A sample illustration is presented using two pavement rehabilitation alternatives. The first involves major reconstruction while the second requires only plain overlay.

5.1 Pavement Life-Cycle Performance

Researchers have long determined the relationship that describes pavement performance in terms of pavement condition over pavement life (Abaza et al., 2001; Maynard, 1986). This relation is depicted through an example as shown in Figure 4 which illustrates the performance curve as a function of PCR and pavement
life in years. The plotted graph reveals the basic trend which is the continuing decline in pavement condition over time in the absence of any active maintenance. The rate of decline in pavement condition increases progressively with aging. For example, the rate of decline in the PCR during the last one-third of pavement life is about three times the rate during the first one-third.

Therefore, the pavement in the last stage of its life is very susceptible to damage and exhibits poor performance. This emphasizes the need for maintenance work to be scheduled at a stage early enough in the pavement life to prevent rapid decline in the pavement condition. The scheduling time of pavement maintenance is very critical in the life of pavement because if the pavement is allowed to reach an advanced stage of distress, any form of maintenance would have very little impact on improving pavement condition. This is because pavement with severe distress is structurally very weak and cannot provide adequate foundation to support maintenance work.

5.2 Pavement Life Cycle Cost

A significant question related to the costs involved in maintaining and operating a pavement network is to be addressed. Researchers have indicated that the choice is very clear: either good roads at low costs or bad roads at high costs (Sheflin, 1983). Implementing a long-term policy of pavement maintenance negligence would allow pavement to reach a condition level below which maintenance work would no longer be effective. The only course of action would then be a major rehabilitation in the form of complete reconstruction as indicated in Figure 4(a).

The costs for implementing such a policy are much higher than the costs involved with implementing a policy that would take corrective measures at earlier stages in the pavement life. There are generally three elements of cost incurred over the life-cycle of pavement: construction cost, maintenance cost, and added user cost. Construction cost is the cost of initial construction, and pavement resurfacing (overlay) or complete reconstruction. Maintenance cost is defined as the cost of routine maintenance such as crack sealing and pothole patching. Added user cost includes the added cost of vehicle operation and excess travel time.

An example showing the differences in performance trends and associated costs for two distinct rehabilitation alternatives is presented in this paper. The first rehabilitation alternative is based on allowing the pavement life, 20-year design life, to expire at a PCR level of 1.0 before applying a new cycle of reconstruction as indicated in Figure 4(a). The second alternative takes corrective measures in form of an overlay at the middle point of the pavement design life, that is every 10 years in the pavement life-cycle as indicated in Figure 4(b). The second alternative makes a conservative assumption by requiring that a new overlay would not restore the pavement to its original condition, that is a PCR of 5.0, but rather exhibits a uniformly decreasing initial PCR value for each overlay cycle. This is because underlying pavement layers would have lost strength over time. A sixty-year life-cycle has been considered in this illustration.

The corresponding design and cost including performance measures for the two selected policies are summarized in Table (3). It is evidenced from the tabulated data that the second alternative is economically much more feasible. The overall performance associated with the second alternative is superior to the first alternative as indicated by the average PCR (PCR) and average Deterioration Rate (DR). The average PCR is calculated as the centroidal ordinate of the area under the performance curve, while DR is calculated as the average slope of the performance curve, as provided in the equations presented in Table (3). The table shows that the average PCR is higher for the second alternative while the average deterioration rate is lower. The superior performance of the second alternative is also combined with lower construction cost, maintenance cost, and added user cost. No specific maintenance and added user costs are considered in this paper, but common sense states that these costs would be lower with improved pavement condition. Therefore, the choice is obvious: maintain good roads with low costs or allow pavement to badly deteriorate at high costs.

6. Conclusions and Recommendations

As a result, some ideas have emerged to be further investigated and pursued. They include the development of an Integrated Pavement Management System (IPMS) for implementation in Palestine, especially for use by local governments. This study mainly dealt with existing roadway conditions and recommended immediate actions. Providing long-term planning and monitoring of the existing roadway network requires a process to be followed on continuous basis. The required process must
be very well thought out in terms of commitments, resources, planning, execution, data requirements, scheduling, and funding. This all means management, which simply means providing the best possible pavement condition by making the best use of available resources.

The proposed IPMS system would have several major modules built into it. These modules include: computerized database for the roadway inventory; a systematic approach for pavement condition surveys and ratings; pavement condition prediction models; pavement rehabilitation plans to be recommended as part of a comprehensive maintenance program; and cost models to be developed based on pavement condition ratings. The comprehensive maintenance program is intended to provide an optimum policy that would maximize pavement life-cycle performance and minimize pavement life-cycle cost. The proposed IPMS must be designed to meet the needs of local authorities considering their limited experiences and resources, be simple and practical to use and implement, and interactive and user-friendly.

The proposed IPMS is intended to provide the local governments with the expertise they lack in the field of pavement maintenance and management. The proposed system is dynamic in the sense that it can periodically receive updated feedback in terms of pavement condition surveys and traffic data. This can result in recommending a revised pavement maintenance program that would reflect the observed new changes in pavement performance after the implementation of a particular maintenance and rehabilitation program.

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Figure 4 (b): Flexible Pavement Life Cycle Performance (Resurfacing).
Table 1: Suggested Pavement Maintenance Program based on Pavement Condition Rating (PCR) “Prescription Method”.

<table>
<thead>
<tr>
<th>PCR Range</th>
<th>Pavement Condition</th>
<th>PRR*</th>
<th>Application Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-1.0</td>
<td>Excellent</td>
<td>RM</td>
<td>Annually</td>
</tr>
<tr>
<td>1.0-2.0</td>
<td>Good</td>
<td>PM-LR1</td>
<td>Every 5 Years</td>
</tr>
<tr>
<td>2.0-3.0</td>
<td>Fair</td>
<td>AO+LR2</td>
<td>Every 10 Years</td>
</tr>
<tr>
<td>3.0-4.0</td>
<td>Poor</td>
<td>SP+LR3</td>
<td>Every 15 Years</td>
</tr>
<tr>
<td>4.0-5.0</td>
<td>Bad</td>
<td>MR</td>
<td>Every 20 Years</td>
</tr>
</tbody>
</table>

* Definition of various Pavement Rehabilitation Plans (PRPs) is as follows:

RM = Routine Maintenance  
LR1 = Localized Reconstruction (0-2%)  
LR2 = Localized Reconstruction (2-10%)  
LR3 = Localized Reconstruction (10-25%)  
PM = Preventive Maintenance + LR1  
AO = Asphalt Concrete Overlay (5 cm) + LR2  
SP = Skin Patch (milling and replacing of a 5 cm asphalt concrete) + LR3  
MR = Major Reconstruction
<table>
<thead>
<tr>
<th>Road Name</th>
<th>Average CBR (%)</th>
<th>Average PCR (%)</th>
<th>ADT (x 10^3)</th>
<th>Overlay Thickness (cm)</th>
<th>Overlay Cost ($/m²)</th>
<th>Reconstruction Cost ($/m²)</th>
<th>Cost Ratio, RC/OC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safinân</td>
<td>2.96</td>
<td>4.50</td>
<td>3.77</td>
<td>30</td>
<td>6</td>
<td>6.25</td>
<td>1.77</td>
</tr>
<tr>
<td>Hares</td>
<td>3.11</td>
<td>2.93</td>
<td>4.87</td>
<td>4.60</td>
<td>8</td>
<td>7.25</td>
<td>1.88</td>
</tr>
<tr>
<td>Qur-Ka'far Sur</td>
<td>2.40</td>
<td>3.02</td>
<td>3.62</td>
<td>7.7</td>
<td>7</td>
<td>8.50</td>
<td>1.88</td>
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<tr>
<td>Qarah</td>
<td>4.31</td>
<td>3.00</td>
<td>3.47</td>
<td>3.40</td>
<td>2</td>
<td>3.40</td>
<td>1.88</td>
</tr>
<tr>
<td>Samur-Mawiya</td>
<td>4.03</td>
<td>3.38</td>
<td>3.19</td>
<td>3.19</td>
<td>10</td>
<td>7.05</td>
<td>1.77</td>
</tr>
<tr>
<td>Zababish</td>
<td>4.41</td>
<td>1.86</td>
<td>1.046</td>
<td>2.00</td>
<td>7</td>
<td>4.00</td>
<td>1.88</td>
</tr>
<tr>
<td>Al-Khijân</td>
<td>4.78</td>
<td>1.86</td>
<td>1.046</td>
<td>2.00</td>
<td>7</td>
<td>4.00</td>
<td>1.77</td>
</tr>
<tr>
<td>Al-Sha'bân</td>
<td>4.53</td>
<td>3.15</td>
<td>3.09</td>
<td>6.60</td>
<td>10</td>
<td>10.73</td>
<td>1.77</td>
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<tr>
<td>Sâeeb-Al Ra'amah</td>
<td>2.73</td>
<td>4.85</td>
<td>4.85</td>
<td>10.80</td>
<td>10</td>
<td>10.80</td>
<td>1.77</td>
</tr>
<tr>
<td>Shoufêh</td>
<td>2.98</td>
<td>2.50</td>
<td>1.605</td>
<td>8.50</td>
<td>10</td>
<td>8.50</td>
<td>1.77</td>
</tr>
<tr>
<td>Taroun</td>
<td>1.93</td>
<td>2.50</td>
<td>1.605</td>
<td>8.50</td>
<td>10</td>
<td>8.50</td>
<td>1.77</td>
</tr>
<tr>
<td>Beit Leed</td>
<td>4.06</td>
<td>1.048</td>
<td>1.85</td>
<td>18.50</td>
<td>10</td>
<td>18.50</td>
<td>1.77</td>
</tr>
</tbody>
</table>

Average=1.81

\[ AC = \text{Asphalt Concrete Thickness} \]
\[ AB = \text{Aggregate Base Thickness} \]
\[ AS = \text{Aggregate Subbase Thickness} \]

Prediction Models:
\[ ESAL_{10} = 0.327e^{1.66ADP^{0.25}} \]
\[ OT = 0.073e^{(2.32PCR^{0.2} + 0.22ESAL_{10}^{0.2})} \]
Table 3: An Example of Flexible Pavement Life-Cycle Rehabilitation Alternative Plan Comparison.

<table>
<thead>
<tr>
<th>Item</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rehabilitation Plan</td>
<td>Reconstruction</td>
<td>Resurfacing</td>
</tr>
<tr>
<td>Structural Section</td>
<td>25cm AB+7cm AC</td>
<td>5cm Plain Overlay</td>
</tr>
<tr>
<td>Application Rate</td>
<td>Every 20 years</td>
<td>Every 10 years</td>
</tr>
<tr>
<td>Removal Cost</td>
<td>None (No Removal)</td>
<td>None (No Removal)</td>
</tr>
<tr>
<td>Cost per Square Meter</td>
<td>$12.4/m²</td>
<td>$5.8/m²</td>
</tr>
<tr>
<td>60-year Life-Cycle Cost</td>
<td>$37.2/m²</td>
<td>$34.8/m²</td>
</tr>
<tr>
<td>Design Life (T_j)</td>
<td>20 years</td>
<td>10 years</td>
</tr>
<tr>
<td>Number of Cycles (n)</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Average PCR (PCR_j)@</td>
<td>2.52</td>
<td>3.42</td>
</tr>
<tr>
<td>Average Deterioration Rate (DR)@</td>
<td>0.20</td>
<td>0.125</td>
</tr>
<tr>
<td>Construction Cost</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Maintenance Cost</td>
<td>Higher</td>
<td>Lower</td>
</tr>
<tr>
<td>Added User Cost</td>
<td>Higher</td>
<td>Lower</td>
</tr>
</tbody>
</table>

@ \[ PCR = \frac{\sum_{i=1}^{n} T_j \sum_{i=1}^{T_j} (PCR_i) \times i}{\sum_{j=1}^{n} \sum_{i=1}^{T_j} i} \quad i = 1, 2, 3, ..., T_j \]

where: PCR, = Pavement Condition Rating at (T_j) age.

# \[ DR = \frac{\sum_{j=1}^{n}[(PCR_{i,j}) - (PCR_{f,j})]}{n \times T_j} \]

where: \((PCR_{i,j})\) = Initial Pavement Condition Rating of the jth cycle.
\((PCR_{f,j})\) = Final Pavement Condition Rating of the jth cycle.
Figure 1: Flowchart of Basic Components Involved in the Implementation of a Pavement Management System (PMS)
Figure 2: Flowchart of Basic Steps Involved in the Road Condition Evaluation and Recommended Pavement Rehabilitation Plans (PRPs)
Figure 3: The Distribution of Pavement Conditions for Studied Local Village Roads

Figure 4(a): Flexible Pavement Life-Cycle Performance (Reconstruction)

Figure 4(b): Flexible Pavement Life-Cycle Performance (Resurfacing)
الخطوات العريضة لإدارة أنظمة الرصفات

وترسم خطط تأهيل الطرق القروية في الضفة الغربية، فلسطين.

ملخص

يُحور هذا الحxia حول وضع خطط العريضة من أجل إنشاء نظام متكمّل لإدارة أنظمة الرصفات ووضع الخطط العامة لإعادة تأهيل الطرق القروية في الضفة الغربية، فلسطين. وتشمل خطط إعادة تأهيل الرصفات القيام بأعمال الصيانة الروتينية، والصيانة الوقائية، ووضع نقطة اتخاذية غير جديدة. وإعادة الأمور بشكل كامل. وقد تم في هذه الدراسة استخدام معلومات ميدانية تم جمعها من حوالي 300 كيلومتر من الطرق القروية في شمال الضفة الغربية. وتستهدف النظم المتكاملة لإدارة أنظمة الرصفات تحقيق خاصية بالدول الدائمة. تقوم على مراقبة الرصفات بناءً على إدارة أعمال الصيانة وذلك حسب توصيات البنك الدولي. ويتطلب ذلك من خلال التدريب الشاملية للنظر في مفاهيم الطرق التي يوجد خلالها فيها. وبناء عليه، يتم احتساب معدل أوضاع الرصفات، ومن ثم يتم إعداد التوصيات الفنية لإعادة تأهيل الطرق. وبناءً على تلك الدراسة، تمت التوصيات التالية:

1. إعداد التوصيات الفنية لإعادة تأهيل الطرق.

2. تدريس مهارات تدريس ومتابعة تدريس تأهيل الطرق.

3. تدريج التدريس غير المتكافئ، ووضع الرصفات، حيث بيت الدراية أن 65% من مجموع الطرق القروية تعتبر شبيلة أو ضعيفة، وذلك في أطراف الطرق السريعة لإعادة تأهيل الطرق.

4. وضع بيانات الرصفات التي تمتد دراساتها تشمل توفير وجهة النظرية أو قائمة بإعادة الإشارة إلى أن نسبة كبيرة من الرصفات تمثل توزيع وجهة النظرية. وقد تم تقديم نماذج لبناء تأهيل الرصفات من خلال التنبؤ بتحديد الأوزان الموجهة للخصوبة الإنجابية. ومن ثم تنبؤ بعملية التدريس في الرصفات، وبناءً على أن التحدي الإجعليه أن معدلات الرصفات تتجاوز 90% وأن هناك أمثلة إجعليه لكل من المواقع التي تحوي كل من المواقع. وقد تتجاوز الرصفات تحللهم في المرحلة الأولى، وتحدد الهدف الأفضل الذي يفي فعالية نورة عبر الرصفات وفق كلها.

كلية الهندسة، جامعة النجاح الوطنية، وكالة الهندسة، جامعة بير زيت، فلسطين، تاريخ استلام البحث 2011/12/21، وتاريخ قبوله 2012/3/25.