Spatial Analyses of Pavement Condition at Intersection Sites

Ahmed B AL-kazaz1* and Hussein A Ewadh2

1 Graduate Research Student, Engineering College, University of Babylon, Iraq.
2 Professor Doctor, Engineering College, University of Babylon, Iraq.
*Corresponding Author: Ahmedalkazaz78@gmail.com

Abstract. Repeated and periodic assessments of pavement conditions at intersection sites to improve the serviceability of intersection, is an essential component of the transportation system. Further, continuous maintenance of deterioration and defects that appear on the surface layers of pavement at intersection sites according to pavement condition indices (PCI), is a vital process in pavement management. This research aims at conducting spatial analysis for pavement conditions at intersection sites. The application of the developed measure is demonstrated for three signalized intersections in Hilla city, Iraq, by using distress definition. Point density Estimation (PDE) as spatial analyses and interpolation tool (IDW) in ArcGIS software is used to estimate the position intensity. PDE for Pavement condition applications enables the visualization and extraction of distress density in a selected zone or a network of road, which gives the makers of decision an advanced vision to the problem within a location. In this paper, PDE is used to generate potential distress hotspots map based on distress definition data. The result of this research shows the suitability of the heat map for the maintenance entitlement of a particular intersection. It gives a clear indication of the deterioration in the pavement layers depending on the severity of the colours shown in the heat map. For instance, a section of high score of PCI may include a very deteriorating units of low score of PCI due to the presence of many defects. Hence, it can be concluded that, it is doubtful that the PCI section represents the reality of all units. As a sample section (D) of the AL Thawra intersection where there were damaged units, PCI reached 55, 56, 59, while the PCI of section (D) was 74. The developed heat map demonstrates deterioration condition thoroughly for all units and provides advanced vision to pavement condition at the studied sites.

1. Introduction

Nobody disputes that the road network is one of society's vital infrastructure assets. Improvement and improvement of these essential transport assets would help the public gain more excellent health, convenience, and efficiency in the field of public transport. It is, therefore, important for society to manage maintenance properly. The Pavement Management System (PMS) is a structural process or approach, which could provide a comprehensive inventory and coordinate work while having saved effort and time. As well as, the Pavement management system includes data that indicates the present state of the network of a roadway with the capacity for storing historical information that helps predict the future status of the road. The program could also evaluate the way and assess the related maintenance requirements relating to the funds available [1,2].

Geographic Information System (GIS) is a technological system that helps to manage, implement, and applying PMS. Within the PMS, GIS is being utilized to display, analyse, and store geographic data, including the heat map in color-coding. Rare experiments are underway to combine GIS with PMS. This
work revolves around the development of intersection sites management system for the pavement issues and defaults in Hilla city, Babylon Governorate, Iraq, using GIS and Micro PAVER programmes.

In this study, Micro PAVER is used as a platform management software by entering pavement status data that is collected visually at the investigated intersections. Also, ArcGIS is utilized for spatial analysis, pavement data display, and forecast prediction work. A limited or available budget may not be sufficient for intersection piers maintaining. Therefore, GIS-based PMS is an appropriate solution to these problems. The conventional methods of locational referencing and road pavement management were not suitable for the comprehensive computerization of highway information [3]. Road information is geospatial and has recently been managed in Geographic Information System (GIS) environment [4].

GIS incorporates hardware and software tools to help manage, evaluate, and graphically represent all types of geospatially referenced data. It gives information about the form of graphs, reports, and charts, to view, query, monitor, and visualize data in ways that will create trends, patterns, and relationships. GIS assists in answering questions and solving issues by looking at data in a way that is readily understood and easily shared to allow better decision making. The infusion of GIS has benefited the PMS development and implementation effort in these regards [5]. GIS has been utilized, for instance, in road conditions evaluation, maintenance approaches, and progress suggestions, road upgrades prioritization, and the production of preliminary cost estimates [4,6]. This realization, along with the need to enhance and improve Pavement Management (PM) in the study area, informed the study decision, which could serve as a prototype for other Pavement management agencies.

2. Defects in Flexible Pavements
As the scope of this research is limited to sites paved by flexible pavement, characteristic of associated defects are reviewed. These may be a result of reduced production of product components, design or development defects, environmental and temperature conditions, and unusually heavy traffic. One can differentiate two defects' types: structural and functional.

Functional defects express superficial deterioration of the pavements wearing course; this degradation decreases all vehicle grip to ground and road surface evenness and therefore jeopardizes road safety. Factors responsible for this form of deterioration and causing anti-slip problems to include total flattening (or polishing), exposure to the bitumen surface (recognized as bitumen blooming) [7], and total separation. Issues with smoothness include longitudinal undulations, transverse undulations (more commonly called ruts), bulges or hollows, dips on substantial surfaces, and cracking of the tops.

Instead, design deficiencies exist in the superstructure supporting courses. These faults include surface fractures and splits and, more commonly, longitudinal and transverse cracks, longitudinal cracks alone, transverse cracks alone, ramified cracks (spider or alligator cracks), and failures [8,9].

3. The Pavement Management System (PMS)
The Pavement Management System (PMS) is defined as: "a group of methods or tools which could assist decision-makers in identifying cost-effective strategies to provide, evaluate and maintain pavement in a condition of serviceable" [10].

Based on above description PMS can address the following questions:
- What are the most cost-effective rehabilitation and maintenance (R & M) approach?
- Where are needed treatments of (R & M) (which segments of paving)?
- When could the best time (condition) for preparing a treatment to be?

4. GIS within PMS
In the management program, pavements management needs an appropriate decision support structure. GIS may be an integral part of the decision support network by enabling geographic data planning,
review, presentation, and management. GIS enables the user to view, query, monitor, and model data in ways that define trends, patterns, and interactions in the form of maps, graphs, and reports [11]. In other words, GIS works by looking at data to answer questions and fix challenges, so developers can easily interpret the results. GIS will improve research and provide details in the PMS.

5. Micro PAVER and PAVER
PAVER is a pavement management system that was designed for use by military installations, municipalities, airports, and counties. Recently the PAVER programs were rewritten and updated for the microcomputer and released as the Micro PAVER pavement management system. The Micro PAVER system uses the PCI rating as the basis for a practical decision-making procedure for identifying cost-effective maintenance [4] and repairs on airfield pavements, roads, streets, and parking areas. The PCI of a section is used to determine the appropriate type of maintenance and repair alternative and to determine the resulting cost. In addition, the PAVER system also provides many other important capabilities including data storage and retrieval, pavement condition rating, project priority ranking, inspection scheduling, determination of present and future network condition, determination of maintenance and repair needs and costs, and budget planning. [12].

6. Spatial analysis
Spatial analysis or spatial statistics comprise all of the formal methods that use their topological, geometric, or geographic characteristics to analyse entities. Spatial modelling includes several strategies. Complex problems emerge in spatial analysis, most of which are not well described nor entirely answered but are the focus of current work. The most significant of these is the question of identifying the spatial position of the individuals under analysis. Classification of spatial analysis methods is difficult due to the huge vast number of various study areas included, the many general strategies that could be used, and the various types that the results could take. Forms of spatial analysis methods are; kernel density, lane density, point density, in addition to the weighted inverse distance (IDW) interpolation method utilized.

6.1 Kernel density
Kernel density is a tool of spatial-analysis in Arc GIS, KDE involves placing asymmetrical surface over every point and then measuring the distance from the point to the reference location based on a mathematical theorem, and then sums the value for all the surfaces for that location. The following points are reoccurred with this procedure. This sequential enables us to put a kernel over every point, and summing up these individual kernels gives us the density calculation for an unsafe event point’s distribution [13]. See Equation (1.1)

\[
f(x, y) = \frac{1}{nh^2} \sum_{i=1}^{n} k \left( \frac{d_i}{h} \right)
\]

Where \( f(x, y) \) represents the density predicted at the point \((x, y)\); 
\( k \): is the kernel function, 
\( n \): is the number of the observation, 
The distance between \((x, y)\) point and the \((i\) remark) point is called \(d_i\), and 
\( h \): is the kernel size or bandwidth.

6.2 Line density
The line density function measures the linear character density of every output raster cell in the neighbourhood. The density is measured in length units per unit area. Functionally, using the quest radius, a circle is drawn around the centre of raster cells. Its position in the field Inhabitants determines the portion’s length of every line falling inside the circle. These estimates are rounded up, and the number divided by the area of the circle.
6.3 Point density Estimation (PDE)

The point density device measures the point density characteristics around every raster output unit. Thematically, unit distress is specified around each middle of the raster cell, and the points’ number within the units is summed and separated by the unit area. The expected density at a new position \((x, y)\) is calculated by the equation below [14]:

\[
\text{Density} = \frac{1}{(\text{radius})^2} \sum_{i=0}^{n} \left( \frac{2}{\pi} \cdot \text{pop}_i \left(1 - \left(\frac{\text{dist}_i}{\text{radius}}\right)^2\right)^2 \right)
\]

(2)

Whereas:

- \(i = 1, \ldots, n\) are the points of input. Involve points in the sum only if they are within the radius distance of the location \((x, y)\).
- \(\text{pop}_i\): is the inhabitant's field value of point I, which is an optional parameter.
- \(\text{dist}_i\): is the distance between the point \((i)\) and the \((x, y)\) location.

The distinction between the Line Density and Point Density methods is that point features are added first and linear features second. The two measure the amount defined by the PCI sector, which falls within the segment described, separate that amount by the unit area. The difference between the output of these two tools and that of Kernel Density is that a section is defined in point and line density, which calculates the section density around each output cell. At every point out from the point position, the kernel density extends the known volume of distress. The resultant surfaces at every kernel density point are centred on a quadratic formula with maximum value in the surface centre (the position of the point) and tapering to zero at the distance of the quest radius. The cumulative number of the cumulated intersections of the individual distributed surfaces is determined for every output cell. The point density is used in this research because it needs weights, which is represented by the value of PCI for each defect within the unit, which gives high accuracy in drawing the heat map, as well as the kernel density concerned with traffic studies and events mostly.

6.4 Inverse Distance Weighted (IDW)

Utilizing variables from similar measured positions (PCI value), the IDW method calculates an estimated value for unsampled places. The weights are comparable to the similarity of the points of the sample to the position of unsampled, and the power coefficients of the IDW could be defined. The greater the power multiplier, the greater the weight of neighbouring points as gleaned from the following equation, which calculates the value \(z\) at an unsampled position \(j\):

\[
Z_i = \frac{\sum_{i=1}^{n} Z_i^2/d_i^n}{\sum_{i=1}^{n} d_i^n}
\]

(3)

All these methods are tools such as density of point, line and Kernel are mentioned as theoretical part without using the equations due to GIS use the input data to draw the heat map directly without returning to the related equation for each tool.

7. Methodology

The study area and major adjoining features were mapped using a Garmin GPS receiver to provide the base map. Rating and Evaluation of Pavement Surface were performed on every road utilizing rating scale and rating form of pavement condition. A visual conditional survey was conducted by walking through the road lengths. Data collected include:

- Defect type,
The geographic location of each defect (X, Y coordinates) was captured with GPS, the program deals with x and y only.

- The severity of the defect by the visual inspection,
- To which extent defect will be influenced on the surface of the road i.e., a measure of the area, length or count associated with the defect,

The data about the extent, location, kind of the defect, etc. that have been collected were inserted into EXCEL to process and then imported into (10.7 Version) ArcGIS Software to apply additional analysis and present the results.

8. Study Area

This investigation involved three intersections located in the centre of Hilla, Babylon, Iraq, which mainly distributed in Al-Thawra intersection, Bab- AL Hussain–40st (near to AL-Kahraba office street), and Bab- AL Hussain (TAJNED) as demonstrated in figure 1. The area of study is considered a strategic location in centre al Hilla city. Each of the three intersections that were mentioned in the study area was drawn and defined using (GIS) and as shown in figure 2. The intersection region represented by the intersection body was taken, and a distance of (100 m) for each intersection approach was taken for spatial analysis after it was divided into units.

9. Data Collection

Each approach in intersection is divided into two streets, one of them represents inside the intersection, and the other one is outside the intersection. Each street is 100 meters long for each direction divided into several units (from the observation and the statically researches in the city center of Hilla, the load traffic that caused distress is reached to 100 m as a max) [15]. The number of these units depends on the width of the street [1]. The area of the unit is 2500 square feet. The survey of street defects are summarized as a sample in table 1 represent pavement condition at section (SB) inside of the AL-Thawraa Intersection.
Table 1. Sample of Distress Data of AL-Thawra Intersection at SB.

| No. Unit | Code distress | Type distress         | Severity | Quantity | X Unit center | Y Unit center | PCI |
|----------|----------------|-----------------------|----------|----------|---------------|---------------|-----|
| 1        | 11             | Patching and still cut| ✓        | 1m²      | 445683        | 3595821       | 83  |
| 8        | 8              | Jt. Cracking Reflection| ✓        | 15 m     |               |               |     |
| 3        |                | Block Cracking        | ✓        | 1.5 m²   |               |               |     |
| 2        | 11             | Patching and still cut patching| ✓      | 2 m      | 445635        | 3595787       | 73  |
| 8        | 8              | Jt. Cracking Reflection| ✓        | 15 m     |               |               |     |
| 3        |                | Block Cracking        | ✓        | 0.5 m²   |               |               |     |
| 3        | 8              | Jt. Cracking Reflection| ✓        | 15 m     |               |               |     |
|          | 10             | Lang and Trans Cracking| ✓        | 15 m     |               |               |     |
|          | 19             | Weathering Raveling   | ✓        | 10 m²    |               |               |     |
| 4        | 11             | Patching and still cut patching| ✓     | 1 m²    | 445614        | 3595778       | 75  |
| 8        | 8              | Jt. Cracking Reflection| ✓        | 15 m     |               |               |     |
| 11       |                | Patching and still cut patching| ✓      | 1 m²    |               |               |     |
| 6        |                | Depression            | ✓        | 3 m²     |               |               |     |
| 19       |                | Weathering Raveling   | ✓        | 20 m²    |               |               |     |
| 10       |                | Patching and still cut patching| ✓     | 3 m      |               |               |     |
| 5        | 11             | Patching and still cut patching| ✓     | 0.5 m²  | 445603        | 3595766       | 51  |
| 6        |                | Depression            | ✓        | 2 m²     |               |               |     |
| 8        |                | Jt. Cracking Reflection| ✓        | 15 m     |               |               |     |
| 3        |                | Block Cracking        | ✓        | 0.4 m²   |               |               |     |
| 6        |                | Depression            | ✓        | 4 m²     |               |               |     |
| 6        | 19             | Weathering Raveling   | ✓        | 15 m²    | 445596        | 3595751       | 83  |
| 6        |                | Depression            | ✓        | 3 m²     |               |               |     |
| 7        | 10             | Lang and Trans Cracking| ✓        | 3 m      | 445590        | 3595739       | 95  |
| 6        |                | Depression            | ✓        | 2 m²     |               |               |     |

10. Analysis and Results
The (PCI) was extracted for the intercept units in the paver program by inter-data of distress for the unit and calculate (PCI). Defects of the units were entered into the pavers programme and extracting the PCI magnitudes for each unit via the program as shown in figure 3 as a model of inputs and outputs.
After defects were entered in the paver program and extracting the PCI for each unit, a procedure of using GIS program is summarized as follows:

1) The intersection is divided into sections and each section into sample units depending on the type and severity of pavement distress, which is evaluated by visual inspection of the pavement sample units. And then using the distress data to calculate the PCI for each unit and entering it in the GIS program, the program converts the digital PCI of the intercept to the colour grading according to the severity shown in the figure 4 where they represent them as points using symbology.

2) The site and the coordinates (X, Y) were logged through the GPS device (Dual Electronics XGPS160 Multipurpose Universal 5 Device Bluetooth GPS Receiver with Wide Area Augmentation System and Portable Attachment) of each unit centre, and then these coordinates were entered into the GIS program with PCI via tables using IDW. IDW is one of the tools Interpolation in the GIS program where a heat map of the units was extracted, as in figure 5.
The location and the coordinates (X, Y) are recorded for each defect by GPS, and not for each unit. Then the coordinates were entered into the GIS program by using the Point tool of the density tool in the program (GIS). A heat map was extracted with every defect that represents the deterioration in the gradient intersection of the colours from best to worst, knowing that the red colour represents the top of the deterioration in the pavement as in Figure 6.

In the intersection zone, a level of deterioration is categorized into five various levels applying an equal interval data classification technique in Arc-GIS tools. So, the whole assessed grid cells group (well-organized in respect of PCI magnitudes) was separated into five sets (from very little to very high) depending on IDW analyses and in this research we used just used five colours instead of 7 colours that indicated in [15] since multicolored causes blurring and overlapping of affected areas and other areas due to convergence. Thence, the top-mostly levels (for example, level 5) representing very highly distress for the intersection was selected as hot spots, table 2 shows the classification of IDW and symbology levels at an intersection.
Figure 6. Heat Map of Distress at AL Thawra Intersection Using (Point Density).

Table 2. Classification of (IDW and symbology) Distress Levels of An Area at Intersection [15].

| The level of PCI | Kind of zone within the site | The colour indicated for every PCI |
|-----------------|-------------------------------|----------------------------------|
| 1.              | Very little distress          |                                  |
| 2.              | little distress               |                                  |
| 3.              | Average distress              |                                  |
| 4.              | Highly distress               |                                  |
| 5.              | Very highly distress          |                                  |

11. Conclusions and Recommendations

The managing of road pavement conditions, especially the spatial analysis, needs more attention. This study aims to focus the light on the utilizing of the pavement condition index in geographic information systems (GIS) to draw a heat map that represents the degree of deterioration of pavement in intersections.

- The Heat map represents a very clear indication of the priorities and entitlements of intersections maintenance.
- For instance, a section of high score of PCI may include a very deteriorating units of low score of PCI due to the presence of many defects. Hence, it can be concluded that, it is doubtful that the PCI section represents the reality of all units. As a sample section (D) of the AL Thawra intersection where there were damaged units, PCI reached 55, 56, 59, while the PCI of section (D) was 74.
- The developed heat map demonstrates deterioration condition thoroughly for all units and provides advanced vision to pavement condition at the studied sites.
- By collecting distress data for some of the intersections, it is observed that most of the deterioration in the pavement layers due to misuse of the exposure of pavement to large quantities of water for the disposal of restaurants and commercial areas. As well as the absence of sewage networks for the region, which led to the deterioration of pavement, so it is recommended to establish drainage networks in these areas for the pavement not to deteriorate quickly.
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