International Journal of Construction Engineering and Planning
ISSN-2456-2335(online)
Vol. 1: Issue 1
www.journalspub.com

Using Pavement Automated Monitoring System in Prioritization of Maintenance Decisions

Ibrahim Abed Mohammed[1], Saad Issa Sarsam[2]*, Abbas M. Burhan[2]
[1]Department of Building and Construction, University of Technology, Baghdad, Iraq
[2]Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

Abstract

The road transportation system greatly affects the development of economy and social activities for the country. However, pavement maintenance and rehabilitation may be extremely costly and require a lot of funds and resources. Therefore, it is essential to spend these funds in an optimal way. In recent years, the major challenge that have faced most of highway management agencies in Iraq is how to preserve the road network at an acceptable level of serviceability because of the limitations in the allocated budget for pavement maintenance works, the external interferences in the process of decision making, and absence of the effective decision making tools. Maintenance and rehabilitation of highway networks have become a central issue in most of highway agencies due to scare funding coupled with rapid increase in the total length of network. The research presents developing a mathematical model using a prioritization technique to prioritize the pavement maintenance works. The developed model, which is named RMPI (Road Maintenance Priority Index), aims to help the decision makers in making effective decisions for the selection of roads that should be maintained firstly according to the allocated budget.

Keywords: *Pavement maintenance management, prioritization method, priority index, budget, decision*

****Author for Correspondence:*** *Email ID: saadisasarsam@coeng.uobaghdad.edu.iq*

INTRODUCTION

The traditional method in determining the priorities of highway maintenance is by identifying all roads, which need maintenance work, then identifying the road that firstly will be maintained, and then identifying the next road and so on, according to the percent of deterioration in each road, the available funds, and the judgment of highways management. The result is preparing a list containing all roads that needed maintenance work and ranked according to their priorities. External interference may affect this list. Somewhat, this method may be acceptable when the road network is small and the available budget is sufficient for all roads that needed maintenance works[1,2]. However, when the roads network is huge and the budget is limited, this traditional manner is considered unsuccessful and the manager of roads maintenance finds himself in front of the reality of the impossibility of implementation of the maintenance works for all roads.

Statues of Pavement Maintenance in Iraq

Most of roadway network in Iraq were not monitored effectively by the relevant government agencies, which are responsible for monitoring, maintenance, and managing these roads. Therefore, most of these roads are not maintained in

regular manner or even no maintenance actions are implemented for some roads. For this cause and the limitations of yearly budget allocated to pavement maintenance, a large number of roads in Iraq are in a bad condition. The State Commission for Roads and Bridges (SCRB) confirmed in the yearly report that 80% of the existing roads were in a bad condition and needed maintenance actions[3]. Abdul Hameed stated that the strategies of pavement maintenance in Iraq lack the following[4]:

1. Technology such as using computer.
2. Applying the new methods and procedures in planning and decision-making.
3. Increasing funding requirements. A study conducted by the Ministry of Planning 1991 on the technical and economical evaluation of roads maintenance in the country showed that Iraq spent on road maintenance for every 1 km length of the pavement about 34% of the funds spent in Jordan, 10.1% spent in Saudi Arabia, 17.1% spent in Syria, and 11.1% spent in Yemen.
4. Preparing future maintenance plans, while routine maintenance is not applied on scientific bases but it is usually applied every five years.

Problems of Pavement Management in Iraq

In addition to the above points, the government agencies of pavement management in Iraq lack the scientific bases on which roadways managers must depend in making the important decisions concerning which road must be maintained first according to the available fund. In addition, there is no efficient procedure to collect data related to pavement condition, nor even a database for highways networks. For example, the department of planning and monitoring in the SCRB in each governorate prepares an annual report about the statues of roads within the governorate. Then, the worst condition road will be selected and the department presents a request for Ministry of Construction and Housing (MCH)/SCRB to insert the selected road in the annual budget of maintenance works. The selection process of worst condition road(s) is accomplished by a visual inspection by the engineer of planning and monitoring department without adopting the scientific procedures used in PMMS (personal interviews).

PRIORITIZATION METHOD

Prioritization is a procedure whereby an individual or group presents a number of items in rank order according to their perceived or measured significance or importance. Prioritizing issues is a significant process that helps an organization detects the issues on which it should focus its limited resources[5]. Prioritization is essentially executed in a sequential manner by first enlisting all pavement maintenance projects needed to be executed. The next step is to prioritize these projects according to their relative perceived urgency of requirements for repair. The projects with the highest priority are executed firstly until all the finances are expended. Then, reprioritization process is done for any projects left together with the new projects upon funds allocated.

A common practice is to rank all projects and treat those sections or roads in the worst condition first irrespective of the outcome on the network-wide pavement condition or maintenance cost. Such approach is well known as "Worst-first" ranking approach. This approach seems to be reasonable in a sense that the worst condition pavements will give the highest user cost, and the most grumbles from the users of road. However, it fails to calculate the level of change in the value of benefit for the funds expended[6]. Highways needs for maintenance and rehabilitation are related to the budget. Therefore, there are three situations for maintenance:

1. The maintenance requirements match the budget.
2. The maintenance requirements are less than the budget.
3. The maintenance requirements exceed the budget.

If the maintenance requirements match or are less than the available budget, there is no problem, but the problem usually occurs when the maintenance requirements exceed the budget. Therefore, a ranking procedure for roads wanted maintenance is required to decide which sections or roads are maintained firstly and which of them should be delayed to the next years. For efficient ranking procedure, many factors should be considered which might affect the decision of pavement maintenance. This paper takes into account six factors in developing the priority model. These factors are pavement condition, security and stability of region, maintenance cost, traffic load, road class, and the importance to community. These factors can be divided into two types: quantitative and qualitative factors. Quantitative factor has a numerical value such as pavement condition, maintenance cost, and traffic load. While, qualitative factor is a legal factor that does not have a numerical value directly, but it significantly affects the decision of pavement maintenance such as road class, security and stability, and the importance to community.

Factors Affecting the Decision of Pavement Maintenance Priority

Many factors that affect the decision of pavement maintenance are assumed in this paper. These factors may be considered partially or fully by the decision-makers to take the decisions about which roads must be maintained firstly according to the budget available. These factors include:

1. Pavement condition factor (PCF).
2. Traffic load factor (TF).
3. Maintenance cost factor (MCF).
4. Road class factor (RCF).
5. Importance to community factor (IF).
6. Security and stability factor (SF).

Iraqi companies suffer from an additional negative factor that significantly influences the decision of pavement maintenance. This factor is known as "External Interference". Therefore, the developed prioritization model will take into account the six factors mentioned earlier to assist the decision-makers in overcoming the problem of decisions making according to bad considerations resulted from the external interferences.

Model Definition

In this paper, the pavement maintenance priority-ranking model was developed using a composite priority index method. As principle, the priority index will be composed consisting of six influence factors. These factors will affect significantly the decision of pavement maintenance. One appropriate quantifiable indicator represents each factor for which reliable and comparable data are available. The general form of the composite index is:

$$PI=\sum F_i W_i \quad \text{Eq. (1)}$$

Where:

PI = priority index.

F_i = the value of factor (i) that affect the priority decision.

W_i = a weight represents the importance level of factor (i).

$\sum W_i = 1$.

According to the six factors proposed in this paper, the suggested pavement maintenance priority-model will be as follows:

$$RMPI=(PCF*W1)+(TF*W2)+(MCF*W3)+(RCF*W4)+(IF*W5)+(SF*W6) \quad \text{Eq. (2)}$$

Where:

RMPI = road maintenance priority index,

PCF = pavement condition factor,

TF = traffic load factor,

MCF = maintenance cost factor,
RCF = road class factor,
IF = importance to community factor,
SF = security and stability factor,
W1, W2, W3, W4, W5, W6 = weights that represented the importance level of factors, since, $\sum Wi = 1.0$.

Pavement Condition Factor (PCF)

One of many indices represents pavement condition; the most common are PCI (Pavement Condition Index), PSI (Present Serviceability Index), and IRI (International Roughness Index). Where IRI is used, pavement condition will be proportional to priority decision, whereas the value of IRI increases the priority of maintenance increases as well and Eq. (3) will be used to identify pavement condition factor (PCF). However, using other indices such as PCI and PSI will make the relation between pavement condition and the priority decision to be inversely, whereas these values increase, the priority decreases and Eqs. (4) and (5) will be applied. Table 1 shows the proposed scales of PCI, PSI, and IRI.

PCF_{IRI}=IRI value Eq. (3)

PCF_{PCI}=100÷PCI value Eq. (4)

PCF_{PSI}=1÷PSI value Eq. (5)

Table 1: *The Proposed Scales of Pavement Condition Indices.*

Pavement Condition	Proposed Ranges of Indices		
	PCI	PSI	IRI (m/km)
Excellent	100–90	5–4	0–1
Good	90–70	4–3	1–1.5
Fair	70–55	3–2	1.5–2
Poor	55–25	2–1	2 - 2.5
Very poor	25–0	1–0	>2.5

Traffic Load Factor (TF)

Traffic load is one of the major causes of pavement deterioration. Traffic loads mainly generate load-associated distresses, such as alligator cracking, and rutting. Traffic load is expressed by average daily traffic (ADT), and has a significant effect on determining the priority index of pavement maintenance for different roads or sections. Traffic factor (TF) is related to the value of ADT. Some researchers such as Ramadhan and Stevens, suggested values for TF equivalent to each range of ADT[7,8]; as shown in Table 2. In this paper, TF values are assumed to be scaled from 0.0 to 1.0 scale to facilitate the priority index calculations. To obtain this scale, ADT is normalized to 1.0 using the following equation:

$$TF_i = \frac{ADT}{Max.ADT} \quad \text{Eq. (6)}$$

Where:
TF_i = Traffic load factor for section *i*.
ADT_i = Average daily traffic for section *i.*
Max.ADT = Maximum measured ADT for the sections of road understudy.

Table 2: *Values for Traffic Load Factor[7].*

ADT Range	Traffic Factor
0–99	10
100–499	20
500–999	30
1000–1999	40
2000–4999	50
>5000	100

Maintenance Cost Factor (MCF)

Overall maintenance cost is the total cost of every maintenance cost action needed for the pavement section under consideration. This cost includes the preparation of the defective locations, the cost of material to be used in the repair, the cost of man power and equipment used in executing the repair, and any additional cost needed such as traffic detouring. Usually, maintenance contractors specify a unit cost for each maintenance and repair activity. The cost of any repair activity (slurry seal, for example) has a direct effect on the priority ranking[7]. Depending on the funds allocated for pavement maintenance, if the maintenance cost is small, there are two viewpoints. The first is that the maintenance work can be postponed to later stage, and the second is that the maintenance work can be executed directly. The researcher agrees with the second opinion because whenever the maintenance cost is lower, there will be

possibility to execute the maintenance procedures easily. So, if maintenance cost factor (MCF) is considered alone to identify the maintenance priorities, then the roads or sections will be ranked in ascending order from lower cost to higher cost. Maintenance cost factor can be computed using the following equation:

$$MCF=\frac{1}{MC} \quad \text{Eq. (7)}$$

Where:

MC = maintenance cost ($/m^2).

Road Class Factor (RCF)

The classification of roads has a significant impact on the decision of maintenance work. Major roads are considered more important than a small street within a district serving number of homes. Garber and Hoel stated that highways are classified according to their functions in terms of the service they provide[9]. The classification system facilitates a systematic development of highways and the logical assignment of highway responsibilities among different jurisdictions. Highways and streets are categorized as rural or urban roads, depending on the area in which they are located. This initial classification is necessary because urban and rural areas have significantly different characteristics with respect to the type of land use and population density, which in turn influences travel patterns. Within the classification of urban and rural, urban roadway network is categorized into principal arterials, minor arterials, major collectors, minor collectors, local roads and streets.

Freeways are not listed as a separate functional class since they are generally classified as part of the principal arterial system. However, they have unique geometric criteria that require special design consideration. For the purposes of developing the prioritization model, the classification that is depended on in this paper is by dividing urban network into three major classes: arterial, collector, and local. Since the road class factor (RCF) is a qualitative factor that does not have a numerical value, so a numerical value is assumed for each class. Roadway classification and suggested values for road class factor (RCF) are described in Table 3.

Table 3: *Functional Classification System and Suggested Values for PCF.*

Road Class	Service Provided	RCF
Arterial	It provides the highest level of service at the greatest speed for the longest uninterrupted distance, with some degree of access control.	(3/3) 1.0
Collector	It provides a less highly level of service at a lesser speed for smaller distance by gathering traffic from local roads and linking them with arterial road.	(2/3) 0.67
Local	It consists of all roads not defined as arterial or collector; it mainly provides right of entry to land with slight or no through movement.	(1/3) 0.33

Importance to Community Factor (IF)

The importance to community can be identified by the following considerations:

1. Road type, whether the road is arterial, collector, commercial, or residential. For example, local roads may have lower importance than arterial roads and commercial roads have more importance than residential roads.
2. The nearness of road from central business district or the market area where most of people activities are located.
3. If the road passes through government compounds, or it is used by VIPs.
4. Availability of alternative roads for the road under consideration at times of maintenance work.

5. The distance of road from important strategy places such as police stations, civil defense, hospitals, schools, universities, airports, etc.

As road class factor, the importance factor (IF) does not have a numerical value. In this paper, the importance of road is divided into three levels (high, middle, and low) and a numerical value is assumed for each level as shown in Table 4.

Table 4: *Recommended Values for Road Importance Factor (IF).*

Importance Level	IF
High	(3/3) 1.0
Middle	(2/3) 0.67
Low	(1/3) 0.33

Security and Stability Factor (SF)

The security and stability of the area through which the road passes significantly affects all maintenance activities, starting from the stage of survey and data collection until the implementation of maintenance work. Also, security and stability factor (SF) does not have a numerical value. In this paper, this factor is divided into three levels (good, middle, and bad) and a numerical value is suggested for each level as shown in Table 5.

Table 5: *Recommended Values for Security and Stability Factor (SF).*

Security and Stability Level	SF
Good	(3/3) 1.0
Middle	(2/3) 0.67
Bad	(1/3) 0.33

DETERMINATION OF FACTORS WEIGHTS

After identifying the factors affecting the decision of pavement maintenance, a weight must be given for each factor, which will represent the importance of this factor for maintenance priorities. Factor weights can be identified depending on the opinions of specialists in the subject of pavement maintenance and highways engineering. So, personal interviews and closed questionnaire process was conducted and a sample of respondents was selected for this purpose. This sample consists of academicians, senior engineers, managers, and experts. Most of them have a wide experience in the subject of pavement maintenance and roads reconstruction projects.

Personal Interviews

In this stage, the researcher conducted many of personal interviews with many senior engineers who have experience in the field of roads maintenance and rehabilitation. About 15 senior engineers were selected to be interviewed. Those engineers were from academics in the colleges of engineering, top project managers, and senior engineers working in the State Commission for Roads and Bridges (SCRB) and Mayoralty of Baghdad. Most of them had 10 years or more of experience in the field of pavement maintenance.

A group of questions was prepared for the personal interviews relating to the following issues:

1. The government agency that is responsible for carrying out the maintenance work in Iraq.
2. Common maintenance work in Iraq.
3. The implementation of PMMS in Iraq.
4. The annual Budget allocated for pavement maintenance work.
5. The cost of road maintenance treatments in Iraq.
6. Roads classification in Iraq.
7. The process of selection the road to implement maintenance activities according to the available funds.
8. Is there a data base for road in Iraq?
9. Is there a systematic procedure to give a priority index for each road needed maintenance work?
10. The level of pavement monitoring and maintenance in Iraq.

Discussion of the Results of Personal Interviews

The results of personal interviews can be summarized as follows:

Regarding which government agency is responsible for carrying out the maintenance work in Iraq, the results showed that the responsibility is shared between all of Mayoralty of Baghdad, municipalities, and the States Commission for Roads and Bridges (SCRB). Mayoralty of Baghdad is responsible for the main roads inside Baghdad city; while, all roads and streets inside local or residential areas are under responsibility of the municipalities. Elsewhere, all highways such as bridges, interchanges, freeways and expressways in all Iraqi governorates are under the responsibility of the State Commission for Roads and Bridges (SCRB)/Ministry of Construction and Housing (MCH).

Regarding the common maintenance work in Iraq, the results showed that the milling of the deteriorated pavement surface layer with a given thickness and making overlay strategy comes in the first order and is common in most of pavement maintenance projects. Other maintenance strategies come in the second order such as crack treatment, patching, and walkways maintenance. Also, the results showed that routine and periodic maintenance works are rarely applied in Iraq, and all agencies preferred the corrective maintenance because of the limitations in the available resources. Regarding the implementation of PMMS in Iraq, the results showed that this system is not applied in Iraq and all maintenance work is accomplished according to a subjective judgment or external interferences without any previous planning and modern technologies. Regarding the annual budget allocated for pavement maintenance work, the respondents confirmed that the allocated funds for pavement maintenance work are not enough to maintain all roads that needed maintenance. Some of them believe that the allocated funds for maintenance work do not cover 10% of the actual need. Regarding the maintenance costs in Iraq, the results, based on documents provided by some of the respondents, stated that the maintenance costs vary from one project to another depending on its location and its nature. Generally, some of local maintenance costs can be summarized in Table 6.

Table 6: *Some of Pavement Maintenance Costs (SCRB).*

Maintenance Strategy	Maintenance Cost
Crack treatment	0.5–1 $/m
Milling	2–3 $/m^2
Patching thickness 50–120 mm	10–15 $/m^2
Hot mix overlay	1–2 $/m^2
Shoulder maintenance	1–2 $/m

Regarding road classification in Iraq, some of respondents classified roads into two classes (rural and urban), since they stated that urban roads include freeway, arterial, ring road, collector, and residential or local roads; while, rural roads include expressway, highway, and ring roads. Most of respondents pointed to the functional classification of AASHTO, which classifies roads into three classes: arterial, collector, and local. Regarding the selection process of road to implement maintenance work according to the available funds, the respondents confirmed that there is no systematic process adopted in Iraq to select a specific road that needed maintenance work. Since the maintenance department in the responsible agency in each governorate makes a visual inspection for all roads and selects the worst, then, a report will be prepared to introduce it to the responsible government agency such as the State Commission for Roads and Bridges (SCRB) to enter the selected road(s) in the annual maintenance

plan. Regarding the question "is there a data base for roads in Iraq", the results showed that there is not any database for Iraqi roads, and any current data related to the roads and bridges are documented as hard copies. Some of respondents stated the disadvantages of hard copy documents, since most of documents related to Iraqi roads and bridges were subject to damage and burn during the 2003 crises in Iraq.

Regarding the question "is there a systematic procedure in Iraq to give a priority index for each road needed maintenance work", the results showed that there is no scientific procedure for this purpose. Usually the roads are selected to implement maintenance work according to a visual inspection performed by the engineer of responsible agency without adopting the scientific procedure of PMMS. In addition, road maintenance is sometimes performed according to external interferences or administrative corruption. Regarding the level of pavement monitoring and maintenance in Iraq, the opinions of respondents were that the level of monitoring is bad and the maintenance work is not at the required level because of high percent of deteriorated roads and insufficient allocated funds.

Closed Questionnaire Stage

In this stage, a questionnaire was conducted; the main objective was to determine the weighted values of priority factors that were assumed by the researcher to develop the prioritization model. Sixty questionnaire forms have been distributed, but only 43 forms were received, which represent 71.7% as response rate. This sample size is adequate to achieve the required objectives and will be adopted as a basis for the statistical analysis. All of closed questionnaire forms were distributed on respondents working in the field of highways and transportation engineering; most of them were from the state sector.

The results for the statistical analysis of answers are shown in Table 7. It is obvious that the importance to community factor (IF) is produced from six sub-factors which are assumed by the researchers. Therefore, the weighted average (WA) of this factor is equal to the average of weighted averages for its sub-factors. In addition, it is obvious that only six factors are considered when developing the prioritization model. These factors are SF, PCF, MCF, RCF, TF, and IF. External interferences factor is not considered and it's found in the questionnaire process was for showing the agreement level of respondents with the negative effect of this factor on the process of pavement maintenance decision. The results showed that the external interferences play sometimes an effective role in the execution of maintenance work on a road that has a priority index lesser than other roads that needed maintenance.

By applying Eq. (2), the prioritization model will be:

$$RMPI=0.19\,SF+0.19\,PCF+0.15\,MCF+0.16\,TF+0.16\,RCF+0.15\,IF \quad \text{Eq. (8)}$$

In addition, the results of closed questionnaire process showed that most of respondents agree with the priority factors assumed by the researchers. They confirmed that there are no other factor affects the decision-making process of pavement maintenance.

APPLICATION OF PRIORITIZATION MODEL

Application of the proposed model will be done by using the case study of expressway no. 1 in Iraq to test the efficiency and the effectiveness of the model. The application is done by dividing expressway no.1 into four sections as follows:

(Baghdad–Basrah–Safwan), (Safwan–Basrah–Baghdad), (Baghdad–Al-Walid–Treibil), (Treibil–Al-Walid–Baghdad).

Table 7: *The Results and Statistical Analysis for the Answers of Closed Questionnaire Process.*

I	Effective Factors (Fi)	No. of Frequencies					Weighted Average WAi	Factor Weight Wi
		Always	Often	Neutral	Low	No effect		
1	SF	35	3	4	1	0	83.49	0.19
2	PCF	26	17	0	0	0	82.09	0.19
3	MCF	10	20	9	3	1	66.28	0.15
4	TF	18	15	7	2	1	71.86	0.16
5	RCF	12	21	8	2	0	70	0.16
6	IF						65.81	0.15
6–1	Road type	10	21	9	0	3	66.28	
6–2	Nearest from market and work places	11	15	12	1	4	63.02	
6–3	Founding alternative roads	10	19	8	3	3	63.95	
6–4	The road passes through government buildings	10	14	11	4	4	60.23	
6–5	The road is used by VIPs	18	13	5	1	6	66.74	
6–6	The road passes through important places	19	19	2	2	1	74.65	
The sum of weighted averages for the sub-factors of importance to community factor (IF)							394.87	
The sum of weighted average for the considered six factors							439.53	
The sum of factors weights								1.0

Course visual inspection technique of the pavement-surface condition has been implemented for both directions along the entire project length. Such assessment was performed by Consolidated Consultants (CC) Company, in order to record the observed surface distresses on the laser profiler laptop computer using the pre-assigned function keys, therefore, the corresponding function key for each type of distress was pressed when observing a particular distress during the roughness measured survey.

The Consolidated Consultants (CC) Company used Australian Road Research Board (ARRB) laser profiler technology as shown in Figure 1 in the survey process to obtain roughness Index and texture depth of the expressway no.1 road. The used laser profiler model is Hawkeye 1000 DUO. The system is a portable road and asset information-collection system, consisting of an accuracy laser profiler, combined with a high-resolution camera.

The laser profiler is a World Bank Class 1 profiler, consisting of precision laser sensor and accelerometer that is used to compensate for vehicle body movement.

The survey process was carried out during the period from September 17 to September 20, 21012, along the total length of the project. The existing road was divided into four sections, Section1: (Baghdad–Basrah–Safwan), Section2: (Safwan–Basrah–Baghdad), Section3: (Baghdad–Al-Walid–Treibil) and Section4: (Treibil–Al-Walid–Baghdad).

The system is equipped with an accurate distance measuring instrument (DMI) and heartbeat module that are used to precisely link the collected data to distance. The observed distresses included bleeding, rutting, longitudinal and transverse cracks, weathering and raveling, patching, potholes, depressions, and bumps and sags.

Fig. 1: *Australian Road Research Board (ARRB) Laser Profiler Technology.*

The next step of model application is determining the factors that affect the process of pavement maintenance decision-making for each project or section. The values of effective factors are summarized as follows:

Security and Stability Factor

This factor significantly affects the process of pavement maintenance. Because of the nature of expressway no.1 represented by its long distance (about 1200 km) and passing through many governorates and regions in Iraq, the security and stability factor (SF) is variable from region to region. In this research, it is assumed that the security and stability of (Baghdad–Safwan) road is better than (Baghdad–Treibil) road, because the last one passes through an area (Al-Anbar governorate) with security problem. Therefore, it is assumed that the value of SF for (Baghdad–Safwan) sections equals 1.0 (i.e. good) and for (Baghdad–Treibil) sections, it equals 0.33 (i.e. low).

Pavement Condition Factor (PCF)

The international roughness index (IRI) was used to determine the condition of pavement for expressway no.1. Table 8 shows the values of IRI for the four sections understudy.

It is obvious from the field survey results that pavement condition of (Baghdad–Al-Walid–Treibil) road is better than (Baghdad–Basrah–Safwan) road. This may increase the maintenance priority for (Baghdad–Basrah–Safwan) Sections.

Table 8: *The Average of IRI Values for the Four Sections of Expressway No.1.*

Sections	IRI Values
Baghdad–Basrah–Safwan	1.53
Safwan–Basrah–Baghdad	1.70
Baghdad–Al-Walid–Treibil	1.37
Treibil–Al-Walid–Baghdad	1.45

Maintenance Cost Factor (MCF)

The value of MCF depends on knowing the required quantities of maintenance activities. Then a qualified contractor is required to execute these activities versus a price per kilometer for each maintenance strategy. Table 9 shows the estimated required quantities and maintenance cost for each recommended strategy and for each kilometer length of expressway no.1. The information in Table 9 indicates that (Baghdad–Al-Walid–Treibil) section is the most expensive one despite its pavement condition is the best. While, (Baghdad–Basrah–Safwan) section is the least cost in spite of the high level of its deterioration. This indicates that most the maintenance cost does not necessarily depend on the deterioration level of pavement condition, but it depends on many things such as types and quantities of distresses.

Traffic Load Factor (TF)

Traffic load is one of the major causes of pavement deterioration. Traffic loads mainly generate load-associated distresses such as alligator cracking, and rutting. These distresses usually have the highest deduct points in any pavement condition-rating method. For planning purposes such as priority ranking process, traffic volume as measured in average daily traffic (ADT) plays an important role in determining the priority index of different pavement sections. This factor determines how much the road section is utilized by the community. For expressway no.1 case study, the State Commission for Roads and Bridges (SCRB) accomplished a traffic

count in order to estimate the average daily traffic (ADT) for the four sections of road. Table 10 shows the (ADT) and Traffic factor (TF) values computed based on Eq. (6) for the four sections of expressway no.1.

Table 9: *Estimated Required Quantities and Maintenance Cost for Expressway No.1.*

Maintenance Procedure	Length of Road in Kilometers				Maintenance Cost ($/km)
	Baghdad–Basrah–Safwan	Safwan–Basrah–Baghdad	Baghdad–Al-Walid–Treibil	Treibil–Al-Walid–Baghdad	
Patching	0.5	2.5	-	-	10000
Crack filling	14	17	20	15	750
Milling and repaving	26	53	58.5	64.5	2500
Surface treatment	38	36	47.5	40	7000
Filling and compaction	-	-	0.5	-	510
Total maintenance cost ($)	346500	422250	494005	452500	
Total length (km)	520	520	486	486	
Maintenance cost $/km	666.35	810	1016.5	931	
MCF	1.50	1.23	0.98	1.07	

Table 10: *The Average Daily Traffic (ADT) for Expressway No.1.*

Sections	ADT	TF
Baghdad–Al-Walid–Treibil	12427	0.85
Treibil–Al-Walid–Baghdad	14313	0.98
Baghdad–Basrah–Safwan	14566	1.0
Safwan–Basrah–Baghdad	13154	0.90

Road Class Factor (RCF)

As previously mentioned in this chapter, there are three functional classifications for roads: arterial, collector, and local. All streets and highways are grouped into one of these classes depending on the character of the traffic and the amount of land access that they allow. Expressway no.1 is classified as arterial road, so RCF for all of its sections equals 1.0 according to Table 3.

Importance to Community Factor (IF)

The road importance factor (IF) is related to sub-factors which were mentioned previously in this chapter. Expressway no.1 has the most importance to community because of its nature represented by linking the countries of Eastern Mediterranean Sea to Arab Gulf States, in addition to linking the country's governorates, western and central to southern. In addition, this road can be considered as a commercial road because most of traders and institutions of government commerce use this road to import and export the goods. Therefore, the value of IF for all sections equals 1.0. After the values of all effective factors are identified, the decision-maker can apply road maintenance priority index (RMPI) Eq. (8) for each section of the road understudy. Table 11 shows the values of effective factors and RMPI for the four sections of expressway no.1. The final result of RMPI application is a list that contains all sections that needed maintenance work ranked in descending order from the higher priority to lower priority as shown in Table 12.

Table 11: *The Values of Effective Factors and RMPI for the Sections of Expressway No.1.*

Sections	Effective Factors						RMPI
	SF	PCF	MCF	TF	RCF	IF	
Baghdad–Al-Walid–Treibil	0.3	1.37	0.98	0.85	1.0	1.0	0.91
Treibil–Al-Walid–Baghdad	0.3	1.47	1.07	0.98	1.0	1.0	0.96
Baghdad–Basrah–Safwan	1.0	1.53	1.50	1.0	1.0	1.0	1.17
Safwan–Basrah–Baghdad	1.0	1.70	1.23	0.90	1.0	1.0	1.15

Table 12: *The Four Sections of Expressway No.1 Ranked According to RMPI.*

i	Sections	RMPI	Maintenance cost ($)
1	Baghdad–Basrah–Safwan	1.17	346500
2	Safwan–Basrah–Baghdad	1.15	422250
3	Baghdad–Al-Walid–Treibil	0.96	452500
4	Treibil–Al-Walid–Baghdad	0.91	494005

Because of the limitation in the budget allocated for pavement maintenance work, which may lead to not executing all sections that need maintenance in the same year, the decision-maker needs a methodology to support his decision about which road or section must be maintained firstly. Therefore, a table must be prepare listing all roads or sections that need maintenance in a descending order. Using the developed priority model (RMPI) will provide a suitable methodology for decision-makers to implement the maintenance work on the appropriate roads. However, sometimes and because of budget limitations, the decision-maker faces a challenge when amount of money will be available but not enough for applying the maintenance works on all parts of a specific road. For example, if the available budget to maintain expressway no.1 is 1.0 million dollar, RMPI model will rank the four sections of expressway no.1 according their priority index as shown in Table 12. Therefore, the available budget will be enough for maintaining (Baghdad-Basrah-Safwan) and (Safwan-Basrah-Baghdad) sections whose maintenance cost is $ 768750 (346500+422250). The remaining money from the available budget is $ 231250, which will put the decision-maker in a challenge of how to use this remaining money. This research proposes a way to overcome this challenge by dividing the road under consideration into sub-sections and then the maintenance cost, and the benefits resulted from the maintenance work should be determined. Then, Benefit/Cost (B/C) method is applied. B/C method is based on calculating B/C ratio for each section. This ratio results from a depth analysis for costs and benefits for road sections due to implementing the maintenance work. The cost is determined by calculating all costs related to pavement maintenance. While, the benefits are determined by some of terms such as the savings in vehicle operating costs, the extension in the expected life of pavement, and the jump of pavement condition.

CONCLUSIONS

The main goal of this paper is to develop a prioritization model for roads maintenance decision making which will assist the decision makers in Iraq to overcome the problem of external interferences and to give effective decisions about which roads must be maintained firstly according to the limitations in the budget allocated for maintenance works. Some conclusions resulted from accomplishing this paper can be summarized as follows:

1. Through conducting personal interviews with some decision makers in Iraqi companies, it is concluded that most highway networks in Iraq suffer deterioration because there is not an effective monitoring by the relevant

government agencies, which are responsible on managing these roads. In addition, the allocated funds for maintenance work do not cover 10% of the actual need.

2. There are many factors that may affect the decision making of pavement maintenance. These factors include pavement condition, security and stability, traffic load, road class, maintenance cost, and road importance to community. Iraqi companies suffer from an additional bad factor that significantly influences on the decision of pavement maintenance.
3. The developed prioritization model was built based on the current circumstances of Iraq. Therefore, the factors entered to the RMPI can be changed with regard to the changes in the future circumstances.
4. Through closed questionnaire process, it is concluded that pavement condition and stability and security factors have the highest importance weight from the other factors.

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