Spatial Pavement Condition for Specific Urban Roads in Karbala City

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Abstract. Roadway pavements are an important structural element in most countries. For preserving the status of pavements at a satisfactory level of service, attention should be paid to managing maintenance work and applying it in the appropriate time. The survey of the pavement distress and status, significantly helps improving the system of managing the pavement (PMS) capabilities. This research aims to conduct spatial analysis for pavement conditions at arterial streets. Two major roads were selected in the city of Karbala, AL-Mulhaq and Dhbat Al-Osra street. The data collection process was performed based on the type of distress, severity and quantity. Analyzing the collected data and evaluating the index of pavement condition (PCI) was carried out by software PAVER version 6.5.7. Consequently, estimation of position intensity was conducted by ArcGIS software: a spatial analysis using Points Density Estimation (PDE) and Inverse Distance Weighted (IDW). PDE for applications of pavement status allows the distress density extractions and visualizations in elected location or road or network that grants the decision-maker an advanced view of the problem in the region. In this study, PDE is applied to create a map for possible distress hotspots depending on selected distress data. The outcome of this study indicates the appropriateness of the entitlement maintenance heat map for a specific road, which provides a clear denotation of the pavement layers damage on the heat map displayed in relation to the colors intensity. For example, a segment of high PCI score can include very degrading units of low PCI score owing to many faults. Thus, it could be inferred that the PCI segment at all units reflects the truth of pavement condition. The heat map established explains degradation situations for all units and supplies the last vision of pavement condition at the arterial positions surveyed.

Keywords. Point density estimation (PDE), ArcGIS software, PAVER 6.5.7, IDW.

1. Introduction
A significant aspect of a Pavement Management System (PMS) is the capacity to assess a pavement network's current status and forecast its potential status. An objective, a replicable ranking method, must be used to accurately estimate the state of the pavement. The PCI affects the number, varying from 0 for failing paving to 100 for pavement in a good condition as seen in Figure 1. PCI estimation is focused on the findings of a visual condition survey defining type, severity and quantity of distress [1]. In planning, design, construction, operation, and maintenance, a PMS depends on pavement condition details. Geographic information system (GIS) technology is a new instrument for the avail of the PMS that transacts with spatial data. Government mandates including ISTEA force communities...
are used to build management schemes for pavements, bridges, protection, pollution, public transport, intermodal equipment and services. GIS tool could be utilized to enhance data exchange across multiple government entities at all levels. A large amount of data is needed to define a whole pavement network, and data are constantly revised or modified as pavement deteriorates or rehabilitates. A GIS may have an advanced information management tool suite. Pavement component details may be identified by position and attribute in the GIS database for inventory and repair recognition. GIS can easily download attribute data from the paving database and create custom maps to address unique needs, including repair positions [2].

![Figure 1. The range of PCI](https://example.com/image.png)

2. Software PAVER version 6.5.7
The program of PAVER version 6.5.7 was utilized to assess existing PCI and to forecast potential pavement condition, choosing repair and renovation requirements at optimum time and goals. It is a decision-making method for cost-effective rehabilitation and maintenance options for airfields, parking lots, streets, and highways. PAVER's gives several essential capabilities [4]. PAVER 6.5.7 presents several valuable capabilities as well as: an inventory of pavement networks, condition ranking, creation of PCI models (family curvatures), determination of existing and potential pavement requirements (condition analysis), identification of (M&R) requirements and analysis of the implications of various expenditure situations (work planning), and project specification [5].

3. Pavement management
The managing of pavement is an effective strategy to examine and fix road-network pavement conditions. It is a valued gadget that cautions the manager of the road concerning the acute period in a life cycle of the highway. A PMS 'essential feature is the potential to infer the current conditions of the road network and forecast its future state. A proposed System of Paving Management (PMS) [6] is a global technique to assist decision-makers in "seeking an optimal solution" for road repairs. Road failure is split into two main components. The first one is functional failure, in which situation, the roadway cannot perform its purpose function without causing a nuisance to passengers and high effects on vehicles [7]. The reason for functional failure is a pavement surface distress, which is depressions, cracks, rutting formation and poor quality of riding [8]. The second is a structural failure, causing the collapse of the pavement layer or the fracturing of one or two pavement layers, making the pavement unable to sustain loads on the pavement surface [9]. Pavement control includes, among several other tasks, their preservation. Control of pavement requires awareness of its state and dependent on it is the requirement and optimum period for maintenance [10]. When certain knowledge regarding a road system is installed, it becomes even simpler to determine the goals, whether for maintenance or?
4. GIS software (Arc GIS 10.4.1)
A GIS is a system for the accumulation, storage, retrieval, analysis and display of spatial data in a computerized database management system. There are two broad categories of information in GIS: georeferenced spatial data and attribute data. Georeferenced spatial data describes objects that, in two or three-dimensional space, have an orientation and relationship. Attributes associated with a street segment could involve its width, lanes' number, history of construction, and condition of pavement and volumes of traffic [11]. As GIS is progressively utilized in government authorities. There is also a rising movement towards incorporating PMS data into geographic information systems. Through technical advancements in software and hardware, this convergence becomes more practical. The benefits of this integral include editing of flexible database and the ability to visually show the result of database queries, statistics and graphics, analyses of pavement management on the highway network map, displaying network conditions via dynamic color coding of highway parts, and accessing sectional data through the graphic map interface [12].

5. PMS/GIS integration
Since geographical information systems balance the geographical nature of road networks with their spatial analysis capabilities, they are considered to be the most suitable tools for improving pavement management operations, with features such as graphical pavement condition display [13]. Integration can be accomplished by full integration, such that the PMS is part of the GIS, by exporting PMS data to fit the GIS, or by exporting the map to the display / query module of the PMS map. Advantages and disadvantages of such incorporation may be measured, but the disadvantages were not taken into account in light of disclosing the advantageous use of GIS applicability to each component of pavement management [14]. Some of the benefits of GIS/PMS integration are:

1. Ability to inspect pavement management data based on geographic location.
2. Showing the outcomes of database queries on the network map and pavement management studies.
3. Demonstrating pavement conditions on a highway network map and predicting work plans.
4. Ability to update and edit the network map of the pavement.
5. In addition, it can help pavement management information by using a format that is easily understood by the managers [15].

6. Spatial analysis
It is analyzing the positions and forms of geographical characteristics and their relations. Spatial mapping helps determining suitability, forecasting and having a deeper understanding of how geographical characteristics and occurrences are found and spread [16].

6.1. Point density estimation (PDE)
The point density method tests the point density characteristics over any raster output unit. Unit distress is determined thematically around each middle of the raster cell, and the points number inside the units is summarized and divided by the unit area. In this research, the point density has been utilized since it needs weights, exemplified by the value of PCI to every defect in the unit, which provides high accuracy when drawing the heat map. Interpolation: A collection of features of the spatial analyst that forecast surface magnitudes from a restricted number of sampling data points to construct a continuous raster.

6.2. Inverse distance weighted (IDW)
An interpolation process in which the cells magnitudes are calculated by combining the data points magnitudes of the samples near every cell. The closest point is to the approximate center of the cell, the most impact it has in the averaging phase, or weight. This methodology suggests that the mapped vector reduces its effect with distances from its measured position. [16].
7. Study area
In the selected study area, the pavement maintenance management system (PMMS) was investigated. This investigation involved two roads located in Karbala city, Iraq. These roads are Al-Mulhaq and Dhbat Al-Osra street in two directions, the lengths of these roads are 1111.2 m, 1023 m respectively. The data such as locations, distress and images for the study area were collected, and the database was established. The distress intensity levels were established utilizing a highway distress guide by the use of all the data from the survey. Computing the total number of the sample units in the pavement section (N) was conducted by dividing the area of section by the area of sample units which is (225±90 m²) [1]. Table 1 demonstrates further research area details.

| Selected area          | Directions | Area segment (m²) | Sample unit's area (m²) | No. of inspected units(N) |
|------------------------|------------|-------------------|-------------------------|---------------------------|
| Al-Mulhaq Street       | Side 1     | 10001.2           | 231                     | 43                        |
|                        | Side 2     | 10001.2           | 231                     | 43                        |
| Dhbat Al Osra street   | Side 1     | 8695.5            | 300                     | 29                        |
|                        | Side 2     | 8695.5            | 300                     | 29                        |

8. Methodology
The following tasks were carried out to achieve the study objectives:

1. Each sample unit was inspected visually to determine type, quantity and severity of the defect.
2. GPS was used to capture the X, Y coordinates in each defect and the center of every unit.
3. A digital photo for every segment in the roadway was presented.
4. The Software of PAVER version 6.5.7 was utilized to calculate the PCI value of each unit, which was visually collected at investigated roads.
5. Direct integration was made between PAVER 6.5.7 software results and databases of Arc GIS.

9. Analysis and results
In this study, Micro PAVER and ArcGIS programs were used to improve the road sites management system for pavement issues in Karbala city, Iraq. After distress information was inserted into PAVER 6.5.7, the program automatically calculated the PCI of each sample unit surveyed. It calculated the total PCI for a section, in addition to the distress quantities shown in Plate 1.

Plate 1. A window of PAVER 6.5.7 Software to Calculate PCI.
In this study, Inverse Distance Weighted (IDW) and Point Density Estimated (PDE) are the primary tools for drawing a heat map for road defect. In addition to the X, Y coordinates of the defects that were collected by GPS, a heat map of road defect was produced. It can easily identify the exact location of the distress. Besides, data collecting can also be presented in Excel worksheet form. The map created by GIS shows the current condition of the road or road defects. More details about IDW and PDE are:

9.1. Heat map by inverse distance weighted (IDW)

Excel worksheet prepared consists of PCI for each unit and X, Y coordinates in the center of each unit. Then, excel worksheet was inserted in ArcGIS software for spatial analysis by using Inverse Distance Weighted (IDW). The heat map color identifies the deterioration of pavement condition depending on the PCI value. IDW converted the PCI value to the color grading according to severity, with green being the best possible pavement condition and red being the worst possible pavement condition as shown in Figure 2 & 3 and Table 2. Clicking on the heat map displays a window containing the value of PCI and the site of the defect (X, Y) as shown in Figure 4.

![Figure 2](image1.png)

**Figure 2.** Spatial pavement condition of sample units in the heat map using (IDW) for Al-Mulhaq street.

![Figure 3](image2.png)

**Figure 3.** Spatial pavement condition of sample units in the heat map using (IDW) for Dhbat Al-Osra street.
Figure 4. Window of PAVER showing the value of PCI and defect location.

9.2. Heat map by point density estimation (PDE)
GPS was used in the center of each defect to capture the X, Y coordinates. The coordinates were inserted in Arc GIS software by using the point density tool. The value of density was determined to every raster output cell. Heat map has mostly been generated from point data, and a circular searching region was added to every cell in the raster output generated. In order to determine the value of density for each cell in a raster output; the search area dictates the distance to find points, as seen in Figure 5.

Figure 5. Pavement distress in the heat map at Dhbat Al-Osra using point density.
Table 2. Levels of distress (IDW) categorization for selected road’s zone.

| The PCI levels | Type of area within the location | The color specified for each PCI |
|----------------|---------------------------------|----------------------------------|
| 1              | Very low distresses             |                                  |
| 2              | low distresses                  |                                  |
| 3              | Average distresses              |                                  |
| 4              | Highly distresses               |                                  |
| 5              | Very highly distresses          |                                  |

10. Conclusions

Heat maps that display the exact sites of the defects were successfully generated by the combination of spatial data and GIS. The heat map will improve the road maintenance management process, from gathering data to making road repairs decisions based on priorities. The purpose of this study is to focus on the use of the pavement condition index (PCI) in geographic information systems (GIS) to draw a heat map reflecting the degree of road pavement deterioration. The Heat Map is a good indicator of road maintenance aims and entitlements. For example, a section of high score of PCI may contain very deteriorating units of low score of PCI due to the presence of several defects. So, it can be concluded that it is doubtful that the PCI section represents the reality of all units. PAVER software was used to analyze the collected data and calculate the Pavement Condition Index (PCI). The value of PCI for Al-Mulhaq and Dhbat Al-Osra streets were 84, and 80 respectively, which means the pavement at a satisfactory level and preventive maintenance operations will be required in order to keep the pavement in a good condition. The benefits of spatial analysis of heat map drawing are:

1. By looking at heat map, the condition of the pavement can be determined, whether it is good or poor, through the color. For instance, the green color means that the pavement is in good condition while the red color means that the pavement is in a deteriorating condition.
2. The location of the defect and the value of the PCI can be determined by a heat map.
3. Ease of identifying deteriorating samples and conducting the necessary maintenance.

11. References

[1] Shahin M Y 1994 Pavement Management for Airports, Roads, and Parking Lots
[2] Lee H N, Jitprasithsiri S, Lee H and Sorcie R G 1996 Development Of Geographic Information System-Based Pavement Management System For Salt Lake City (Transp. Res. Rec.) vol 1524 pp 16–24
[3] U S Army Corps of Engineers-USACE 2012 New Dimensions in Pavement Maintenance management (About File)
[4] Ismail N, Ismail A and Atiq R 2009 An Overview Of Expert Systems In Pavement Management (Eur. J. Sci. Res.) vol 30 pp 99–111
[5] Almuhanna R R A, Ewadh H A and Alasadi S J M 2018 Using PAVER 6.5, 7 and GIS Program for Pavement Maintenance Management for Selected Roads in Kerbala City (Case Stud. Constr. Mater) vol 8 pp 323–32
[6] He Z, Qin X, Wang H and Comes C 2017 Implementing Practical Pavement Management Systems for Small Communities: a South Dakota Case Study (Public Work. Manag. Policy) 22 378–91
[7] Sarsam S I 2016 Pavement Maintenance Management System: A Review (Trends Transp. Eng. Appl.) vol 3 pp 19–30
[8] Zumrawi M M E 2015 Survey and Evaluation of Flexible Pavement Failures (Int. J. Sci. Res.) vol 4 pp 1602–7
[9] Smith R E, Darter M I and Herrin S M 1979 Highway Pavement Distress Identification Manual
[10] Karim F M A, Rubasi K A H and Saleh A A 2016 The Road Pavement Condition Index (PCI) Evaluation and Maintenance: A Case Study of Yemen (Organ. Technol. Manag. Constr. an Int. J.) vol 8 pp 1446–55
[11] Neelam J, Nanda P K, Durai B K and Prasada R 2003 *Geographical Information System for Pavement Management Systems* (Development.net, Map Asia conference, India)

[12] Ibraheem A T 2012 Applying Geographic Information System (GIS) for maintenance strategy selection

[13] Parida M, Aggarwal S and Jain S S 2005 *Enhancing Pavement Management Systems Using GIS* (Proceedings of the Institution of Civil Engineers-Transport (Thomas Telford Ltd)) vol 158 pp 107–13

[14] Breen T J and Smith A E 2008 *Airport Pavement Management System*

[15] Broten M 1997 *Local Agency Pavement Management Application Guide*

[16] McCoy J and Johnston K 2001 *Using ArcGIS Spatial Analyst* (Environmental Systems Research Institute)