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Jordan Journal of Civil Engineering, Volume **17**, No. **2**, **2023**
DOI: https://doi.org/10.14525/JJCE.v17i2.07

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ABSTRACT

This paper aimed at utilizing GIS software in calculating pavement condition index (PCI) values, using four different interpolation methods: IDW, spline, trend and kriging. The case study covers four major streets in Nablus city with a total length of about 6.50 km. The PCI values were calculated using the ASTM conventional method. The four streets were divided into equal 100- meter sections. The PCI values were also calculated for each point of defect in both directions of the streets. The results of the four methods (point by point of defects) were compared manually with the conventional method (ASTM procedure). The results showed that the spline method had a strong correlation with the conventional method in terms of multiple R and R-square calculation (multiple R for left 0.918, right 0.947 and R^2 for left 0.843, right 0.897). This method also fitted the data better than the other methods, as seen from the linear regression model results, in addition to producing the minimum error value. The results indicated that by identifying the PCI value, it would be possible to select the proper pavement maintenance and corresponding cost for each point of defect. This in turn would help in prioritizing pavement sections.

KEYWORDS: Pavement condition index (PCI), GIS, Interpolation, Distress, Maintenance, Spline.

INTRODUCTION

Background

Nablus city is the second largest Palestinian city, after East Jerusalem, in terms of population. In addition to its strategic location, it is also considered the economic capital of Palestine. Nablus is also home to An-Najah National University, the largest Palestinian university.

The purpose of this paper was to assess the existing pavement conditions of street sections in the western part of the city nearby An-Najah National University. This assessment of the targeted streets is needed, because they serve the students of An-Najah National University and receive a considerable amount of daily traffic volume from surrounding governorates, such as Tulkarm, Salfit and Qalqiliya. Moreover, some of these streets are commercial. Accordingly, the assessment of such streets in terms of pavement conditions would be reflected in the comfort of riding and the safety of both drivers and pedestrians. The total length of the targeted streets is 6.50 km: Yasser Arafat (1.90 km), Omar Ibn Al-Khattab (0.60 km), Adeeb Mihyar (1.50 km) and Moh'd Bin Rashid Al-Maktom (2.50 km).

Research Problem

Pavement or sidewalk conditions affect directly the safety and comfort of people and the quality of their lives. Accordingly, it is necessary to assess the existing conditions of pavements by applying part of the pavement management system and supporting municipalities in investigating their road assets. Furthermore, the existing pavement conditions need to

Received on 12/1/2022.
Accepted for Publication on 23/12/2022.

be assessed, in terms of severity and density in these critical streets, by rating them and calculating the pavement condition index (PCI) value for each street defect. Identifying their related ratings would help in determining the proper maintenance strategy and action. Moreover, the rating of these points on these streets would contribute to their rearrangement based on their priority maintenance needs. The conditions are represented by the following common existing pavement distresses: patching, surface deformation, bleeding, rutting, raveling and potholes. Therefore, it is important to study these problems, because they affect the traffic flow on these streets.

Objectives

The objectives of this paper were two-fold. The first objective was to assess the existing conditions of four streets in the western section of Nablus in terms of pavement distresses. This assessment is expected to help Nablus Municipality and Palestinian municipalities in general apply part of the pavement management system preventive maintenance strategy: applying the right treatment to the right section at the right time. The pavement conditions, usually expressed by the existing distresses, were collected for each point of distress by filling certain forms considering both traffic directions. The second objective was to predict the PCI value for each point of distress using four methods and utilizing the GIS tool and then compare the results and find the most PCI-correlated method.

LITERATURE REVIEW

Street conditions can be assessed and evaluated by different agencies and models, as there are many periodical surveys made by transportation agencies for assessing, evaluating and tracking pavement conditions to measure distress types and levels. Major distress types can be listed: as permanent deformations or distortions; cracks and patches; and surface defects (Cafiso et al., 2006).

Micro-PAVER is a systematic approach that has been developed for the determination of maintenance, improvement needs and priorities for pavement management. This approach is used to manage roads, streets, airfield pavements and parking lots based on PCI (Obaidat et al., 2018; Shahin and Walther, 1990; Norlela et al., 2009). PCI is a numerical index that identifies the pavement conditions. It ranges from 0, meaning failed pavement conditions, to 100, meaning excellent pavement conditions (Cline et al., 2003).

However, the standard PCI scale uses seven different categories to assess pavements while the special PCI scale uses only 3 or 5 different categories. The micro-PAVER marks each category with a different color to characterize different situations or pavement qualities within both standard and special scales (Kirbas and Gursoy, 2010).

Many researchers have studied GIS, PMS and PCI integration by measuring distress type, severity and pavement condition using PCIs.

Ibraheem and Falih (2012) studied the use of GIS as a tool for pavement management decision-making. In their study, a GIS-based system was built to provide data that can be used as a platform for all types of pavement maintenance and management system (PMMS) process. They selected 23 distressed sections and drew a map for their explanation. Then, they suggested the treatment and maintenance for each section based on the type of distress and present serviceability index (PSI) value.

Boyapati and Kumar (2015) used the PCI method to determine the conditions of the pavements in two different sections (Sathamagalam - Keelapur and Thanjavur - Ayyampetai) based on the procedures outlined in ASTM D5340-18. The first section had PCI values ranging from 40 to 45. It was classified as in a fair pavement condition, with a priority PR3 level (rehabilitation). The second section exhibited PCI values ranging from 24 to 56. That is to say, it had three different pavement conditions: very poor, poor and fair. Its maintenance priority levels were PR1 reconstruction; PR2 and PR3 rehabilitation.

Ali et al. (2022) utilized ASTM D6433-18 to assess the pavement condition index. The PCI rating utilizes a scale of seven different classifications (excellent, very good, good... etc., failed) to show different situations within the rankings.

Al-Neami et al. (2018) conducted an assessment of Al-Amarah Street in Iraq's Al-Kut downtown using PCI and GIS techniques to estimate flexible pavement conditions. They conducted visual surveys to make use of the PCI method.

Pinatt et al. (2020) made a functional analysis of the objective and subjective assessment of PCI, using GIS, to identify the most damaged pathways based on the urban pavement management system (UPMS). After conducting both objective and subjective assessments, they compared them with each other using Pearson's correlation coefficient and finally, they generated maps in the ArcGIS software.

Issa et al. (2021) predicted PCI by modeling the relationship between distress type and severity, with PCIs through a straightforward and adaptive model. They used the artificial neural networks (ANN) approach and capabilities to forecast the PCI values of different sections. They reduced the required technical expertise and efforts to estimate PCI values. The use of ANN supported the possibility of introducing new localized variables, like the presence of manholes in pavement sections.

Dušan et al. (2021) used different interpolation methods, including IDW, spline and Topo to Raster in ArcGIS and the regularized spline method with the tension method in GRASS GIS (GRASS GIS Spline), to generate map layouts of the chosen sections according to PCI values.

Mitašová et al. (1990) proposed a method which supposed that the GRASS GIS environment would create a combination of the regularized spline and the tension methods and determine the nature of the resulting surface, thus providing better results (qualitative and visual) not only in topography, but also in other modeling types (Mitášová and Mitáš, 1993).

This paper's contribution is represented in its checking of the interpolation between the calculation of PCI, using the conventional method [100 m section length] and the calculation of the PCI for each point distress using four different interpolation methods. The results revealed that the point method was more accurate than the conventional one and the spline method was the most accurate among the four interpolation methods.

METHODOLOGY

Methodology Followed and Steps

To realize the objectives of this paper, the researchers collected data for each distress as a point. They identified the coordinates (x, y) in terms of density and severity of all existing pavement distresses. Then, they fed the collected data into the GIS software and generated several maps. The collected data included attributes for: types of defects, severity, characteristics, dimensions (quantity), coordinates (x, y) and station. After that, the researchers calculated the density. The role of GIS was substantial in this paper, as the coordinates and PCI values were fed into the GIS and different methods of interpolation were used to find the PCI value for each point on the street and hold a comparison between the different methods. The process was concluded with the generation of several maps using GIS and the selection of the best one.

The results of predicted PCI values of the four interpolation methods were compared with the results of the PCI values calculated using both the conventional method and regression statistics to validate the initial results.

Finally, five categories were identified for each point of pavement distress according to the special PCI scale: very poor, poor, fair, good and very good. Figure 1 illustrates the methodology followed in the research.

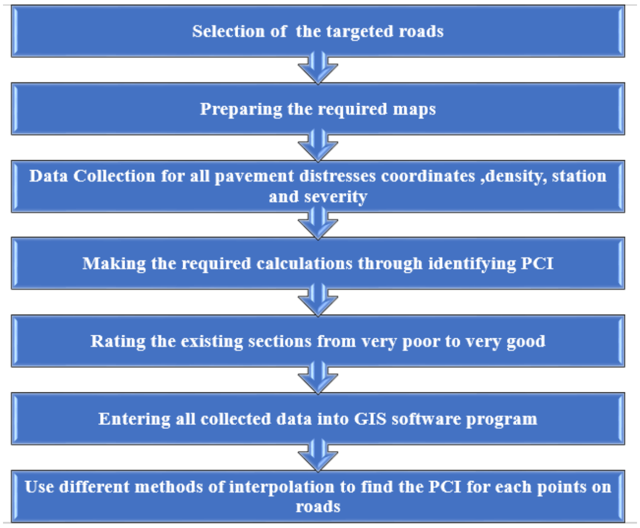

Figure (1): Research methodology

Assessment and Rating Analysis

Pavement condition rating analysis was conducted for all existing defects on the targeted streets. Their numbers were recorded according to their classification and level of severity. The PCI rating was calculated based on ASTM – D6433.

Feeding Data into GIS

All collected data was fed into the GIS software program to generate several maps. The rating of each point of defect was achieved by calculating PCI, which was one version of the maps. The presentation of the rating of each point, by using a special color, facilitated the process of investigating/identifying the possible locations of accidents and the locations that needed improvement for safety purposes and accordingly applying the proper treatment and maintenance.

The relevant shape files of the targeted streets for the study area were downloaded from the official MoLG website "Geomolg". Then, the shape files of each street were inserted. The PCI value for each point of defect was added to the ArcMap (GIS) software. Four different methods of interpolation were used to find the PCI value for each point on the street.

The final output was a GIS map that indicated the PCI values and ratings based on which it would be decided to apply the proper treatment. The map would also give an idea to drivers to consider the bad points on the street where there is a possibility for accidents.

DATA ANALYSIS

Interpolation Definition

The process of using points with defined or estimated values for the prediction of unknown values is usually called interpolation. For example, interpolation can predict chemical concentrations, elevations, levels of noise and rainfall amounts.

The objective of the interpolation process is to visit every location to measure the area, severity and other data to find whether the PCI value for each point on the street is indeed difficult, time-consuming and costly. As an alternative, a distributed sample of input locations (points) could be determined and a value can be predicted and assigned to all points.

It can be said that objects which are spatially distributed can make the interpolation a viable option. For instance, if the value of PCI for a specific location on the street were known, we could predict, with a high level of confidence, the PCI value for another neighboring location.

Methods of Interpolation

There are several interpolation methods, like inverse distance weight (IDW), spline, kriging and trend. The GP team uses them to find the PCI value, hold a comparison between them and select the best method. No matter which method is chosen, with more input points and a higher distribution, more reliable results could be obtained (Mitašová et al., 1990).

IDW (Inverse Distance Weight) Interpolation

The first interpolation method, IDW, supposes that each input point has a specific local influence that eliminates the distance. The closest points to the processing cell are given greater weights than the remote counterparts. To determine the output value for each location, a certain number or all points within a certain radius could be used. In the IDW method, the influence of mapped variables decreases with the distance of their locations. For specific types of data, it is possible to go back to the collection site and register a statistically different new value from the original one while keeping the same trend for the areas (Shahin and Walther, 1990).

The moving average technique is used to estimate the interpolated surface. The value should be greater than the minimum and less than the maximum, as shown in Figure 2.

The IDW interpolation method makes the closest points more alike than the distant ones. IDW uses the measured values to predict the value of any unmeasured location. The influence of the closest prediction values is considerably more than that of the farther points. For a measured value, the local influence is reduced with distance as assumed by IDW and the prediction location with close distance is given a greater weight. For each data point, the generated radius around the grid nodes is used in the calculation. Finally, the following options are used to control the use of IDW: radius, power, variable search radius, barrier and fixed-search radius.

Spline Interpolation

Like the previous method, the spline method is used to estimate the PCI value for each point on the street. This method is considered a special type of piecewise polynomial; it is called a spline. This method is often preferred over polynomial interpolation because of the small error value even when using polynomials of low degree. The main advantage of this method is that it avoids the problem of Runge's phenomenon. When interpolating using high-degree polynomials, oscillation can occur between points.

The spline uses both ArcGIS (spline) and GRASS GIS (regularized spline with tension) and aims to verify the reliability and validity of its implementation in the related software. The spline method works as a system of lower-degree polynomials at different intervals. There are many types of polynomial functions, such as linear spline (first-order), quadratic spline (second-order) and cubic spline (third-order) (Fajmon et al., 2005). Each method follows up the others at given points with a functional value. Figure 2 illustrates the estimate of unknown values by bending a surface through known values.

Kriging

This method of interpolation can be defined as a geo-statistical interpolation technique that takes into consideration the degree of variation and distance between identified data points during the estimation of the values in unclear areas. This method estimates the weighted linear combination and takes into consideration the values of the estimated known samples. This procedure generates the estimated surface from a set of points including z-values. The targeted method proposes that the direction or distance between the sample points reflects a spatial correlation that depicts the surface variation. The existing tool appropriates a mathematical function concerning the determined partial or total number of points. Each point has its own radius which helps in determining the location and the result (value). Figure 2 shows the kriging interpolated surface.

The forecast values are calculated through the measurement of the relationship between points, utilizing the weight average complex technique. This method usually uses fixed or variable radii. The produced values for each cell may increase the value of the sample. The surface doesn't pass through the sample. Accordingly, weights are based on the total spatial arrangement. The distance between the measured points and the spatial autocorrelation should be computed.

Trend

This method, a statistical technique, uses the least-square regression to find the appropriate surface and the corresponding sample points. The polynomial equation is used for the targeted surface. The results minimize the variation in the input values. For every input point, the surface is established and the total difference between the predicted and actual values, called the variance, is expected to be as small as possible. Table 1 gives a description of the four methods, while Figure 2 illustrates the trend interpolated surface.

The interpolator is not correct. The output surface seldom goes through the involved points. However, the variation in this method is smooth, as the trends in the sample data are detected like in natural phenomena.

Table 1. Description of interpolation methods

Tool	**Description**
IDW	Interpolates a raster surface from points using the IDW technique.
Kriging	Interpolates a raster surface from points using kriging.
Spline	Interpolates a raster surface from points using a two-dimensional minimum curvature spline technique. The resulting smooth surface passes exactly through the input points.
Trend	Interpolates a raster surface from points using the trend technique.

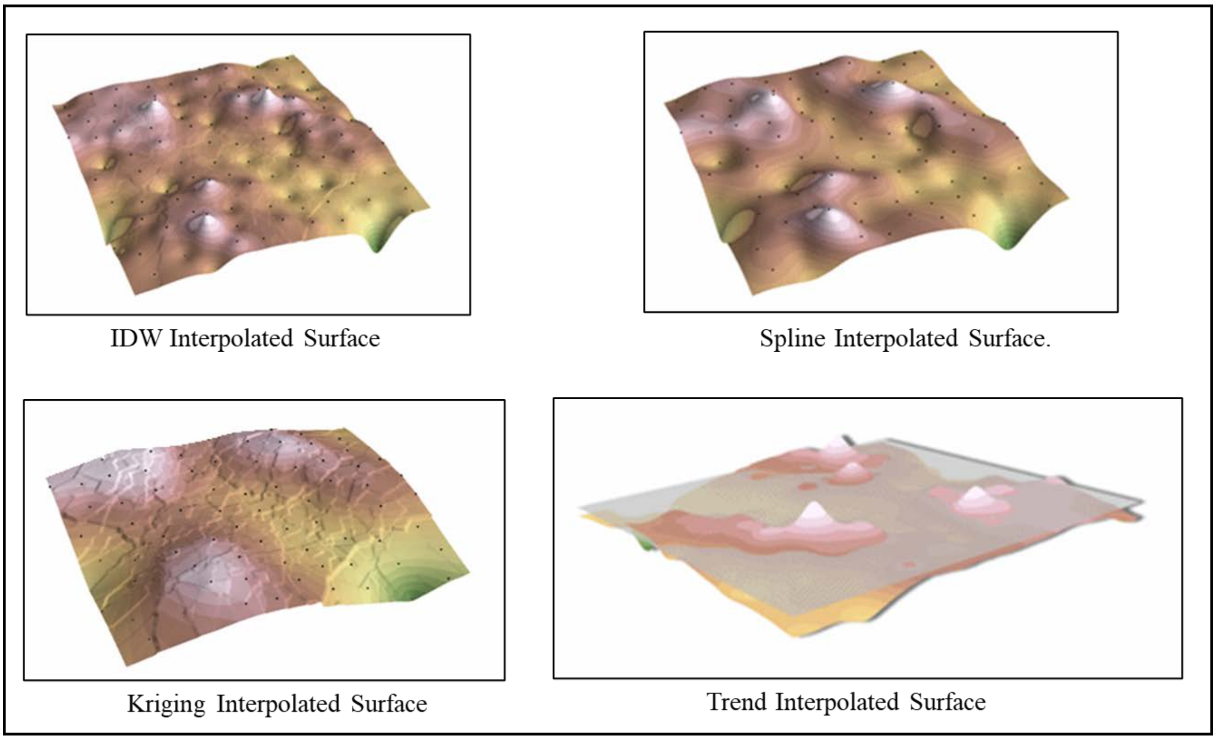

Figure (2): Comparison between types of interpolated surfaces

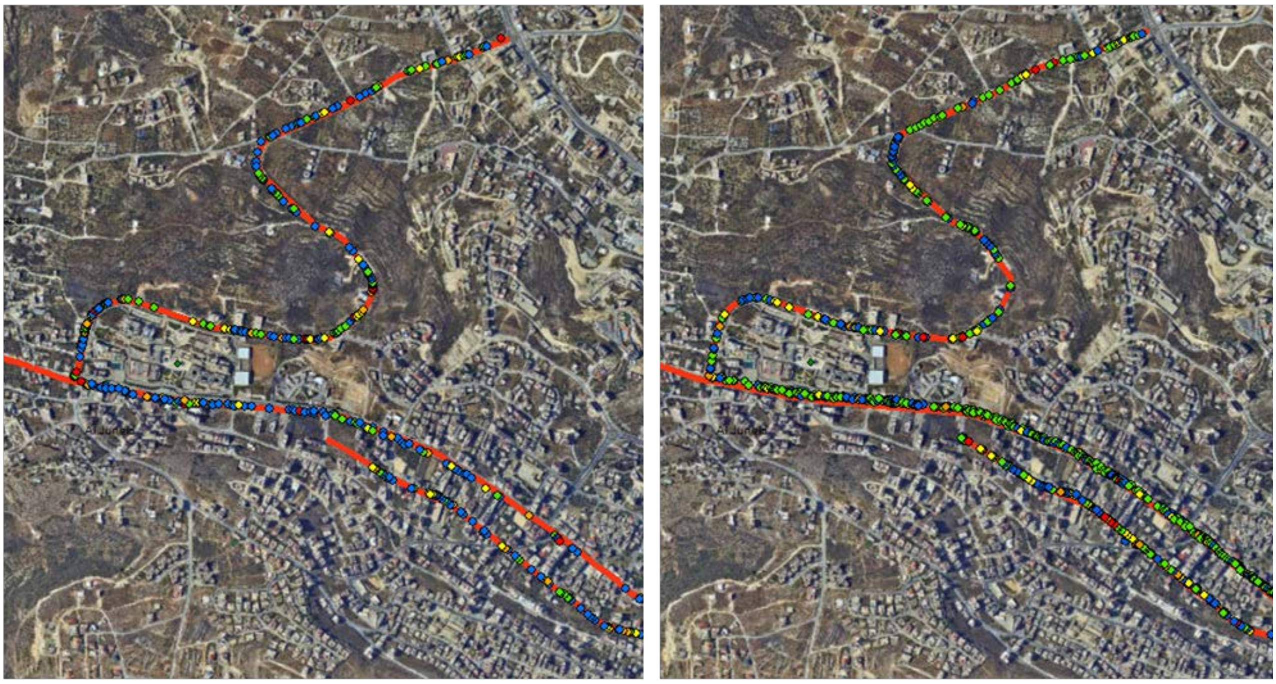

Figure (3): PCI rating for right and left directions

Selection of Proper Interpolation Method

The selection of the appropriate technique largely depends upon many factors. There is no specific technique which can solve all the problems. Moreover, all techniques depend on the characteristics of the variables and the time scale of the presented variable. As there are different techniques of interpolation, the selection of an appropriate one is usually affected by the available data and knowledge of the modeling surface. Each technique works differently, but most of them use the principle of spatial autocorrelation and close objects are better than distant objects. In this research, to select an appropriate method, we compared the four interpolation methods and finally chose the most appropriate one. The choice of the proper interpolation method is usually affected by the sample point quality. Hence, if the distribution of the points in the sample were poor and their number was not enough, the expected results would not represent the actual result very well. The comparison between the four interpolation methods was done by calculating the percentage of the four errors that were used as an accuracy index. The higher the value of this index is, the higher the accuracy is and the lower the errors are. Figure 3 shows the real calculated value of PCI (rating) and the method of interpolation that provides the best prediction. By comparison, the values provide an indication of that the selected method is considered the best.

RESULTS AND ANALYSIS

The interpolation technique is commonly used in literature to produce continuous surfaces, such as elevation surfaces. The use of interpolation for data collection is considered qualitative and accurate. It aims at generating a continuous representation of street conditions. This section of the paper checks the error propagation by using the aforementioned four techniques.

The accuracy index uses and measures typically four errors. These errors are the mean absolute error (MAE), as presented in Equation 1, the root mean square error (RMSE), as shown in Equation 2, the systematic root mean square error (RMSEs), as depicted in Equation 3 and finally, the unsystematic root mean square error (RMSEu), as illustrated in Equation 4. Accordingly, the results with lower mean values and fewer errors give higher accuracy and better performance (Wu and Hung, 2016).

$$MAE = \frac{\sum|Pi - Si|}{n} \qquad Equation\ 1$$

$$RMSE = \frac{\sqrt{\sum(Pi - Si)^2}}{\sqrt{n}} \qquad Equation\ 2$$

$$RMSEs = \frac{\sqrt{\sum(Pii - Si)^2}}{\sqrt{n}} \qquad Equation\ 3$$

$$RMSEu = \frac{\sqrt{\sum(Pi - Pii)^2}}{\sqrt{n}} \qquad Equation\ 4$$

where:

n: The sample size.

Pi: The predicted value of PCI at point i.

Si: The real value (calculated) of PCI at point i.

Pii: The estimated value of PCI at point i, by best-fit regression.

Interpolation Methods: A Comparison

The interpolation technique forecasts a limited number of sample data values for the cells in a raster form. This technique is usually used to forecast the unknown values for any geographic point data, such as chemical concentrations, noise levels, elevation and rainfall. The predicted PCI values are obtained by using the aforementioned four interpolation techniques.

IDW

This method utilizes the average cell values interpolation in the neighborhood of each processing cell for the sample data. The influence or weight of each point on the average process depends mainly on the closeness of the points to the center of the cell.

A sample calculation for the abovementioned 4 errors is presented here for both left and right directions. The percentage of errors with the IDW interpolation process can be calculated as an example:

- For left direction:
  - ✓ Mean Absolute Error (MAE):

$\sum|Pi - Si| = 6770$, n=955… MAE =6770/955=7.09

- ✓ Root Mean Square Error (RMSE):

$\sum(Pi - Si)^2$ =156483.5 … $RMSE = \frac{\sqrt{156483.5}}{\sqrt{955}} = 12.8$

- ✓ Systematic Root Mean Square Error (RMSEs):

$\sum(Pii - Si)^2$ =678063.5 ... $RMSEs = \frac{\sqrt{678063.5}}{\sqrt{955}} = 26.65$

- ✓ Unsystematic Root Mean Square Error (RMSEu):

$\sum(Pi - Pii)^2$ =546098.1 … $RMSEu = \frac{\sqrt{546098.1}}{\sqrt{955}} = 23.91$

- <u>For right direction</u>:
  - ✓ Mean Absolute Error (MAE):

$\sum|Pi - Si|$ =2052.1, n=428…

MAE = 2052.1/428=4.79

✓ Root Mean Square Error (RMSE):

$\sum(Pi - Si)^2$ =33510.31 … $RMSE = \frac{\sqrt{33510.31}}{\sqrt{428}} = 8.85$

✓ Systematic Root Mean Square Error (RMSEs):

✓

$\sum(Pii - Si)^2$ =288936.5 … $RMSEs = \frac{\sqrt{288936.5}}{\sqrt{428}} = 25.98$

✓ Unsystematic Root Mean Square Error (RMSEu):

$\sum(Pi - Pii)^2$ =217746 … $RMSEu = \frac{\sqrt{217746}}{\sqrt{428}} = 22.55$

It can be noticed that the maximum error value is $RMSEs$ =26.65.

Spline

This method uses interpolation which can forecast values, using a mathematical function. It has the potential to minimize the overall surface curvature, resulting in a smooth surface that passes directly through the input points.

The values of percentage of errors in the spline interpolation process for both left and right directions are presented in Table 2.

Kriging

This method is described as a processor-intensive one. The speed of processing depends on the database, number of points and search window size.

Table 2 presents the values of percentage of errors in the kriging interpolation process for both left and right directions.

Table 2. Errors within interpolation methods

Type	MAE		RMSE		RMSEs		RMSEu	
Direction	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
IDW	4.794	7.089	8.848	12.80	25.98	26.646	22.55	23.91
Spline	**4.955**	**5.092**	**8.135**	**8.208**	**25.299**	**20.414**	**23.40**	**18.828**
Kriging	18.397	14.525	23.513	19.528	35.825	23.742	27.213	14.961
Trend	19.967	15.896	25.149	20.758	25.302	20.816	2.133	0.499
PCI each 100 m	**40.04**	**33.52**	**47.27**	**39.1**	**42.39**	**35.38**	**22.87**	**19.21**

Trend

As stated earlier, this method is a global polynomial interpolation technique that uses a mathematical function for the input sample data and fits it into a smooth surface. The trend surface gradually changes and captures the coarse-0 scale in the database. The values of percentage of errors in the trend interpolation process for both left and right directions are presented in Table 2.

Selection of Best Interpolation Method

The four error values for the four interpolation surfaces are presented in Table 2. At the first glance, they are quite compatible with each other, which means that these interpolation methods have similar performances. It can be noticed that the kriging process seems to have higher error measures, which means more errors and therefore, poor performance. This particular interpolation has a large error (35.83) in RMSEs measure, while those of other resulting surfaces are around 25. Of all these four error measures, spline interpolation has considerably lower values than those of the other surfaces in these measures .As a result, the best interpolation process is the spline method. The IDW method also performed similarly to the spline method and both seem to be better than the kriging and trend methods of interpolation.

As Table 2 shows, the results of the predicted PCI of the four interpolation methods were compared with the results of the PCI values which were calculated using the conventional method (for 100- section length). Moreover, Table 2 summarizes the four error measures for different methods of PCI value calculation. It can be noticed that the percentage of errors was larger than that of the spline interpolation method (collection of every point of defect). The method of finding the PCI value by collecting data from every section of 100-meter length is not accurate and does not represent the real value, because a small part of this section may have cracks while other parts may be in good conditions.

After that, several regressions were conducted to validate the initial results. These regressions were built to find the level of correlation between the actual PCI values (the conventional method) and the values of the other proposed methods.

Results in Table 3 and Figure 4 show that the spline method is more efficient than the other methods.

Table 3. Comparison of regression statistics for the four methods

Regression Statistics				
Type	Multiple R		R-square	
	Left	Right	Left	Right
IDW	0.787	0.940	0.620	0.884
Spline	**0.918**	**0.947**	**0.843**	**0.897**
Kriging	0.352	0.369	0.124	0.136
Trend	0.007	0.050	0.00045	0.002

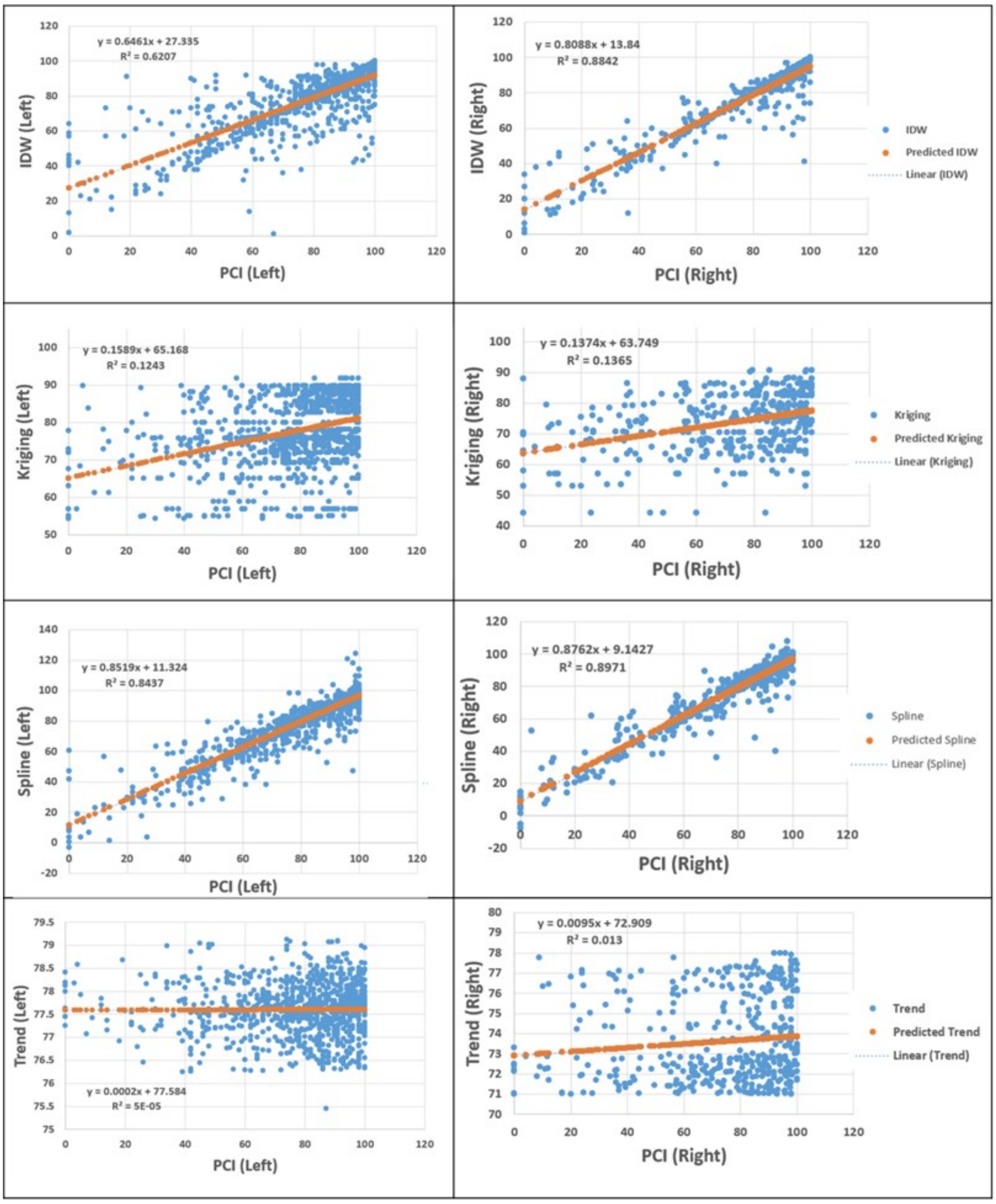

Figure (4): Relationship between PCI values of conventional and spline methods for each point of defect for right and left directions

The regression analysis showed that the spline method performed better than the other three methods (multiple R for left 0.918, right 0.947 and R^2 for left 0.843, right 0.897). It also fitted the data much better than the other methods, as can be seen from the linear-regression model.

Figure 5 shows PCI classifications and ratings, using ArcMap GIS program in both directions.

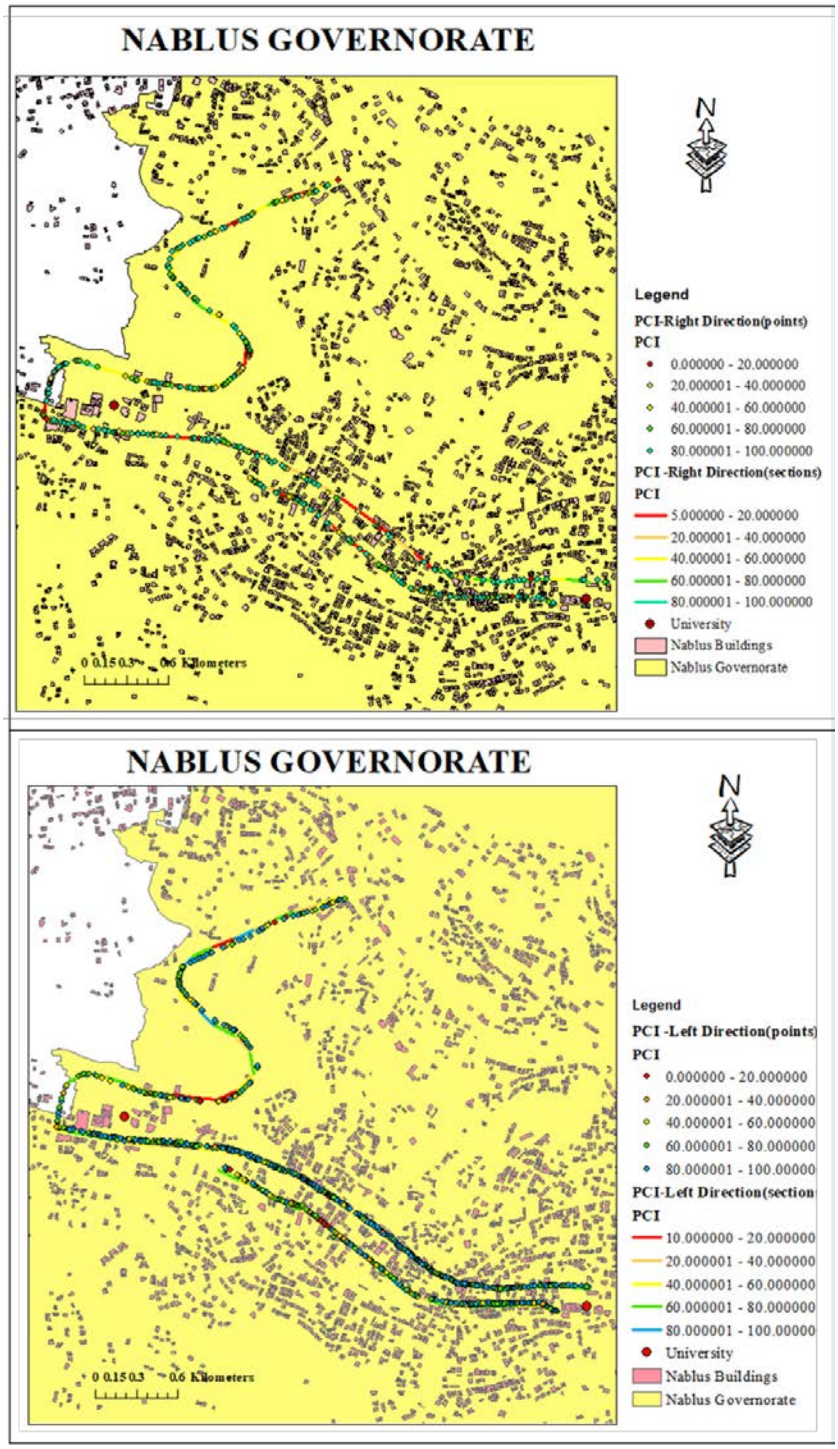

Figure (5): GIS map of PCI rating for right and left directions

CONCLUSIONS

This research aimed at utilizing GIS software in calculating the PCI value using four different interpolation methods. The results of the four methods (point-by-point of defects) were compared with the conventional method (manually) by calculating PCI (ASTM procedure). The results showed that the spline method had a strong correlation with the conventional method in terms of multiple R and R-square calculation. GIS software can be utilized in calculating the PCI for each point of distress and for both right and left directions.

The comparison between the four methods of interpolation showed that the spline method yielded the least error. Furthermore, the results of the regression analysis proved that the spline method outperformed the other three methods (multiple R for left 0.918, right 0.947, and R^2 for left 0.843, right 0.897). Moreover, the spline method fitted the data better than the other methods, as can be seen in the linear-regression model.

The results also showed that it was possible to select the proper specific pavement maintenance and corresponding cost for each point of defect by identifying the PCI value. In addition, the rating of pavement defects for each point, in terms of coordinates and utilizing GIS, would yield more accurate results compared with the conventional method. Finally, identifying specific defects and determining the corresponding proper maintenance treatment and cost for a specific location, using the spline procedure instead of the conventional PCI method, is considered an advantage.

Recommendations

In light of the research findings, the researchers recommend developing a GIS model for calculation of PCI value. They also suggest using different GIS processes instead of the interpolation process or using different methods of interpolation, considering density and severity of distresses. In addition, the researchers recommend conducting a similar study on other streets and sections in other Palestinian cities. They also suggest studying the relationship between the current traffic accidents and the corresponding pavement conditions (improvement of safety and riding comfort). Finally, they suggest identifying the black spots in order to relocate the exact locations of accidents based on the existing pavement conditions.

Acknowledgement

The authors would like to thank very much the GP students for their help in data collection.

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