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A GIS-ENHANCED PAVEMENT MANAGEMENT SYSTEM: A CASE STUDY IN IRAQ

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Abstract

Pavement management system (PMS) is a valuable tool and one of the crucial elements of the highway transportation infrastructure with the main purpose of obtaining an optimum maintenance and rehabilitation process for a given road network. The last 10 years have witnessed a rapid increase in highway construction in Iraq reaching 2008 km in 2014, besides the large amount of funds being allocated to this sector. Based on the general characteristics and restricting environment of roads in Iraq and particularly in Babylon, a new GIS-enhanced pavement management system is presented. This GIS-enhanced PMS is integrated with life-cycle assessment and proposed to enhance the strategies and decision-making processes of pavement preservation. The proposed system provides a framework and a methodology to integrate life-cycle and surrounding conditions for developing a reliable pavement deterioration prediction model that can be used for maintenance priority and life-cycle cost analysis. This model introduces the involvement of information technology represented by GIS with pavement management system. This can be the first of its type management system that can be applied to Iraqi roads starting with Babylon city as a case study. It allows highway engineers and agencies make the future plans in accordance by obtaining an accurate data of roads conditions which lead to allocate the maintenance budge more accurately and prevent widespread deterioration of highway infrastructure.

Keywords: Deterioration model, GIS, Highway infrastructure, Life-cycle, Pavement management system.

1. Introduction

Pavement management system (PMS) is a valuable tool and one of the crucial elements of the highway transportation infrastructure [1] with the main purpose of obtaining an optimum maintenance and rehabilitation (M&R) process for a given road network. Proper management of the M&R process is necessary to ensure that communities can continue to prosper. Uddin et al. [2] explained infrastructure management as a system of planning, coordinating and programming of investments or expenditures on design, construction and maintenance of a facility. Highways are significant infrastructure components covering more than 50% of the total transportation infrastructure expenditures. Pavements are usually and most certainly the major load-carrying element of the highway system [3].

According to Highways and Bridges directorate of Babylon governorate, 400*109 Iraqi Dinars (IQD) ($34*105) were spent on maintenance and expansion of highways in the last 10 years. This cost affects every community in Babylon. This amount of money seems more than sufficient. However, not even 1% of this money was spent properly. This is because of many reasons, first is that there is not effective pavement management system with its inspection and deterioration models. Second, lack of engineering estimation of the maintenance cost. In addition, the roads are mostly deteriorated and reaching the state of major rehabilitation before considered for maintenance, which makes the cost higher. Fig. 1. shows the state of most roads in Babylon which were not been maintained until complete failure, which increase the cost of rehabilitation or major maintenance. With the instability of oil prices since 2014, it is more difficult to allocate enough budget for road maintenance. This should make the highway maintenance management a crucial task for highway agency in Iraq.

The aim of this paper is to explain the benefits of collecting roadway data and keeping a database for highway agencies in Iraq. Also, to present a maintenance plan that is essential to put in place to gather the data, analyse that data with feasible deterioration models, and then implement the plan. The procedure of the plan is to implement the maintenance using a GIS to track it with continuous visual and structural inspections.

Fig. 1. Sample of a road state without being maintained.

Road pavements start to degrade the moment they are placed and continues regardless of funding. However, proper maintenance could extend the life of

pavement and could save some finances required for full rehabilitation. Costs for maintenance are significantly different from that for construction of highways. The cost of maintaining a highway in a good condition is approximately $\$1.5/m^2$, while the cost of constructing a new road or major rehabilitation could be $\$80/m^2$ [4]. Most highway agencies in the world are now looking for new methods to reduce the money spent on pavement maintenance. Some studies are dealing with self-healed asphalt pavement in order to defer the routine maintenance [5, 6], which showed some improvements but needs lots of work and further investigation. The World Bank shows many activities that could be taken to maintain roads in a workable condition as shown in Fig. 2.

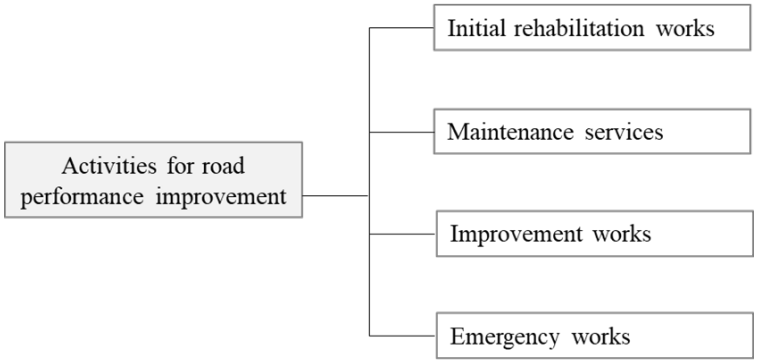

Fig. 2. Performance activities of roads based on contract services [4].

The earliest PMS concept can be traced back to the 1960s. Then, it developed to a working process in the 70s and progressed significantly for implementation in the 90s. Improvements in the application and implementation of the PMS should match the improvement of the PMS fundamental technologies, which could be a challenge [7]. The information technology [8, 9] and geographic information system (GIS) [10] have been integrated into PMS and implemented successfully to manage large scale roads. GIS is necessary to support decision-making processes related to road pavements by storing, retrieving, analysing and reporting the information required in that context.

Lee et al. [11] called the system of integrating GIS into PMS as a G-PMS. One of the main characteristics of a GIS system is that it can link data and information to its geographical location such as their latitude or longitude. Also, it can state plane coordinates instead of the reference-point system, which is traditionally used in transportation. The GIS technology can identify maintenance locations of highways as it can rapidly retrieve data from a database and automatically generate customized maps to meet specific needs. Additional information may include traffic volume, sign and signal locations, political and check points locations, population, weather data and any other data that could have an influence on road functioning [12]. Therefore, a GIS-enhanced PMS can functionally perform pavement management operations, create maps of pavement condition, provide cost analysis for the recommended maintenance strategies, and long-term pavement budget programming.

There are significant number of roads in Iraq need to be maintained and inspected periodically. And despite the development of information technology and specially

the GIS, many highway directorates as well as the leading highway agencies do not use GIS to track maintenance of roads. The reason could be a lack of resources or just not updating the knowledge of the different methods available to manage road maintenance. In this way, this paper presents a research effort undertaken to explore the applicability of GIS technology to managing pavement maintenance in Iraq, taking Babylon governorate as a case study, to better decide maintenance strategies, set rehabilitation priorities, and make investment decisions. This GIS improvement plan may help reduce road construction and maintenance costs.

2. Plan implementation

The GIS-enhanced PMS includes three basics elements: a database of the road network, pavement condition evaluation and the decision-making process (see Fig. 3). The database of the road network is crucial to include information on road geometry, designed and expected rate of traffic loadings, pavement deterioration rate, pavement maintenance and inspection history, and M&R costs. The pavement condition evaluation is based on the available database the road network, and particularly on the pavement condition data, which is used to calculate the pavement condition index (PCI) for the road segments in study. The values adopted by this index range from 1 to 5, where 1 refers to the best condition, and 5 is the worst condition. All these data are recorded and stored to represent each road segment. The main variables used to characterize pavement condition are cracking, rutting, potholes. In addition, another variable can be included, such as bleeding because it appears in some road sections in Iraq due to the hot weather in summer, which causes flow of asphalt. The decision-making process is aimed at selecting the optimum M&R actions to be applied to each segment in a priority process based on the condition records stored for each segment.

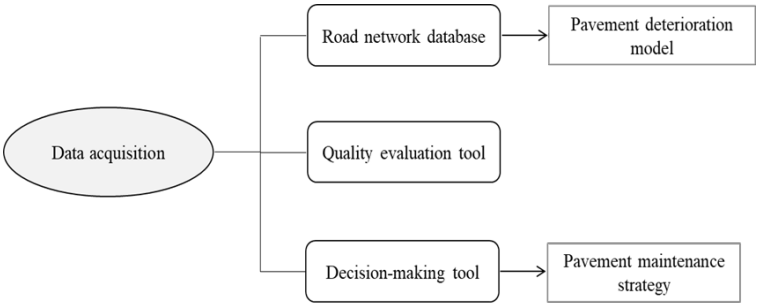

Fig. 3. Structure of the GIS-PMS model.

The model of pavement performance evaluation used in this research is a probabilistic (stochastic) model based on Markov chains [13]. The maintenance actions involved in the model are variable depending on the road class (functionally and physically). Those actions can be described as a function of temperature and traffic loads. Arizona PMS used this model. This aims at maximising the service quality and life with minimum expected cost of maintenance and rehabilitation [14]. Maintenance and deterioration data on road sections stored in or produced by this model can be monitored on a map. MATLAB codes are used to solve the differential equations representing the deterioration rate and maintenance effect. ArcGIS software [15] is used to perform advanced mapping operations (e.g., display a map

with multiple layers for the road sections, analyse or modify sections database as well as pan and zoom throughout a map. Furthermore, it can identify features on a map, and so forth. The GIS models help to estimate the M&R priorities which lead to effective maintenance system [16].

3. Comprehensive pavement condition inventory

The data collected are comprehensively focused on the pavement condition evaluation. The data collected as a PMS, which maintains a comprehensive inventory of the highway system in the study area. The data stored in the system consist of the pavement design data, deterioration rate, inspection periods, maintenance type and quality records. These details are crucial for providing an adequate pavement preservation. To support spatial and temporal analysis of the collected data, the PMS is enhanced with GIS technology to integrate the data spatially. To identify the location of any highway section in study, the direction of the road, number of lanes, and station are used for this purpose. With the aid of GIS, the PMS can make pavement distress and the corresponding maintenance at any specific location or traffic lane spatially examined.

4. Case study

The model performance is evaluated by applying it on some sections of highway network in the city of Babylon, its borders shown in Fig. 4. These sections of the highway network have a total length of 224km, consisting of about 1490 sections. For the consideration of long-term maintenance strategies for all the pavement sections in the road network, two different maintenance policies were considered:

- Policy 1: routine maintenance or corrective-preventive policy, which involves all possible ways of applying maintenance and rehabilitation operations. The number of applications should be limited to five performed operations for each highway section over the planned frame of time.
- Policy 2: policy of minimising total costs, which include agency costs, road user costs and pavement construction costs. This approach involves optimising the corrective–preventive maintenance.

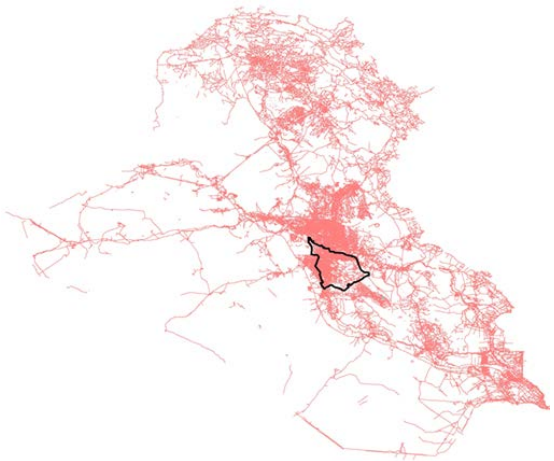

Fig. 4. Map of Iraq showing the city of Babylon in black border.

The objective to be achieved through these two policies is to minimise agency costs while keeping pavements in desired standards of quality. As well as to minimise total costs related to pavements while keeping it within good quality standards. All deterioration data and maintenance records are taken from Babylon highway directorate, which lacks too many records of maintenance and the level they keep the road section after application.

4.1. Network-level management

Network level management includes road segments that are put together in a GIS, which are used to investigate the road database. Management model for a network level is usually a representation of pavement sections. These sections usually have start and end points and the data for deterioration and maintenance records are referenced by these start and end points. Those sections who identifies the road network must have unique reference names and numbers in order to accurately identify each section's deterioration and priority for maintenance actions. Four scenarios are followed in this level as shown in Table 1.

Table 1. Description of network-level scenarios for road management.

Scenarios	Description
Network budget definition	The network budget can schematically be evaluated by the highway agency or engineer during tender preparation phase.
Sensitivity analysis	This gives the highway agencies and traffic engineers the authority to increase the level of service of each section to the design level, taking in consideration the cost of this increment.
Life-cycle cost minimisation	Maintenance contractors can implement the optimum maintenance strategy taking into consideration the improvements of level of service and the estimated cost of the highway construction.
Maintenance optimisation	This scenario is about achieving the required level of service for any road section with minimum effect on total life cycle cost of the road.

GIS technology is not included in data survey but to define directions and locations of sections. Furthermore, GIS technology might not be perfect in urban areas. Therefore, small road sections could be more effective and straightforward for management system. These road sections can be considered as survey units (road segments), which are defined according to management needs and road conditions. In this paper, the established network model is performed using ArcInfo, which is used in such a way that all future operations can be carried out with ArcView. The basic representation of Babylon network model is presented in Fig. 5. In this way, a great variety of data and scenarios can be analysed and visualised in the network database.

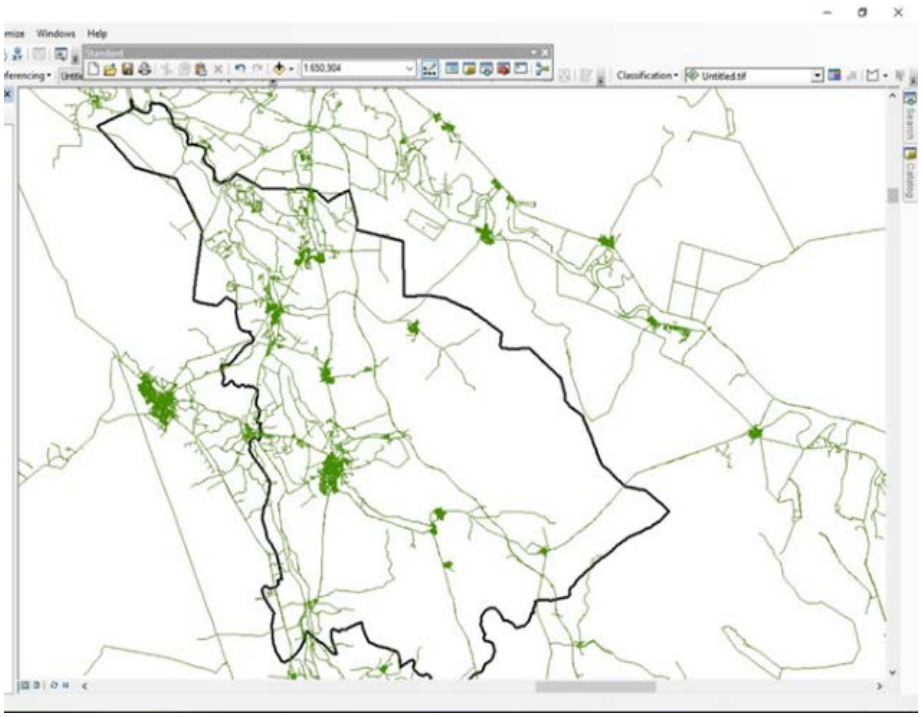

Fig. 5. Babylon's road network, taken from a GIS map.

Generally, the challenging issue in network level management in Iraq is the budget deficit regarding highway maintenance and inspections, which results in a poor highway asset management.

4.2. Project-level model

The GIS technology used in project level PMS for its intelligent spatial database regarding the highway sections. This technology can include all records for each pavement section with their future condition prediction, which is predicted from the deterioration model and maintenance records. Scenarios of managing this level are presented in Table 2.

Project level road management is better controlled by both the highway agency and maintenance companies that they will be notified, by the aid of a GIS system about any deviations in the overall pavement condition. In this way, GIS performs as a visualization tool for the highway engineers to track the maintenance performance and the inspection priorities throughout the service life of each road section. Fig. 6 shows a sample from the project-level GIS in Babylon city. The project level management will focus on the area in sky blue colour, which represent the central city of Babylon. Each section of roads in this area is related through the highway name, which is an essential key for project management. Furthermore, to notify the management engineer or agency of the condition and state of any road section, a coloured dot that represents the condition state must be developed. In this way, the highway agencies and/or maintenance contractors could be notified and to intervene quickly in case of critically deteriorated sections.

Table 2. Description of project-level scenarios for road management.

Scenarios	Description
Network budget definition	The network budget can schematically be evaluated by the highway agency or engineer during tender preparation phase.
Highway improvement definition	The highway agency should determine the optimum improvement road sections within the allowable limits that meet certain budget.
Sensitivity analysis	This gives the highway agencies and traffic engineers the authority to increase the level of service of each section to the design level, taking in consideration the cost of this increment.
Life-cycle cost minimisation	Maintenance contractors can implement the optimum maintenance strategy taking into consideration the improvements of level of service and the estimated cost of the highway construction.
Maintenance optimisation	This scenario is about achieving the required level of service for any road section with minimum effect on total life cycle cost of the road.

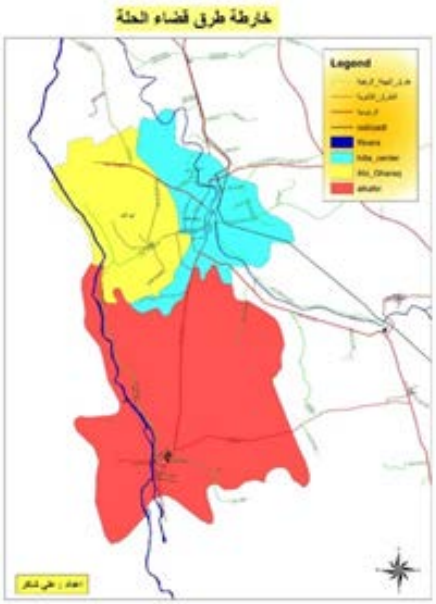

Fig. 6. The map of roads of Babylon taken from the roads and bridges directorate, taken from highway directorate of Babylon.

5. Conclusions and recommendations

At this section of the paper, it can be concluded that the presented management system can be of a great importance in deciding maintenance actions and giving

priorities in highway sections studied in the city of Babylon. This system can make a more planned attitude of maintenance of highways than a reactive attitude that is applied when needed. Highway agency and engineers can now be able to effectively anticipate the condition of a road and decide what actions are needed. GIS made it a straightforward task to look at any road section in the network and rank the required interventions with respect to priority.

- The use of GIS is of great enhancement to predict future conditions of roads that allows highway engineers and agencies make the future plans in accordance. One of the main reasons of using GIS is to obtain accurate data of roads conditions. In this way, budgets can be allocated more accurately, which can be used to prevent widespread deterioration of highway infrastructure.
- The decision-making tool can be continually manipulated to meet the needs and restrictions of life-cycle cost analysis of the road section. This considers any financial constraints, maintenance and rehabilitation strategies and other costs such as drainage systems and road marking that are related to pavement maintenance. All these could be considered as variables to be applied in the optimisation model. The optimisation model is designed to minimise the cost of maintenance by selecting the suitable maintenance type depending on priority and pavement condition. The pavement condition change over time is assumed to be probabilistic, which will be described by Markov chains in the next research paper of this prospect.
- This direction of research will be carried out as the directorate of highways and bridges in Babylon governorate have expressed their interest and going to provide the research with deterioration data and maintenance records so that the model will be applied, and the plan would be presented in the next paper.
- It is recommended to implement the current model in the other cities in Iraq to produce efficient M&R system and reduce the budget of the roads maintenance.

Abbreviations

ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
IQD	Iraqi Dinar
M&R	Maintenance and Rehabilitation
PCI	Pavement Condition Index
PMS	Pavement Management System

References

1. Tsai, Y.; and Gratton, B. (2004). Successful implementation of a GIS-based pavement management system. *Proceedings of the 8th International Conference on Applications of Advanced Technologies in Transportation*, Beijing, China, 513-518.
2. Uddin, W.; Hudson, W.; and Haas, R. (2013). *Public infrastructure asset management*. 2nd Edition, McGrow-Hill Education, USA.
3. Haas, R.; Hudson, W.; and Zaniewski, J. (1994). *Modern pavement management*. First Edition, Krieger, USA.

4. The World Bank (2002). *Procurement of performance-based management and maintenance of roads (Output-based service contract)*. Washington, D.C., The World Bank.
5. Al-Mansoori, T.; Garcia, A.; Norambuena-Contreras, J.; and Artamendi, I. (2018). Self-healing properties of asphalt mixtures with embedded capsules. *Advances in Materials and Pavement Performance Prediction (AM3P-2018)*, Qatar, 551-555
6. Al-Mansoori, T.; Micaelo, R.; and Garcia, A. (2016). Characterization of polymer capsules used for self-healing asphalt pavements. *Functional Pavement Design. Proceedings of the 4th Chinese-European Workshop on Functional Pavement Design*, CEW. England.
7. Hudson, W.R.; and Haas, R. (1995). Future directions and need for innovation in pavement management. *The Proceedings of Third International Conference on Managing Pavements*, Vol. 2, San Antonio, Texas, USA, 122-123.
8. Tsai, Y.; and Lai, J.S. (2001). Utilization of information technology to enhance asphalt pavement condition evaluation program. *International Journal of Pavement Engineering*, 2(1), 17-32.
9. Tsai, Y.; and Lai, J.S. (2002). A framework and strategy for implementing an IT-based pavement management system. *Transportation Research Record*, 1816, 56-64.
10. Tsai, Y.; Gao, B.; and Lai, J. (2004). GIS-enabled multi-year project-linked network pavement MR&R system. *Transportation Research Record*, No. 1889, 21-30.
11. Lee, H. N.; Jitprasithsiri, S.; Lee, H.; and Sorcic, R. G. (1996). Development of geographic information system-based pavement management system for Salt Lake City. *Transportation Research Record.* 1524, 16–24.
12. Kmetz, R. (2011). *GIS based pavement maintenance: A systematic approach*, MSc dissertation, Purdue University, USA.
13. Ang, A.H-S.; and Tang, W.H. (1975). *Probability concepts in engineering planning and design*, Vol. II, John Wiley and Sons, New York, USA.
14. Liu, F.; and Wang, K. (1996). Pavement performance-oriented network optimization system. *Transportation Research Record*, 1524, 86-93.
15. ESRI - Environmental Systems Research Institute, (2000). *ArcView GIS 3.2*, Redlands, CA.
16. Almuhanna, R.R.; Ewadh, H.A.; and Alasadi, S.J. (2018). Using PAVER 6.5.7 and GIS program for pavement maintenance management for selected roads in Kerbala city. *Case Studies in Construction Materials*, 8, 323-332.