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Utilizing geographic information systems in pavement maintenance applications: Baghdad university as case study

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ABSTRACT

management of the paved network system is a critical issue that always has been the main focus not just in this university, but also to other educational institutions and organizations At the University of Baghdad. These extensive networks are crucial systems at the university as it does not just include the roads, parking spaces, pedestrians' lanes, and sidewalks around the university campus, but also is also extended to a large-scale area, including the bus stations and terminals. This research is conducted in order to set up a smooth and reliable Pavement Maintenance Management System (PMMS) for the university's road lanes and parking spaces. A thorough analysis of related past studies has been done on the PMMS projects in Iraq and other countries to gain a comprehensive understanding on this topic. A PAVER system software is adopted in the study in order to develop a complete and integrated database and the GIS-based map layers for the road pavement and other extended engineering features. While there are past studies discussing the Maintenance and Rehabilitation (M&R) system for road pavement networks, though the systemic approach and forecast method is still missing. Hence, this project is conducted to help in providing a structural M&R system for the pavement networks.

Keywords: Roads and parking network; pavement condition index; pavement maintenance management system; rehabilitation and maintenance

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1. Introduction

At the University of Baghdad, maintenance of the network systems is a great concern not just at this university, but also to other educational institutions and many other organizations around the world. This maintenance includes the pavement of the roads, pedestrians' lanes and sidewalks, and the large-scale area used by an extensive number of people inside the campus, such as the bus terminals and parking spaces [1, 2].The utilization of a reliable PMMS would be an excellent instrument for the M&R project evaluation and organization, financing criteria evaluation, and optimal allocations. Structured and economical maintenance of pavements has enabled the creation of Pavement Management System (PMS) technologies [3-5]. The illustration in Figure 1 below shows that the early decision for the maintenance of the pavement at the initial stages of the pavement degradation managed to deliver significant cost savings before the beginning of the expensive spike in the maintenance costs [6].

A functional pavement management system could be achieved when all the pavements are being kept at an adequate degree of serviceability, which in return would serve a favorable outcome in maintaining lower usage costs, conserve the minimal amount of funds, and would not give any adverse side effects to the safety of the road users and the environment [4]

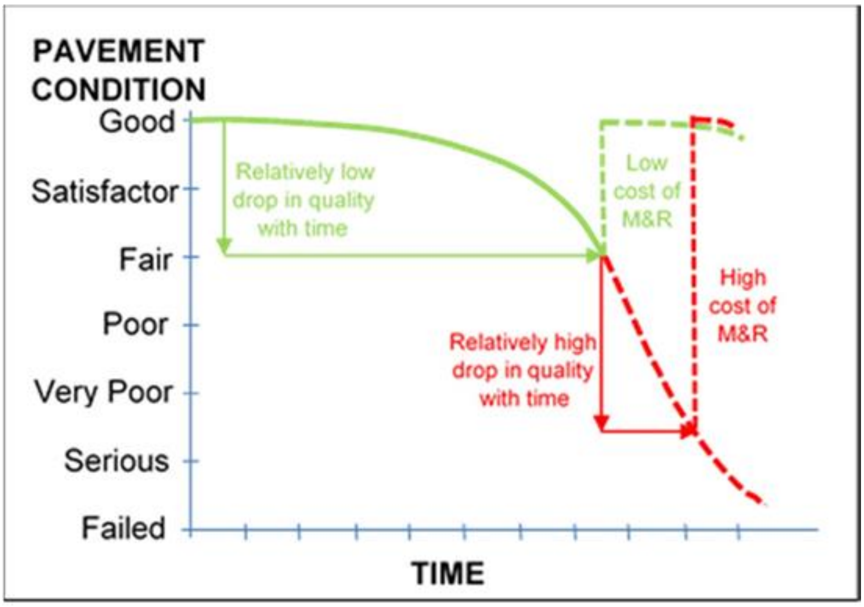

Figure 1. Illustration of Pavement Condition Variability with Cost of M&R over Time.

Back to the history of when people started to notice the importance of keeping the pavement maintenance, it all started in the late 1960s when people earlier preferred to only keep an eye on the road construction development and infrastructure designs. However, later, the focus switched to the maintenance and reconstruction of the infrastructure. Though the system was simpler at the time, merely just focusing only on the data information processing, evaluation of the roads, and ranked them based on the road pavement conditions and traffic congestion. Back to now, the system seems to improve generally as they widen the focus to the surveying and estimation of the current road condition for future pavement maintenance needed, analyzing to come out with ideas to maintain the condition of the pavement and further operations that could be done for the maintenance, designing long term maintenance frameworks, as well as establishing multi-component priority optimization and development [7].Figure 2 shows the PMMS that includes inspection of pavement condition, datasets for road network system, quality control methods, quality analysis and computational mechanisms for predicting and costs of the customer and organization, decision-making, and execution techniques [8, 9].

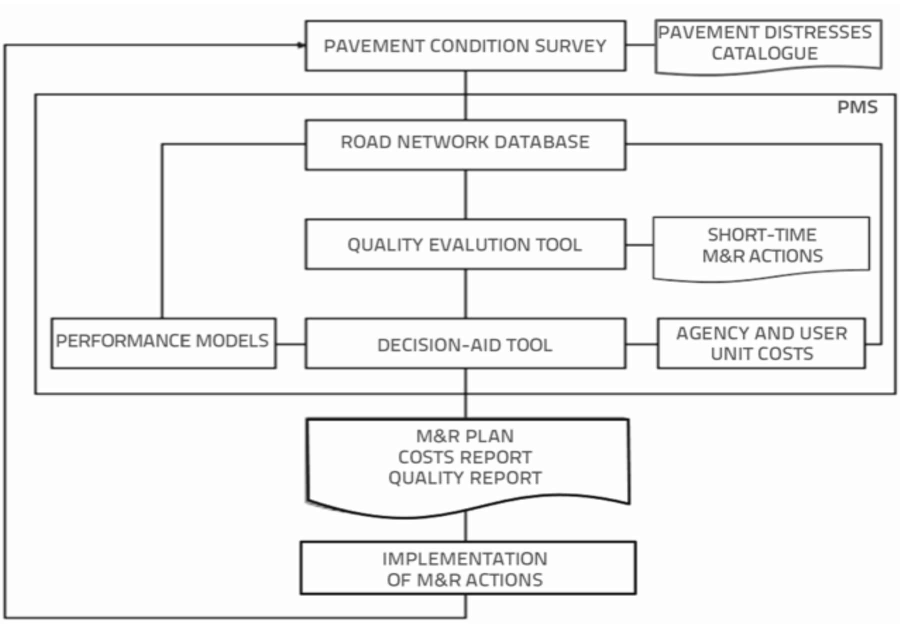

Figure 2. Pavement Management System

2. Literature review

The efficiency of the pavement network systems and the potential variables causing problems in this system have been examined by several past researchers. The major reason that triggers the road degradation systems in Iraq is found to be contributed by the vehicles with shaft loads above the maximum permitted limit, improper drainage networks, and lack of proper quality control [7].
Relevant research on the connection that links the road pavement systems' degradation, engineering criteria, and the underlying sub-grade layer geology was analyzed [8, 10-12]. It was reported that roads with a high level of failures were contributed by the weak sub-grades, while roads with a lower level of failures are because of the weathered sub-grades. Authors have stressed the importance of incorporating well-planned drainage schemes that could be a great help at minimizing road failure rates. Several researchers mentioned that due to the growing numbers of vehicles on the road, rutting is seen to be slowly evolved in the wheel path [9, 13]. They stated that the rutting occurrence was likely because of the convergence that takes place during the early phases of pavement system services, as well as from the occurrence of the shear failures.
It is seen that there are researchers that utilized the Maintenance Management Framework (MMS) in their study to assess the state of the road network, while there are also those who analyzed the pavement condition in Baghdad by using the Micro PAVER system software. They had grouped the roads' conditions into three categories: local, collector, and arterial roads. They observed that in the eastern part of Baghdad, it is seen that the road condition is way better compared to the state of roads in western Baghdad. Some studies implemented the use of computer software in their MMS research. There are also researchers that utilized the Micro PAVER system to evaluate a number of pavement parts in the city of Baghdad [14, 15]. The research came out with a finding that almost 65% of the pavement parts analyzed in Baghdad city needs varying stages of maintenance repairs [1, 16].
In accordance with the current state of the road management system, the “Ministry of Public Works and Housing (MOWH)” in Iraq consistently tries to come out with a well-structured reviewing and analyzing the country's pavement network system. Relevant researches on this area of study consistently suggesting ideas and ways for the enhancement of the current system [6, 17]. Other studies have described that the “Pavement Management System (PMS)” strategy may be adopted to establish maintenance and improvement objective, and at the same time providing an allocation for regularly reviewing pavement efficiency to classify parts that require rehabilitation [18, 19].

2.1 Pavement management system's uses of spatial technologies

To ensure any business's effectiveness, it is crucial for organizations to implement a decision support system (DSS). Same goes for the pavement maintenance system. DSS gives support to the management in making an effective decision while being provided with limited departmental information [20]. Some of the features provided by the DSS are the mode for recovering information and display, scanning and sequence identification, observation, deduction, rational distinctions, and advanced numerical modeling. The planning, evaluation, presentation, and distribution of information data are some of the features offered by GIS or any spatial technologies that could help in validating these choices.
The implementation of GIS could benefit significantly in many sectors, including in the context of PMS [19, 20]. Through the creation of the PMS-GIS device prototype, Osman and Hayashi [21] outlined a list of advantages from the implementation of this system. GIS could provide the ability to generate map spontaneously, improved analysis capability via well-built spatial queries, improved data accessibility, excellent performance and inclusion, and smoother inspection of other road properties during the decision-making stage. For the application of spatial technologies, there is a wide range of benefits in their implementation to PMS. However, there are at least four critical functions provided in supporting the system, which is the map generation and display, assisting data collection, management, and geospatial inspection [22, 23]. A study made by Petzold and Freund in the early 1990s indicated that there are two main vital reasons why it is essential for highway roads to implement the use of GIS in their system construction: for generating maps and data inspection. The most essential thing GIS could do is by enabling a fast representation of data on graphics and plotted maps [23]. The items in the database that are color-encoded by sections or marked by chosen elements may be zoomed into and out on the map view. The incorporation of a vast amount of data which are obtained and stored by transportation organizations may also be very efficient by the integration of GIS [21, 24].

GIS would be a convenient method to link road databases, as all of them are linked spatially. Nevertheless, for a transport organization, existing spatial analytical programs are able to do better. Users may quickly respond to inquiries about the spatial relation between data or data which have similar or linked characteristics, undertake network inspection, and conduct adaptive differentiation, along with many characteristics [25, 26].

Figure (6) below shows how the agencies that took part in the study affected by the implementation of GIS and the other spatial analysis technologies with the pavement system in their operations. The organizations were asked how they would comment and rate the effectiveness of the integration of both technologies in their maintenance system. A high number of organizations gave feedback that they mostly use the integration of GIS and spatial analysis to generate maps and graphic displays (which is under the first category). Some organizations prefer to use these technologies, focusing on the integration of data and central enterprise-wide databases, while there is a small percentage of organizations that participated in this study mentioned that they are incorporating GIS as the dominant database for PMS. Though it is widely seen that many commercial PMS developers mentioned that they integrate GIS in their system, but they are actually not using the GIS. Instead, they incorporate other database management systems (DBMS) into their system. However, this incident does not happen to one organization: Wisconsin DOT. They incorporate full PMS into their spatial technologies, which indicates that their PMS software is entirely generated by the GIS program. The results are illustrated in figure 3.

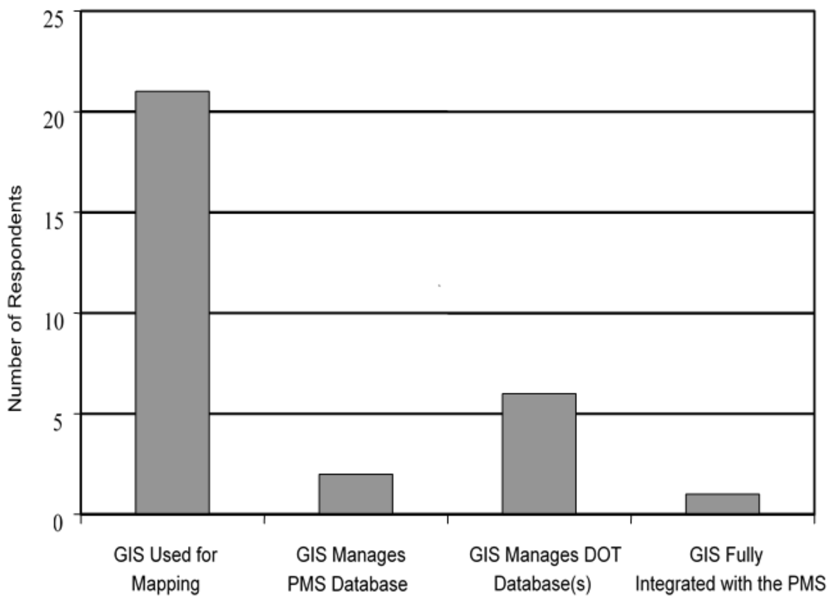

Figure 3. Status of the PMS–GIS integrate

3. Objectives of the study

The study is conducted to establish a "Pavement Maintenance Management System (PMMS)" for the parking spaces and roads networks at the University of Baghdad. The objectives of the research are to:

1. Constructing an extensive and integrated road pavement management database at the University of Baghdad (UOB).
2. Designing a "Geographic Information System (GIS)" based on map layers for road network record and features like traffic density, material resources, the paving width, and well-designed drainage network.
3. Assessing the state of the pavement by utilizing the Micro PAVER software system.
4. Measure the volume of rehabilitation and maintenance and the expense of all pavement parts of the road networks.

4. Research methodology

In order to build a complete and integrated database, the Micro PAVER system was incorporated in the study, along with the utilization of the "GIS-based map layers" for displaying the engineering features and road pavement. The survey was undertaken to determine the "Pavement Condition Index (PCI)" for the parts of the pavement that have been selected, following by the calculation of the approximated amount of M&R. Below is the outline of the methods used to achieve the research goals:

Step 1: Thorough analysis of the past relevant literature materials.
Step 2: Evaluating the pavement process of the road network systems and maintenance documentation at the UOB.
Step 3: Building a road network engineering database by utilizing the GIS.
Step 4: Splitting the road network into pavement parts and branches by employing the Micro PAVER system.
Step 5: Evaluate the chosen parts of the pavement to assess the Pavement Condition Index (PCI).
Step 6: Measure the amount and expense of M&R for each part of the pavement.

5. Process of pavement MMS

5.1 Inventory definition

The explanation of the concept of the inventory that organizing the paving area is the initial phase that has to be taken in order to establish the PMMS. The paved sections are to be split into three categories: networks, branches, and system, and the categorization that is being implemented at the UOB is shown in Figure 2.
The paved selections are all situated in the same geographic locations, and hence, they are known as one single network. They are all generally supported by the same organizations and are built in line with very close requirements and descriptions. The university network was eventually split into divisions to reflect the recognizable portions of the paved regions. Four divisions were then selected to reflect the university's major roads and parking spaces. This research would describe Ring Road's protocol and findings (RINGR), which is a branch of the university road network.
The branches were divided into few parts. Each part has to be categorized in order to recognize sections that possessed almost consistently similar characteristics. In this research project, the paved locations' characteristics were taken into account, for instance, the cross-sectional distance, pavement quality, amount of traffic density, building structure, and the state of the shoulder. A quick count of vehicle numbers was carried out at many primary streets and joints throughout the university road networks in order to approximate traffic volumes. For the paved areas' determination, some consideration on the traffic volumes and the transportations' load rates on the road should be examined.

5.2 Evaluation of the pavement condition

This phase is conducted to assess the current state of the selected areas' road pavement networks. The "Pavement Condition Index (PCI)" ranking protocol established to measure pavement distresses in pavement areas [3].This technique uses 100 points to determine the state of the road segments based on the form, amount, and complexity of the problems displayed in Figure 2.

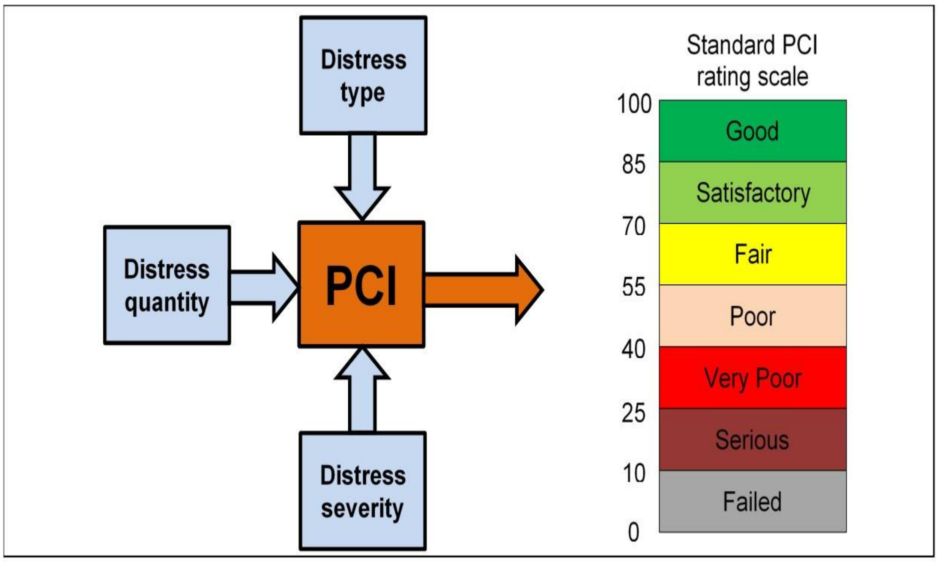

Figure 4. Rating scale used for Pavement Condition Index (PCI) Method.

The initial step that is taken in evaluation method is splitting each segment of the paved areas into unit samples. Sample units are the pavement regions allocated for the evaluation of the pavement. It has been decided that the sample units' sizes are to be almost of the same measurements for each of the pavement selections (in between 140 m2 to 340 m2). All the sample units were to be under inspection during the ongoing process of the study. This is due to the pavement areas size inside the campus is generally smaller, and a higher degree of precision is needed for the success of the research project. The data collected for every sample unit has been recorded in the required PCI survey form that has been outlined for the purpose of the project research. Figure 4 below gives the graphical conditions of the distressed pavement areas found during the pavement network system analysis inside the university.

Figure 5. Types of pavement cracks during data collection

6. Results

The calculations of the PCI were carried out utilizing software-based and manual techniques. Table 1 below shows the results for the PCI calculations for the selected paved areas. It is seen that there are some minor variations in the results for both techniques used. Nevertheless, there is still a substantial difference in the lower end of the PCI measurements. For the manual-based calculations, the person who did the estimation on the paved areas might have encountered some errors while estimating the distress severity. The errors made may be the reason linked to the variations in the finding of the study. For future reference, it is crucial to make sure that the inspections should possess the ability and is an expert at going through the process of inspections; hence no such errors could be reencountered. This finding was also reported by other researchers who are also in agreement that human error could happen while doing the estimation of the pavement distress and related severity [13]. The results on the PCI values found from the human-based calculations were then compared to the values acquired from the Micro PAVER 7. The reports are shown below in able 1. Generally, the values are in agreement, though there are some minor variations reported between both techniques. Figure 6 below shows the outcomes of the inspection of survey in the field and the calculations of PCI values for every pavement area part. The field survey outcomes of the inspection and the PCI values calculations for the segments of the pavement are shown in Table 1. The scheme color was aligned with the color scheme incorporated by “Micro PAVER 7” programmers to display the state of every part of the pavement based on the 7 levels of PCI.

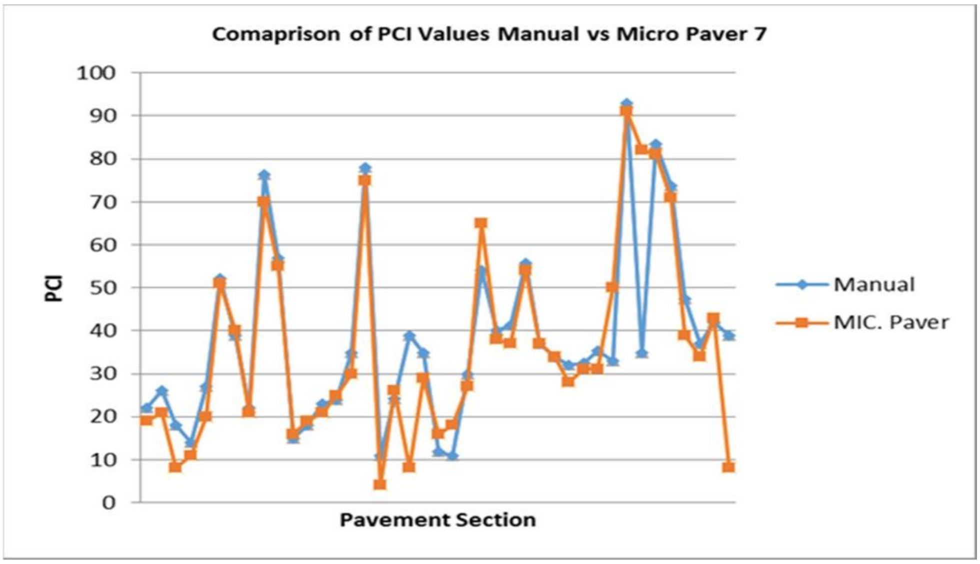

Figure 6. The PCI Comparison.

Table 1. Summary of PCI Calculations

PCI Rating	Manual PCI Calculation		PCI as Calculated by Micro PAVER 7	
	No. of sections	%	No. of sections	%
Good	1	2.5	1	2.0
Satisfactory	2	9.5	5	9.0
Fair	3	10.5	6	8.5
Poor	5	15.0	7	16.0
Very Poor	15	36.0	16	32.2
Serious	10	25. 5	12	25.0
Failed	0	0.0	4	9.0
Total	36	100	51	100

Table 2 provides a preliminary overview of the quantity of pavement distress in the network that can be used to evaluate M&R targets and expenses.

Table 2. Overview of the quantity of pavement distress in the network

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6.1 Identifies problems by using GIS in PMS

Below is the list of some adverse impacts from the implementation of spatial technologies (e.g., GIS-based systems) in the PMS:

1. Check the consistency and accuracy of the references as many Department of Transportations (DOTs) implement various techniques of reference (count, direction, centerline, and link/node). Although an increasing number of GIS and middleware developers are starting to make sure they provide reliable and progressive tools in their system to make it easy for users as a method of reference, though many existing versions of this software lack these features.
2. Database upgrades are expected to include the work-intensive complexity of spatial details and are able to fix any errors on the graphic maps. Nevertheless, one organization said this was also a favorable change since the implementation of a GIS-based software led to the discovery and repairing of problematic data in the PMS database system, thus improving database consistency and the users' trust and device reputation.
3. In the areas where there is lacking time-sensitive discrete adjustment, the precision of the GPS-collected information might not be sufficient for PMS data collection.
4. There are problems involving pending unsolved issues regarding addressing temporal datasets and the problems with coordinating PMS that, although, with stable GIS data, it is still somehow stationary.
5. Each user needs a different level of information regarding the description of the pavement networks.
6. Too much demand in which there are users that expect to get all detailed information from the GIS software even from just one click.
7. GIS software can be quite complicated for users. This makes the applications of the software to be hassle for users who needs to learn more regarding the application of each part of the system.

It can be seen that the majority of the challenges noted are prone to the creation and accessibility of databases, as well as related to the PMS implementations compared to the usage of spatial technology itself. In the last decades, it has been analyzed that many organizations have spent considerable funds to establish these technologies and are seen not to be able to keep up with the very rapid technological advances over the last ten years.

6.2 Suggested geographic information system improvements

It has been discussed previously that many commercial GIS and spatial analysis technologies middleware are trying their best to provide more reliable and better performance systems into the PMS incorporation so that it would be easier for users to navigate around the system provided. Even so, there are also a considerable number of providers who do not care to provide full needed features into their GIS software since they mentioned the details just for commercial purposes without giving a full inspection in the applications' merging. Below is the list of the suggested GIS features that should be incorporated to build up better software for PMS operations:

1. Improve the automation of the systems to render the information gathered and analyzed from multiple referencing mechanisms. For an illustration, it is necessary to combine the background data and M&R documentations stored with the reference route/milepost with the newer data obtained by automated vehicles with GPS equipment. In real-time, ground maps can be generated for GPS-based pavement condition data collection displays with data conversion practices. These graphical interfaces will allow the data obtained with current centerline data and statistical data to be reconciled.
2. Improve map coordination or fusion strategies to cross over current maps and gather data information using GPS to promote data exchange and integration within road management systems.
3. Integration of time-dimensional data for addressing adjustments in the geometry and orientation of highways, road conditions, infrastructure, repairing processes, and expenses. The majority of the respondents comprises of 82%are in agreement that it is necessary for PMS frameworks to be established and statistical data information to be readily available. An illustration that can explain more on this issue is the creation of estimation techniques of pavement results by area or by territory.
4. Advance the capability for flexible differentiation, i.e., abilities to monitor various linear items, occurrences, or conditions.
5. Improve the database management functionality to enable PMS convergence with other maintenance and roadway management programs throughout the organization. The framework should be not only

capable of storing feature and spatial data but also temporal and graphical (photography and videos) data and documentation for maintenance purposes.

NCHRP Project 10-27 [7]has mentioned and most of the suggested improvements that could be done to the existing or upcoming versions of GIS and spatial analysis technologies developed by middleware. It is firmly assured that the suggested improvements would not only help to reinforce the PMS but would also give significant positive impacts to the quality of the data gathered and the accessibility among the organizations and, as the outcome, would facilitate the process of pavement maintenance operations.

After being asked about the GIS improvements, quite a number of organizations commented that they would prefer to possess fully GIS-based PMS mechanisms. They would want to have the ability to incorporate a GIS software that could better facilitate the PMS operations, such as automatically generating advanced detailed maps that showcase real current or future road pavement conditions, exact locations of the projects, arranged projects, and the effect of system-wide asset service budget allocations. Additional technical specifications are needed to save, manage, and view road image data, direct ties to relevant databases (without importing and exporting data), and offer user-friendly accessibility and generate reports.

7. Conclusions and recommendations

Though it is observed that many researchers in Iraq had done studies on the M&R system, specifically in the area of pavement road networks, there is still scarce in the comprehensive and planning strategy. Hence, In the area of the pavement network system, this research would be a great help in providing a comprehensive and structured way of organizing the M&R process. Not only that, this research project would be a good model that could be implemented by other organizations or institutions in Iraq. There are some challenges encountered while in the process of implementing and integration of the PMMS in this research. One of the initial problems encountered while doing the field survey was that there were not enough background records on certain parts of the networks. It was also very tough to evaluate the selected thickness of the pavement layers structures. As a result, it was required to do trenching methods or evaluate the composition and the thickness of the layers from the core pavements. Nevertheless, time and energy are needed for the incorporation of the new PMMS, and skills and expertise are required for the employment of applicable computer software.

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