Optimal maintenance works for Aborshada road in Libyain western region*

M. A. Youssef**

Abdelbary A. Elbasher***

* Received: 25/6/2013, Accepted: 9/9/2013.

** Assist. Prof., Department of Civil Engineering, Faculty of Engineering, Algable Elgarby University, Gharian, Libya.

*** Graduate Student, Department of Civil Engineering, Faculty of Engineering, Algable Elgarby University, Gharian, Libya.

ملخص:

في هذا البحث ، فحص حال الرصف لطريق أبو رشاده في منطقة غريان لتحديد أعمال الصيانة المثلى. في السابق كان الحس الهندسي البسيط هو المستخدم لتقويم الرصف ووضع أولويات الصيانة من مهندسي بلدية غريان. وقد فُحص حال سطح الرصف لطريق أبو رشاده بالأسلوب البصري (دليل حالة الرصف PCI)، لحصر العيوب المختلفة الموجوده بالطريق وتصنيفها طبقاً لمعيار ASTM ، PCI، في عام ٢٠٠٧م تحت رقم D6433-07. وكذلك لمعرفة أكثر العيوب شيوعاً في طريق أبو رشاده لتقديم المسانده لمتخذ القرار لتقويم الرصف واختيار طريقة العلاج المثلي.

هذه الدراسة ، عرضت أساليب تقويم حالة السطح ، وبدائل قرارات الصيانة، وتفاصيل أنواع العيوب بطريق أبو رشاده. وبالاعتماد على تقويم حال الرصف، يستطيع متخذ القرار إيجاد تأثير تنفيذ أعمال الصيانة على حال سطح الرصف. وأيضاً تحديد البديل الأمثل والمناسب لميزانيته. هذه الدراسة عرضت الأداء الفعلي الحالي للرصف واقترحت الأبحاث المطلوبة والمتعلقة بمشكلات صيانه الرصف في ليبيا وبخاصة بالمنطقة الغربية. أوضحت الدراسة أن أفضل بديل لصيانة طريق أبو رشاده هو البديل رقم ٤ (صيانة الحفر – والشروخ الطولية والعرضية – والشروخ التمساحية). وأيضاً أوضحت الدراسة العيوب الأكثر شيوعاً ذات الأرقام ١٣ – ١٠– ١ – ٣ – ٧ طبقاً لتقسيم ASTM.

Abstract:

In this research, road pavement condition was investigated for Aborshada road in Gharian region to determine the optimal maintenance works. Previously, Simple engineering judgment was the only procedure followed by Gharian Municipality engineers for pavement evaluation and maintenance prioritization. Aborshada road pavement surface condition was investigated by using visual technique " Pavement Condition Index (PCI)", to survey the different distresses classified according to the PCI standards (ASTM standard in 2007 (D6433-07)). and to know the most commune distresses in the Aborshada road in order to provide assistance for decision maker in the pavement evaluation and optimum selection of repair method.

In this study, pavement condition evaluation techniques, scenario maintenance decision, and detail sheets for some distresses types in the Aborshada road were presented. Counting on the pavement condition evaluation, the decision maker can find the effect of the maintenance works on the existing pavement condition. Also, he can select the optimum alternative suitable for his fund. This study reveals pavements actual performance and suggests the required research to deal with the pavement maintenance problem in Libya, especially in western region. The study showed that the best maintenance alternative for Aborshada road was the case No. 4 (Potholes , Long. & Trans. Cracking and Alligator Crack Maintenance). Also, it showed that, the most common pavement distresses on the Aborshada road were distresses No. 13, 10, 1, 3, 7, 6 according to ASTM – D6433-07 classification.

Key Words: Pavement Distress; Optimum maintenance Policy; Pavement Condition Index; Pavement Management, Pavement Scores

1. Introduction:

One of the main transportation systems in Libya is the highway system. The main function of this system is to connect cities, towns and villages throughout Libya. Therefore, it is required to have highways in an excellent condition from both structural, and functional point of views.

Every agency responsible for the maintenance of roadway systems faces the problem of insufficient funding to perform all of the necessary repairs on all pavement sections. Therefore, highway agencies must adopt a pavement management system (PMS) to help set priorities. The PMS includes a method for evaluating pavement performance on a routine basis and identifying sections with a need for rehabilitation or maintenance [1]. One of the key components of any pavement maintenance management system is the pavement rating system. These systems involve calculating a numerical score or index based on the pavement distress and surface condition to make a comparison between roadway segments based on their condition [4]. Pavement rating system may be based solely on visible surface distresses, use an index based on ride quality alone, to perform the regular evaluation of pavements and to select projects or using a combination of distress and ride quality. The Ohio Department of Transportation (ODOT) utilizes the Pavement Condition Rating (PCR), which is based on surface distress, for project selection. When evaluating the condition of pavements, there is a need to apply a systematic approach to identify and quantify the distresses that occur on the pavement. In addition to compiling the type, severity, and quantities of observed distress, the use of a single index to describe the pavement condition is also attractive for use in managing a pavement network [6].

The pavement condition data are an important input into the Pavement Management System (PMS) to develop estimates of pavement maintenance and rehabilitation needs based on an optimization analysis. These needs are subsequently used for the development of the maintenance budget and the work plan generated by the optimization and serves as a guide to district personnel for the selection of pavement maintenance works. Once a particular section of pavement is selected for maintenance, a detailed project level analysis is conducted to determine the specific treatment. One of the key components of any pavement management system is the pavement rating system. These systems involve calculating a numerical score or index based on the pavement distress and surface condition to make a comparison between roadway segments based on their condition. Also, Pavement condition surveys play a vital role in the management of a pavement network. The pavement condition survey provides the most valuable information for pavement performance analysis, and is vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding. **Pavement Condition Evaluation Techniques can be divided as :**

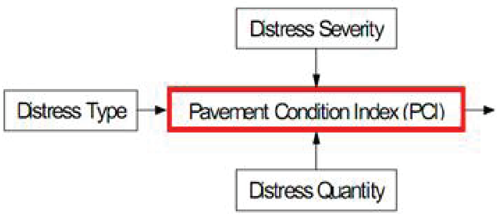
- Visual survey
- Falling Weight Deflectometer (FWD)
- Ground Penetration Radar (GPR)
- Dynamic Cone Penetrometer (DCP)

Visual condition surveys (or distress surveys) vary from the simplistic to extremely detailed and complex. On the simple end of the scale, some agencies use a windshield survey where raters drive along the shoulder of the road and rate the pavement on a scale of 0 to 10 based upon the surface distresses given. No notation of the types or extents of distresses are noted. The obvious shortcoming with this method is that when rehabilitations are recommended, the analyst has no method of determining what types of distresses influence the overall rating. The analyst only knows that the road is in a certain condition state [8].

One of the most popular pavement distress rating systems is the Pavement Condition Index (PCI). On the complex end of the scale is the Pavement Condition Index (PCI) survey. The PCI was developed to provide engineers with a numerical indication of overall pavement condition. During a PCI survey, visible signs of deterioration within a selected sample unit are measured, recorded, and analyzed. Distress type, severity, and quantity are all identified and recorded. The final calculated PCI value is a number from 0 to 100, with 100 representing a pavement in excellent condition, as shown in Figure 1. The results of a PCI survey are used for a myriad of purposes, including planning and programming at the network level and generating information used in a project-level rehabilitation design and assign maintenance work for each pavement link as in this research. The pavement data are used for selection of pavement sections and optimum maintenance works which has a big effect on the pavement condition for Aborshada Road. Typically, the districts have used the data in combination with their local knowledge of pavement conditions to select pavement maintenance projects.

Figure (1)

Pavement Condition Index (PCI), Rating Scale



100

85	Good
70	Satisfactory
55	Fair
40	Poor
25	Very poor
10	Serious
0	Failed

A widely used distress index that is derived from deduct values is the Pavement Condition Index (PCI), developed in the late 1980s by the U.S. Army Corp of Engineers. The PCI scale ranges from 0 to 100, with 100 representing the perfect score (i.e., a pavement in excellent condition). In 2000, the American Society for Testing of Materials (ASTM) adopted the PCI method as a standard practice for roads and parking lots pavement condition index surveys (ASTM Standard D6433-99) [7]. In this search, the roads pavement was inspected to survey the different distresses in each sample unit. There are 19 different distresses classified per the PCI standards (PCI stands for Pavement Condition Index). The PCI for roads and parking lots became an ASTM standard in 2007 (D6433-07). The PCI Index are often used at network-level for identifying when treatments should be applied, the impact of not applying treatments, and projecting future conditions. Also, at project-level, they are often used in determining the long-term impact of various treatment alternatives as applied in this research. Information about specific distresses can be used to determine appropriate maintenance actions for consideration.

2. METHODOLOGY:

Pavement condition surveys play a vital role in the pavement management system at network level and at project level. Also, they provide the most valuable information for pavement performance analysis, and are vital in order to forecast pavement performance, anticipate maintenance and rehabilitation needs, establish maintenance and rehabilitation priorities, and allocate funding.

A fundamental component of any pavement management system is the ability to track pavement condition. This requires an evaluation process that is objective, systematic, and repeatable. A pavement condition rating system, such as the pavement condition index (PCI) rating system is described in ASTM Standard D6433-07. Prior to performing pavement condition measurements by any technique, the pavement network must be defined so as to divide the network into manageable sections for both network and project level management. The network is divided into branches (i.e., a specific road would be a specific branch) and branches are divided into sections using factors such as pavement type, traffic, construction history, structure, and so on. This is generally a one-time effort, as long as it is completed properly and with the “best” information available. This effort, or initial data collection, for each pavement section can be time consuming, but must be completed.

This section includes a brief review of PCI procedures. In this research, the Pavement condition index was used to evaluate the pavement performance. The pavement condition index (PCI) was developed for the U. S. Air Force for airfield pavements and later modified for roads and streets [2,3]. The Pavement Condition Index (PCI) was determined by a visual condition survey which identifies the types, severities and quantities of distresses. Firstly, the pavement section was divided into sample units. The number of sample units to inspect can be determined based on the desired level of reliability. Pavement distresses were classified to 19 distresse according to the PCI standards. Then, these measures were used for allocating resources for maintenance, monitoring the results of maintenance, identifying policy issues, and making budget projections.

2.1. Road description and Pavement Inspection:

The road description accounts for the geometrical characteristics of the longitudinal and transversal profile : In this case, Aborshada Road length is 22 km with 2 pavement lanes width (7m), gravel shoulder in both sides. The road is 2lane-2way, starting from Gharian city to Hera Gate as shown in Figuer (2).

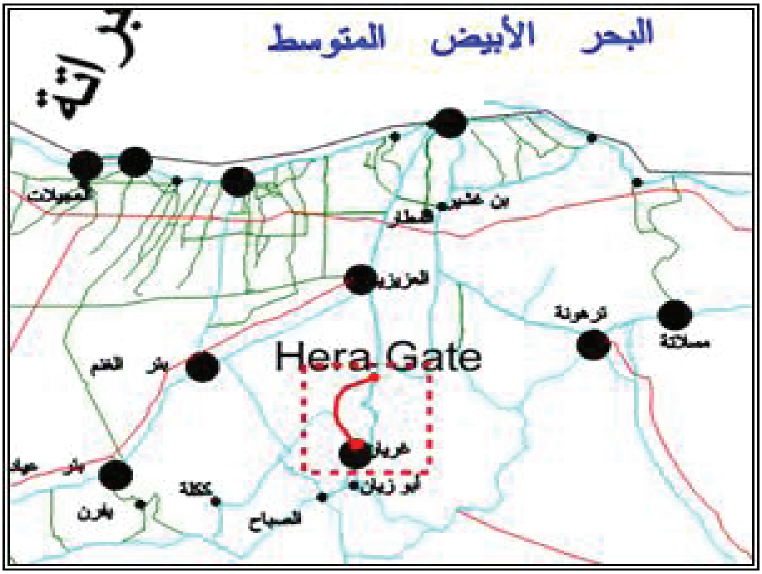


Figure (2)

Aborshada Road with red colour in dot box in the map, start from Gharian city to Hera Gate.

A manual survey is performed following ASTM D 6433. The pavement link was divided into sections, Each section is divided into sample units. The type and severity of sample distress is assessed by visual inspection. The quantity of each distress was measured. Typically, this procedure requires a team of at least two engineers.

Each sample unit is walked upon and the team keeps record sheets for each sample unit surveyed and records the appropriate code for distress type, severity and a measurement of quantity. The Pavement Condition Index (PCI) is determined by a visual condition survey which identifies the types, severities and quantities of distresses. First, the pavement section is divided into sample units. The number of sample units to inspect can be determined based on the desired level of reliability. Deduct values are determined through curves developed for every distress type and severity for all density levels. The deduct values are then summed to acquire a total deduct value (TDV). A correction curve is used to take into account the effect of multiple distresses and adjust the TDV into a corrected deduct value (CDV). The PCI is calculated by the equations:

PCI = 100 – CDV....................................... (1)

If all of the sample units in the pavement link are surveyed, then the PCI was averaged. If less than all sample unites are inspected, the link PCI is calculated using the following equation:

PCIS = [(N-A) x PCI1 + A x PCI2]/N........... (2)

Where:

PCIS : the PCI of the pavement link,

PCI1 : the average PCI of random samples,

PCI2 : the average PCI of additional samples,

N : the total number of samples in the section, and

A : the number of “additional” samples inspected.

2.2. Pavement Condition Evaluation (PCI calculations):

A pavement link is divided into a number of uniform sample units, (i.e., an area of 100m length and 7 m width, with total sample number 22). The following calculations are conducted for each sample unit. For each distress and severity level present, the area/length affected is added up and divided by the area of the sample unit, which is expressed in percent, and is referred to as distress density. Subsequently, deduct values are computed for each distress density, using a series of charts. These deduct values need to be processed to compute the maximum corrected deduct value (max CDV). The correction is necessary to ensure that the sum of the deduct values does not exceed 100%. If fewer than one of the deduct values is larger than 2%, the max CDV is equal to the sum of the individual deduct values. Otherwise, the max CDV is computed through an iterative process, as follows. The deduct values are arranged in decreasing order. The maximum number of allowed deduct values m, which cannot exceed 10, is given below as a function of the highest deduct value (HDV), (i.e., the first in the decreasing order list):

$$m = 1 + \frac{9}{98}(100 - HDV) \leq 10$$

A widely used distress index that is derived from deduct values is the Pavement Condition Index (PCI). The general expression for computing PCI is as follows:

$$PCI = C - \sum_{i=1}^{p} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) F(t,q)$$

where:

C : maximum value of the condition index (perfect score).

a (T,S,D) : deduct value function that varies with distress type (T), severity (S), and density (D).

F(t,q) : an adjustment function that varies with total deduct value (t) and number of deducts (q).

i , j : counters for distress types and severity levels, respectively.

p : total number of observed distress types.

m_i : number of severity levels for the ith distress type. Typically, three levels of severity are used (low, medium, and high).

Pavement management systems involve collecting information on basic surface distresses and then using those distresses to calculate a pavement condition index (PCI). A pavement with no visual distresses rates 100. Points are deducted for each distress, adjusted for both severity and extent of the distress, to calculate the PCI for a sample of pavement.

Pavement Condition Report. This report provides the user with a tabulation of pavement condition for the current status. The report should provide the condition of individual pavement sections and the overall road condition. The projected condition can be used to assist maintenance planning, in future repair needs, and to inform management of present and future conditions. Pavement condition is calculated using the data from the inspections of Aborshada road sections acquired by the author.

2.2.1. Calculation of Pavement Condition Index for Aborshada Road:

The inputs to determine the required treatment for Aborshada road, and the condition survey data which includes distress quantity, severity, and condition index were used. The optimal maintenance activities plan is arrived at by utilizing pavement condition index for Aborshada road.

Pavement distress data were collected by author during the month of March 2013.Random samples of road were selected (22 sample), which represent about 10% of the road area. The road pavement is inspected to survey the different distresses in each sample unit. The pavement distresses were classified to (19) distresses according to PCI standards as shown in Table 1. The surveyed data and PCI calculations for samples and the road were showed in Tables 2 to 7 as example for three samples, the results of remainder samples were showed in Table 8.

2.3. Pavement Maintenance works for Aborshada Road:

The selection procedures of maintenance works were based on the expected performance of pavement, due to eliminate some of pavement distresses by suitable maintenance works. In general, many factors must be evaluated by a specifying agency when selecting a pavement maintenance treatment. These factors may include : Type and extent of distress, Cost of treatment, Traffic type and volume, Climate, Existing pavement type, Expected life, Availability of qualified contractors, Availability of quality materials, Time of year, Pavement noise, Facility downtime (user delays), Surface friction, Anticipated level of service, and Other project-specific conditions.

Table (1)

Distress classification and numbering according to ASTM (D6433-07).

1	Alligator cracking	8	Jt, Reflection cracking	15	Rutting
2	Bleeding	9	Lane/Shoulder Drop Off	16	Shoving
3	Block cracking	10	Long & Trans Cracking	17	Slippage Cracking
4	Bumps and sags	11	Patching & Util Cut Patching	18	Swell
5	Corrugation	12	Polished Aggregate	19	Weathering/Raveling
6	Depression	13	Potholes		
7	Edge cracking	14	Railroad Crossing		

Table (2)

Pavement Condition Data Sheet for Sample No.1, M=5.59 < 9

Distress Severity	Quantity															Total	Density %	Deduct Value
13H	1	1	1	1	1	1										6	0.85	50
1M	3*6	2*2														22	3.14	34
13M	1	1	1	1	1	1	1	1								8	1.14	31
10M	7	11	6	4	7	6	7	13	7	3.5	4	6	10.5	13.5	7	112.5	16	24
13L	1	1	1	1	1	1										6	0.85	19
3M	4*17	3*3	4*5													97	13.85	18
7M	6	3	11													20	2.85	9
6L	3*4	2*4														20	2.85	8
9L	3	4.5	5.5													13	1.85	5

Table (3)

Calculation of Corrected PCI Value for Sample No. 1

#	Deduct value										Total	Q	CDV	Max CDV = 89	PCI = 100 – 89 = 11	Rating = Serious
1	50	34	31	24	19	10.62	5.31	4.72	2.95		181.6	9	81			
2	50	34	31	24	19	10.62	5.31	4.72	2		180.65	8	80			
3	50	34	31	24	19	10.62	5.31	2	2		177.93	7	78			
4	50	34	31	24	19	10.62	2	2	2		174.62	6	85			
5	50	34	31	24	19	2	2	2	2		166	5	89			
6	50	34	31	24	2	2	2	2	2		149	4	88			
7	50	34	31	2	2	2	2	2	2		127	3	75			
8	50	34	2	2	2	2	2	2	2		98	2	73			
9	50	2	2	2	2	2	2	2	2		66	1	70			

Table (4)

Pavement Condition Data Sheet for Sample No.2, M=5.96 < 7

Distress Severity	Quantity																	Total	Density %	Deduct Value
13M	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			15	2.14	46
13H	1	1	1	1														4	0.571	40
1M	5*3	3*2	2*1.5															24	3.428	35
10M	3.5	6	2	3	2.5	3.5	7	9	7	6	11	3	3.5	7	9	6	3.5	92.5	13.21	20
13L	1	1	1	1	1	1												6	0.857	19
3M	2.5*3	6*3	4*3															37.5	5.357	12
7M	4	5	3															12	1.71	4
10L	2	4	2															8	1.14	2

Table (5)

Calculation of Corrected PCI Value for Sample No. 2

	Deduct Value								Total	Q	CDV			
1	46	40	35	20	19	11.52	3.84		175.36	7	78	Max CDV = 82	PCI = 100 – 82 = 18	Rating = Serious
2	46	40	35	20	19	11.52	2		173.52	6	82			
3	46	40	35	20	19	2	2		164	5	75			
4	46	40	35	20	2	2	2		147	4	74			
5	46	40	35	2	2	2	2		129	3	73			
6	46	40	2	2	2	2	2		96	2	65			
7	46	2	2	2	2	2	2		58	1	53			

Table (6)

Pavement Condition Data Sheet for Sample No.3, M=7.24 > 7

Distress Severity	Quantity														Total	Density %	Deduct Value
13M	1	1	1	1	1	1	1	1							8	1.14	32
13H	1	1													2	0.28	32
1M	3*3	4*2.5													19	2.7	31
13L	1	1	1	1	1	1	1								7	1	20
10M	7	3.5	3.5	4	7	7	8	7	4	7	5	4	7	3	77	11	19
7M	22	17	6	3.5											48.5	6.92	13
3M	5*2.5	3*4													24.5	3.42	9

Table (7)

Calculation of Corrected PCI Value for Sample No. 3

#	Deduct value															Total	Q	CDV	Max CDV = 74	PCI = 100 – 74 = 25	Rating = very poor
1	32	32	31	20	19	13	9									156	7	74			
2	32	32	31	20	19	13	2									149	6	70			
3	32	32	31	20	19	2	2									138	5	72			
4	32	32	31	20	2	2	2									121	4	70			
5	32	32	31	2	2	2	2									103	3	65			
6	32	32	2	2	2	2	2									74	2	55			
7	32	2	2	2	2	2	2									44	1	42			

Table (8)

PCI for Samples 1 to 22 for existing condition and distress maintenance alternatives

Sample No.	Existing Condition		Maintenance Alternative 1		Maintenance Alternative 2		Maintenance Alternative 3	
	Case 1		Case 2		Case 3		Case 4	
	PCI	Rating	PCI	Rating	PCI	Rating	PCI	Rating
1	11	Serious	48	Poor	56	Fair	76	Satisfactory
2	18	Serious	54	Poor	62	Fair	86	Good
3	25	Very Poor	58	Fair	64	Fair	84	Satisfactory
4	58	Fair	67	Fair	76	Satisfactory	76	Satisfactory
5	60	Fair	76	Satisfactory	88	Good	90	Good
6	8	Failed	62	Fair	68	Fair	68	Fair

Sample No.	Existing Condition		Maintenance Alternative 1		Maintenance Alternative 2		Maintenance Alternative 3	
	Case 1		Case 2		Case 3		Case 4	
	PCI	Rating	PCI	Rating	PCI	Rating	PCI	Rating
7	28	Very Poor	68	Fair	78	Satisfactory	78	Satisfactory
8	58	Fair	66	Fair	71	Satisfactory	71	Satisfactory
9	18	Serious	46	Poor	53	Fair	68	Fair
10	20	Serious	52	Poor	58	Fair	84	Satisfactory
11	44	Poor	44	Poor	48	Poor	82	Satisfactory
12	50	Poor	56	Fair	66	Fair	75	Satisfactory
13	43	Poor	54	Poor	56	Fair	84	Satisfactory
14	57	Fair	66	Fair	82	Satisfactory	82	Satisfactory
15	10	Failed	25	Serious	30	Very Poor	91	Good
16	32	Very Poor	52	Poor	58	Fair	76	Satisfactory
17	14	Serious	48	Poor	51	Poor	80	Satisfactory
18	44	Poor	46	Poor	50	Poor	79	Satisfactory
19	41	Poor	52	Poor	60	Fair	83	Satisfactory
20	44	Poor	56	Fair	62	Fair	90	Good
21	59	Fair	64	Fair	78	Satisfactory	82	Satisfactory
22	48	Poor	68	Fair	86	Good	86	Good
Road Condition	35.9	Very Poor	55.8	Fair	63.7	Fair	80.5	Satisfactory

Table (9)

Frequency of distress on Aborshada Road pavement.

No. Of Pavement Distress	13	10	1	3	7	6	18	9	Other Distress
Percent of samples	95	90	81	81	68	18	9	5	0

In this study, Aborshada road maintenance works are based on the type and extent of the most common distress found on the pavement surface. The frequency of pavement distress numbers were 13, 10, 1, 3, 7, 6, 18 and 9 in descending percent order as showed in Table 9. The major outcome of any pavement treatment program is to identify the best treatment for the sections in need of treatment. Also, Pavement distresses govern the choice of the best treatment based on their types and severity.

Pavement performance is determined by both distress degree and distress extent. So, distress types and degree should be considered in determining road work activities, and performing project level analysis. Maintenance alternative

No. 1, eliminate pavement distress no. 13 “potholes”, the road condition changed from very poor (35.9) to fair (55.8). Maintenance alternative No. 2, eliminate pavement distresses no. 13 “potholes” and no. 10 “long. & trans. Cracking” , the road condition scale raise from 55.8 to 63.7 but rating not changed. Maintenance alternative no. 3, eliminate pavement distresses no. 13 , 10 and 1 “alligator cracking” the road condition changed from fair with rating 63.7 to became satisfactory condition with rating 80.5.

3. Conclusions and Recommendations:

The major outcome of any pavement treatment program is to identify the best treatment for the sections in need of treatment. Pavement distresses govern the choice of the best treatment based on their types and severity. The outcome of this work is a practical output of application ASTM-D6433-07 for pavement condition evaluation of Aborshada road in Gharian area. and determination of the optimum maintenance works needed to raise of the pavement condition. The existing road condition PCI was 35.9 and rating was very poor. Also, Specific conclusions can be drawn as under, based on observation. **The most commun pavement distresses were the following:**

1. Potholes was observed throughout the length of samples with high, meduim and low severity.

2. Long. & Transverse cracking was observed throughout the length of samples with high, meduim and low severity.

3. Alligator cracking was observed throughout the length of samples with high, meduim and low severity.

Distress-by-Distress repair for the most common pavement distress in the Aborshada road. This study showed that the best maintenance alternative for Aborshada road was the case No. 4 (Potholes, Long. & Trans. Cracking and Alligator Crack Maintenance) which road condition became satisfactory condition (80.5). Based on the above findings, **the following may be recommended to be considered in highway agency :**

1. Using automated survey techniques to reduce labor needs and increase safety of any personnel (in-house or contractor) that may conduct the surveys.

2. Libyan Highway agency must take in its consideration maintenance by contracts.

3. The evaluation of pavement condition before and after maintenance by contract should be performed by a team of well experienced engineers.

4. Time of applying maintenance is an important factor in the quality of the obtained results, thus it is important that routine maintenance should always be performed before any pavement section reaches a poor condition.

References:

1. Youssef M.A, and Essam A.S "A Two Fold Optimization System for Highway Maintenance Fund Allocation", 5th International Conference on Manging Pavements, August, 2001, Seattle, Washington. ISBN 0971174016.

2. Shahin, M. Y., and S. D. Kohn, "Development of a Pavement Condition Rating Procedure for Roads, Streets, and Parking Lots," Technical Report M-268, U.S. Army Construction Engineering Research Laboratory, Champaign, IL, 1979.

3. Athanassios Papagiannakis, Nasir Gharaibeh, Jose Weissmann, and Andrew Wimsatt "Evaluation and Development of Pavement Scores, Performance Models and Needs Estimates" Report No. FHWA/TX-09/0-6386-1, Report Date January 2009 , Published: February 2009.

4. Samer Dessouky, Paul Krugler, A.T. Papagiannakis and Tom Freeman "Review Of Best Practices For The Selection Of Rehab And Preventive Maintenance Projects: Technical Report" Report No. FHWA/TX-11/0-6586-1, Report Date Published: April 2011.

5. Khaled Salah Mansour "GIS Implementation in Operation and Maintenance Dept. Jeddah Municipality, Saudi Arabia, The First National GIS Symposium in Saudi Arabia, 28th July 2005.

6. Reza F., Boriboonsomsin K., and Bazlamit S. "Development of a Pavement Quality Index for the State of Ohio" Paper for 85th Annual Meeting of The Transportation Research Board Washington, D.C. January 2006.

7. American Society of Testing and Materials (ASTM). 1999. Standard Practice for Roads and Parking Lots Pavement Condition Index Surveys. ASTM D6433-99. American Society of Testing and Materials, West Conshocken, PA.

8. Angela W., Max G., Kathryn Z. and John C. "Distress Collection for the City of Philadelphia with an Emphasis on Assessing the Impact of Utility Patching on the Network" September 1, 2002, http://pms.nevadadot.com/2002.asp