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Research Paper

GIS technology for enhancing pavement maintenance and condition assessment: case study

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ABSTRACT

Highways are one of the most crucial infrastructure elements for any city. It is of high importance to keep them maintained to the high performance. This might need to establish a road maintenance department for the continued inspection and decision making. Spatial technologies, such as GIS, are particularly useful for integrating roadway data and enhancing their use and presentation for highway management and operation through the use of spatial relationships and maps. This paper presents a GIS-based system that serves as a platform for all aspects of the pavement condition assessment and maintenance. The resulting map system can enhance the maintenance process significantly by visualising the whole network with the state condition of each section. This paper examines the condition of road sections for a selected area in Al-Qassim, a city to the south of Babylon governorate. These road sections have varying condition states resulting from many factors such as weathering, insufficient drainage, ageing, traffic load, and lack of routine maintenance. The overall condition index (OCI) is used to assess the state of each section on a scale of 1 to 10. Most of the studied sections are falling below 5. Two strategies are presented for maintaining and inspecting the network that highway agencies and road engineers could adopt to save money and extend pavement life in a functional manner. Additionally, the study highlights the importance of recording all road information, including construction details, distress type and severity, and maintenance and rehabilitation processes, to inform future actions.

1. Introduction

Proper maintenance and management of roads are crucial for ensuring the prosperity and well-being of communities. Thus, pavement management systems (PMS) play a key role in this process by providing effective tools for planning, coordinating, and programming investments in highway infrastructure [1]. However, many highway agencies face challenges in implementing an effective PMS, which can lead to increased maintenance and/or rehabilitation costs significantly and reduce the infrastructure quality [2]. Inadequate road maintenance has irreversible effects on road infrastructure, hindering the long-term benefits of road improvements at national and strategic level [3]. Poor road conditions increase accident rates [4–6] and their associated costs, can also restrict mobility and significantly increase vehicle operating costs [2]. Road pavements inevitably deteriorate from the moment they are installed, regardless of materials used and process of construction [7]. However, implementing proper maintenance can extend the lifespan of the pavement and potentially reduce the need for costly full rehabilitation [8, 9]. The cost of maintaining a highway in good condition is around 1.5$/m^2$, whereas constructing a new road or conducting major rehabilitation can cost up to 80$/m^2$ [10]. Over the past decade, it is reported that the Highways and Bridges directorate of Babylon governorate has spent a total of 425 × 107 Iraqi Dinars (equivalent to 34$ × 105) on the maintenance and expansion of highways [9]. Despite the seemingly sufficient amount of money, less than 1% of it was spent appropriately. The reasons for this include the absence of an effective pavement management system with inspection and deterioration models, as well as the lack of engineering estimates of maintenance costs. Furthermore, the roads have largely deteriorated to the point of requiring major rehabilitation before being considered for maintenance, resulting in higher costs. The instability of circumstances in the country has also made it challenging to allocate enough funds for road maintenance, making highway maintenance management a critical responsibility for the highway agency in Iraq. Many highway agencies worldwide are seeking innovative approaches to minimize expenses on pavement maintenance [11–13]. An enhanced pavement maintenance and management system is crucial for making informed decisions on pavement reconstruction, restoration, and maintenance. GIS could be applied for many engineering aspects, such as a tool to identify road crashes and suggest remedial procedures [14, 15], as a data base for collecting spatial information of solid foundations [16], as well as an enhancement tool for highway maintenance and condition assessment [17], which can then be adopted to make informed and timely decisions about road pavements. Utilising GIS for road maintenance and condition assessment can result in more efficient highway management and preventing the propagation of flaws and distresses by continuous and controlled visualisation. Information technology and GIS have been successfully integrated into PMS to manage road networks [18]. The GIS softwares can store, retrieve, analyse, and report the necessary information related to road pavements by associating data and information with their respective geographical location using coordinates such as latitude and longitude or state plane coordinates, [19, 20].

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Nomenclature:

GIS	Geotech Engineering Software	*OCI*	Overall condition index
MJ	Major section	*PMS*	Pavement management systems
MN	Minor section		

GIS can also quickly retrieve data from a database to identify highway maintenance locations and create customised maps tailored to specific needs [21, 22]. The system can also incorporate additional data such as traffic volume, sign and signal locations, political and checkpoint locations, population, weather data, and any other data that may impact road performance [23]. Consequently, a GIS-enhanced PMS can perform pavement management tasks efficiently, generate maps of pavement condition, analyse costs for recommended maintenance strategies, and develop long-term pavement budget plans [24]. This paper aims to demonstrate the importance of an effective pavement management system enhanced with GIS technology for managing highway infrastructure in Iraq, particularly in Babylon governorate. The paper provides insights into the potential benefits of collecting roadway data, maintaining a database, and implementing a maintenance plan. Implementing a GIS improvement plan could result in significant cost savings for road construction and maintenance. The case study provides practical guidance for highway agencies in Iraq, enabling them to make informed decisions about maintenance strategies and investment priorities.

2. Problem statement

Pavement treatment options range from sealing and routine patching to overlaying and reconstruction as a last resort. In Iraq, a considerable quantity of roads requires regular maintenance and inspection and unfortunately, there is no clear pavement management practices in this country. Despite the advancements in information technology, particularly GIS, numerous highway directorates and highway agencies have not adopted GIS for monitoring road maintenance. This reluctance may stem from insufficient resources or a lack of awareness regarding the various methods for effectively managing road maintenance. GIS employs a coordinate system to establish the position of every feature of road network, making it a valuable tool for visualizing current and projected pavement conditions. ArcGIS software is selected to design the system architecture, incorporate data formats, import databases, and sequence all models. By integrating road maps and pertinent data, PMS enhanced with GIS can enable pavement engineers to monitor pavement conditions and estimate maintenance budgets. Additionally, it serves as a reference for advanced research and can enhance pavement maintenance efficiency and quality through adequate calculations. The process implemented in this study is presented in Fig. 1.

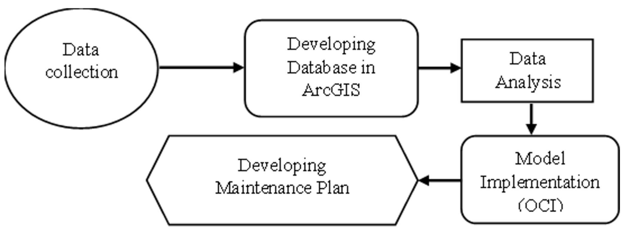

Figure 1. Research methodology.

3. Condition assessment

The appropriate approach to presenting a comprehensive overview of the condition of roads in Iraq is by utilising an overall condition index (OCI). It is a subjective procedure for conducting a condition survey developed by the American Association of State Highway and Transportation Officials (AASHTO) [25]. The procedure is user-friendly and offers valuable information to agencies that have limited resources for collecting data on deterioration and maintenance. However, it is important to note that this method is subjective in nature, as it relies on engineering judgment and expertise for interpreting scores. The index employs a numerical scale that assigns descriptive labels to different road sections. This means that the OCI is not entirely qualitative, as the road conditions can be assigned numbers to quantify the stress level in the road. Trained engineers or inspectors carry out the survey procedure, assigning scores ranging from 1 to 10 to paved road surfaces, as outlined in Table 1. These scores are subsequently used to determine the descriptive rating of the pavement. Road sections with the highest scores receive a satisfying rating, while lower scores are indicative of defects and surface integrity issues.

Table 1. Assessment guide for overall condition index.

Rating of a road section	Defects	Highway condition
9-10 Excellent Condition	None	New construction, recent rehabilitation or repair, like new condition.
7-8 Very Good Condition	Only reflective cracks at joints. No visible longitudinal cracks. Some sort of transverse cracks. Almost no ravelling. Some traffic wear might appear on surface. Very few or no patches.	Emerging signs of aging. No maintenance or could be maintained with routine crack filling.
5-6 Good Condition	Spots of ravelling and traffic wear could be seen. Few signs of block cracking. Moderate longitudinal and transverse cracking. Pavement edge cracking. Spots of patching.	Visible marks of aging. Intact structural condition. Cracks needs sealing coat or thin overlay.
3-4 Fair Condition	Severe loss of fines (ravelling). Multiple longitudinal and transverse cracking. Frequent patching. Occasional potholes.	Clear signs of aging and first signs of structural defect. An overlay layer is necessary.
1-2 Very Poor Condition	Fatigue (alligator) cracking appear to cover more than 25% of surface. Severe loss of surface integrity with highly visible deterioration and distress. Multiple potholes and patching are in poor condition.	Pavement failure or severely deteriorated. Needs reconstruction or major rehabilitation. Old pavement must be pulverised.

3.1 Date collection and case study

To integrate GIS with PMS, all collected data was formatted to be easily transferred into GIS. Typically, road data is collected and stored in spreadsheets of Microsoft Excel. The collected data was then exported to the ArcGIS database. The database is then saved as reference to each road section and updated whenever there is inspection and/or any external intrusion to enhance pavement performance. The study area was chosen to be to the south of Babylon governorate, a suburb called Al-Qassim, which is one of the biggest suburbs in Babylon. It is selected to perform the assessment to some of its roads and subsequently suggest the possible strategies for its road's maintenance and inspection.

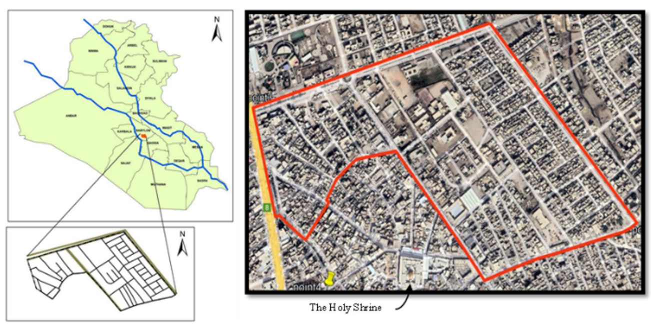

Figure 2. The location of the study area within Iraq, as well as a satellite map of the study area highlighted.

The town is located about 130 km south of Baghdad. Its population is approximately 300,000 who mainly work as public employees and farmers. The town is one of the most important suburbs of Babylon because it has the Holy Shrine of Imam Al-Qassim, which makes it a destination of millions of visitors every year. The location of the city and the selected area of the study is presented in the map in Fig. 2. The figure displays the study area, marked in solid red line. A GIS model for the study area (Al-Qasim, Babylon) based on the types of roads and importance of the location is presented in Fig. 3. The model shows the importance of the study area as it contains many health centres, many primary and secondary schools, a post office, a court, two police stations, the city municipality and more.

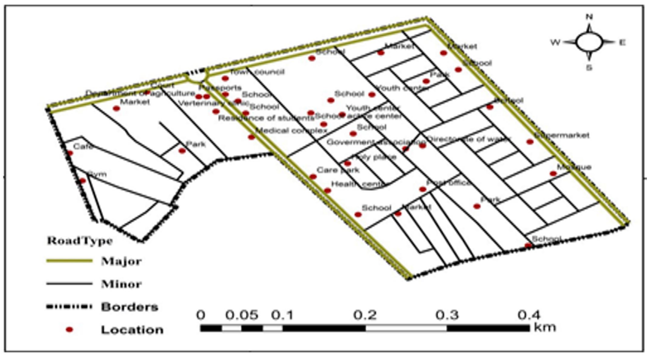

Figure 3. Map of the study location showing the existing roads types and the many facilities in the area.

Figure 4. Common pavement conditions of the study area, a) very good, b) good, c) fair, d) poor.

The study area contains 66 road segments, six of which are considered major roads and the rest are minors. Major roads were represented with solid amber line with a narrow black strip in the middle. These roads connect all the local roads and they are wider. Minors with solid black line and the border of the study area is represented by a wide dashed black line as shown in the legend. The parameters used in defining road sections are the length of each road (local roads), the time of construction, the width, and the use of drains and manholes along the road. Some roads are long but they were constructed or maintained at different stages, so these cannot be considered as a one section. The selected sections for each road were clearly identified on site, the section is defined as a portion from one-way direction of the road that has the same properties of the other side. Those properties are considered in the OCI measures by which the pavement state is registered. The conditions are pavement structural condition, traffic volume, pavement type, drainage facilities and shoulders. Figure 4 presents samples of pavement sections of the study area with different conditions and severity inspected through this research by the authors. They are classified according to OCI scores. The condition assessment of roads performed by the authors took the general pavement roughness as a main indicator. In addition, the cracks, potholes, drainage, and pavement markings are also taken into consideration. Pavement markings are important in physical alignment of roads to improve safety of road users, as they help the drivers to be in the specified lane without wandering. In general, there is a significant percentage of roads in Iraq lack this crucial element, which needs to be taken seriously by road designers and site engineers to impose on contractors and road constructors to consider pavement marking as one of the most important elements of road inventory. The spreadsheet shown in Table 2 is exported from the ArcGIS database, which contains a subset of the information for simplicity. The attributes presented in this example include the street name and type of the road as they are given the codes of MJ for major section and MN for the minors. Also, road length, width, assessment value, and the Overall Condition Index (OCI) are presented.

Table 2. Sample of selected sections after inspection.

Street	Length	Width	Class	Condition value	OCT
MJ-11	676	25	Major	3	Fair
MJ-13	152	25	Major	4	Fair
MJ-09	459	25	Major	7	Very good
MJ-01	182	25	Major	7	Very good
MJ-10	249	19	Major	6	Good
MN-38	430	19	Minor	6	Good
MN-22	195	12	Minor	3	Fair
MN-59	108	11	Minor	1	Poor
MN-21	219	11	Minor	5	Good

3.2 Maintenance procedure

Table 3 below lists the maintenance possibilities that could be adapted by Iraqi highway agencies. These maintenance possibilities could be applied to sections of similar condition. However, when there is insufficient budget, priority of maintenance could be adopted for sections of higher functional use. It should be noted that the GIS model is created and updated according to the maintenance and rehabilitation that can be implemented for any time period ranging from one year to twenty years. This approach would enable a more efficient spending plan of the available budget to optimise the allocation of the budget based on priority. In this way, and due to the absence of inspection and maintenance records before this study, the GIS model was developed solely based on the current pavement condition. The subjective judgements of the road condition raters inherent to visual assessment could lead to variability within quantities given to each section. This could be dealt with by referring to Table 1 mentioned earlier and agreement among raters, who must be experienced in this aspect. Moreover, the evaluation of OCI is used as the basic measure and a starting point for assessing the road states where no information about their conditions ever recorded.

Table 3. Pavement ratings and the suitable maintenance for each one.

Rating of a road Condition	Suitable treatment
9-10 Excellent	Newly construction or recently overlayed. No maintenance.
7-8 Very Good	Routine sealcoat or cold mix repairs. Little to no maintenance.
5-6 Good	Sound structural condition but emerging signs of aging, could be maintained with sealcoat or crack filling.
3-4 Fair	Apparent signs of aging and first signs of need for strengthening. Could be maintained with non-structural overlay (less than 2 inches) or structural overlay (2 inches or more). Could also need patching and repair before a major overlay.
1-2 Very Poor	Severe deterioration or failure. Could need reconstruction with extensive base course repair. Milling and removal of deterioration extends the life of overlay. Total reconstruction might be necessary.

4. Discussion

(OCI) to assess the road conditions in the study area. Figure 5 shows the current conditions of road sections based on the OCI principles, which are usually subjective and depending on the engineering expertise and judgement. It is evident that a significant number of roads are in fair condition, and most of these roads are very close to being in poor condition or out of service soon. The lack of an adopted maintenance strategy might be the reason for this situation. This case of roads is prevalent in most of the Iraqi roads, where different condition states ranging from excellent conditions through good and fair to poor in any study area, whether it was large or small. A legend indicating the Overall Condition Index (OCI) values are also included in the figure. It can be seen that there is no legend for the excellent condition, and the reason for that is that there is no condition of excellent condition has been found during visual inspection. Therefore, the excellent condition is not present in the map of the study area. The map shows that the roads inside the residential areas are more prone to degrade faster than those on outer edges of such areas. This could be attributed to the deficient drainage system of roads near the houses as the sewage water could be higher.

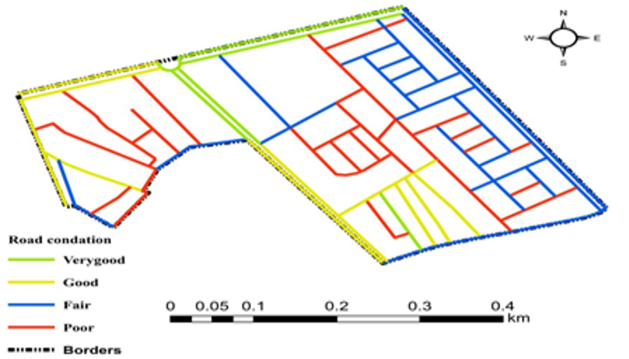

Figure 5. Current pavement conditions in the study area according to OCI.

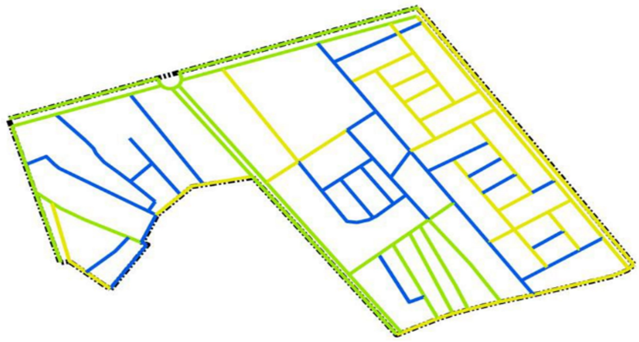

Figure 6. Strategy 1that involves the conditions of all road sections in the study move one step forward.

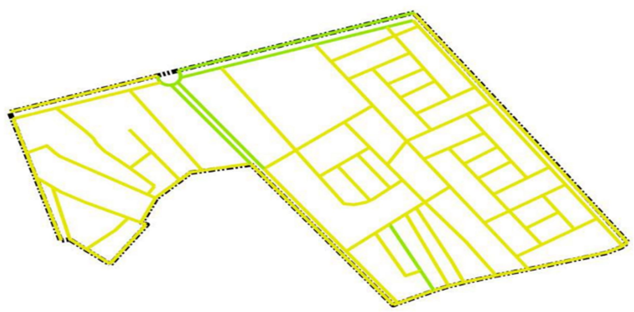

Figure 7. Strategy 2 that involves maintaining all lower condition roads to become good except the very good.

Another reason the authors have noticed is that local directorates of roads do not usually pay enough attention to the roads inside resident areas as these roads not usually visited by officials. Furthermore, due to the lack of maintenance record and inspection strategy, this research presents three strategies that can be adopted by the local directorate of roads in the study area and, if possible, by the highway agency of the municipality and the country as a whole. Figure 6 shows the first possible strategy which includes the routine maintenance with no priority. In this strategy, improving the conditions of the roads is the aim. As it is known for highway engineers and road users, defects are different and can be ranging from very serious needing extensive maintenance to small defects that can be sealed with ease. Therefore, the whole maintenance in this strategy could be time and money consuming, as it needs extended inspection and preparation of plans for each type of defect. Also, some of the sections could not be repaired properly and they decline in service very soon, which makes their maintenance infeasible. It can be noted that this strategy does not involve full rehabilitation or reconstruction of the roads in poor conditions. This could be due to the lack of budget, which is usually divided among all roads equally. This strategy could not be feasible in the long-term. The second strategy is shown in Figure 7. This strategy requires higher expenditure for maintaining all roads of conditions less than very good. The types of maintenance may vary from seals of small cracks to major rehabilitation or reconstruction depending on the state of the road and the type of defect. An example of this type of maintenance strategy was performed in the southern Iraqi city of Al-Basrah, during the Gulf Football Cup tournament in 2022, where Al-Basrah was the host of this tournament. This strategy could be feasible in the long-term, if a maintenance plan is implemented properly. Figure 8 presents the third strategy. This strategy involves some kind of emergent maintenance, where only fair and poor conditions are maintained to an acceptable state without spending too much amount of money for full rehabilitation or reconstruction. This strategy is not a long-term one and does not require a proper maintenance plan or staff. In the long-term process, road networks maintained with strategy could be degraded because the roads with conditions of good and more are neglected until their defect becomes visible and dysfunctional, which would need an emergent intrusion and that could be a major rehabilitation or reconstruction.

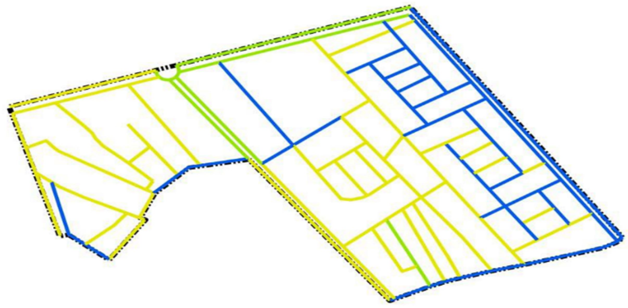

Figure 8. Strategy 3 that only roads in poor condition are turned into good.

5. Conclusions

To make informed decisions about maintenance actions and priorities, it is crucial to enhance pavement management with GIS. GIS can be used for effective communication of pavement management information by visualising the road maps and monitor the processes of inspection and maintenance. This makes road maintenance and management a straightforward task. After achieving the objectives of this research, the following conclusions can be drawn:

- The integration of GIS into pavement management is crucial for making accurate decisions about maintenance actions and priorities. The ArcGIS software is a valuable tool that is used to visualize and assess the network of roads spatially, allowing highway engineers and agencies to make cost-effective maintenance decisions, accurate plans for inspections and allocation of funds, besides future developments. In addition, it is recommended that highway agencies and directorates establish a maintenance team for roads in the study area of Babylon governorate or the whole country. This team should consider all possible repairs that can fit with each road defect.
- The OCI is a valuable and accurate measure that can be considered to start with. Records of maintenance and road conditions should also be taken as a database to be kept with highway agencies for future plans and records. Field testing of the proposed conditions and maintenance strategies could be implemented over and extended timeframe for further validation.
- The prevailing condition of roads in the study area is moderately fair to poor, which means it needs extensive maintenance to start the plan with, after that they can be maintained regularly to extend pavement life with lower expenses. However, funds should be assigned for this reason.
- Finally, there is a great necessity for a long-term commitment of highway agencies, the public, and the road users to keep the road drainage facilities as well as the shoulders efficient in high functionality. Without public collaboration and responsibility, all the official efforts would go in vain.

Authors' contribution

All authors contributed equally to the preparation of this article.

Declaration of competing interest

The authors declare no conflicts of interest.

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This study didn't receive any specific funds.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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