Evaluation of rigid pavement using the Pavement Condition Index: A Case Study

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Abstract
The pavement is one of the most important components infrastructures of the transport, and so, that has a major and direct effect on the general levels of transportation safety, as well to providing transport services with high quality for movement of people and goods. It is difficult to keep the road on same current specifications that was it since the beginning of the opening of traffic. This requires periodic and preventive maintenance. A methodology was suggested to inspect the current pavement condition; this study focuses on concrete pavements only. A manual inspection has been done according to ASTM D 6433. Depending on two methods; the current pavement condition was calculated by manual calculations and Micro PAVER software method 5.2. The study area is divided into two sides and different sections. Each side or section is divided into sample units. The inspection includes the assessment of the distress type and severity which is assessed by visual inspection for each sample unit and the quantity measurement of each distress. Also, Arc Map 9.3 has been employed in this study for the selected roads in the study area. Therefore, it is necessary to establish or implement an integrated maintenance system for each road in the presented study area, in addition to the establishment of such a system in the future to include all the main and important roads within the province of Baghdad using the GIS program). In this study, two major roads were surveyed; the pavement type is rigid. One of these roads is Salah Al-Deen Road with both sides and the other road is one segment of the Baghdad International Airport Road. The length for each side and section for these roads are 8Km, 7.25Km, respectively. The total length of study area is 23.25 km. Results indicated that the pavement condition index PCI for the two roads mentioned above using manual calculations were as follows; 64.3 and 61.5 for side1 & 2 of Salah Al-Deen Road, respectively, and 80.9 for the segment of Baghdad International Airport Road. While using Micro PAVER software the results were as follows; 62 and 61 for side 1& 2 of Salah Al-Deen Road, respectively, and 80 for segment of Baghdad International Airport Road. The priority of maintenance for the selected roads in the study were as follows; the first road to be maintenance is side 2 of Salah Al-Deen Road, then side 1 for the same road and finally the Baghdad International Airport Road segment.

Keywords:
pavement condition index, Micro PAVER, pavement evaluation

1. Introduction
Road network within the City of Baghdad suffers from lacking and weakness in the system of road management and maintenance techniques based on scientific bases. In addition, it suffers from lacking in performance indicators that may be used in evaluating the pavement condition during its service life.
As the area of the country increases the significance of roads increases, especially in the absence of other wherewithal of transport such as railways and water transport, which often happens in developing countries. Pavement distresses are caused by some or a combination of causes like lack of structural capacity, unsuitable design, poor material quality [1], lack of preventive maintenance and/or poor construction techniques [2]. Surface distresses are generally categorized as several types of blow up, cracking, corner break, faulting, divided slab, spalling corner, etc. In general, pavement professionals were able to classify around 19 distress types that may occur in rigid pavements. The objectives of the study is to find PCI values for rigid pavement using both methods in addition to the rating conditions for selected roads in study area within Baghdad governorate as follows: the first road is Salah Al-Deen Road and the other road is one segment of Baghdad International Airport Road, to produce an integrated database system for the selected roads and considering it as a reference in the road maintenance works in future, to find priorities of the maintenance work, creating a geographic map, which illustrates all distress types and the pavement condition index (PCI) values for each sample unit for the selected roads using GIS software and to compare and validate between the PCI values obtained from the micro paver program and the PCI values, which are obtained arithmetically. The US Army Corps of Engineers developed the most common and important distress manual around the world, with detailed and accurate information on each type of distress in the flexible pavements [3]. It was subsequently adopted by, the American Society for Testing and Materials ASTM D6433-03 for roads.

2. Description of the Study Area

Baghdad governorate is the capital of Iraq republic is selected as the study area. It is located in the middle part of Iraq. The geographical coordinates of Baghdad governorate are (44°25`59.99") longitude and (33°19`59.99") latitude and (34 meter) elevation average. This is an urban area, different types of distresses and same pavement type (rigid). The study area involves part of the major and important roads in Baghdad governorate, as shown in Figure B1 in Appendix B.

The total length of the study area within Baghdad governorate is 23.25 km, which consists of two main and important roads, the highways, serves a large number of government institutions, recreational centers, hospitals, Baghdad International Airport and companies. It also serves residential areas. A big part of damaged area was found in these roads.

2.1. Salah Al-Deen Road

Salah Al-Deen Road is one of roads that is located in a residential urban area in Baghdad governorate, type of pavement is rigid, divided, geometric type is urban and with two directions; this road has eight lanes, four in each direction and it is considered as one of important roads. It is a vital street in Baghdad governorate, which links the north of Baghdad to its south. The satellite image for this road is presented in Plate 1. It is an unsignalized control street; also it has four inlets from the surrounding area for both directions.

2.2. Segment2 of Baghdad International Airport Road

It is an active and a vital road in Baghdad governorate; it is considered as the only entrance for travellers to Baghdad International Airport. This road consists of four segments and two types of pavement (flexible and rigid); where three segments are flexible pavement, while one segment is rigid pavement, which was chosen in this study. It is divided and the geometric type is urban. It is an unsignalized control street; also it has six inlets from the surrounding area for both directions. Plate 2 shows the satellite image for Baghdad International Airport Road.

3. Pavement Condition Rating

PCI is an index, which shows the current condition of pavement according to synchronous assessment of distress type, density and severity. The standard PCI uses a scale of 7 different divisions; a specific version of PCI scale uses only 3 divisions, with different colors assigned by Micro Paver to demonstrate
various states within the scales. Concurrently, current condition is associated to pavement quality (PQ) with the characterizing descriptions. This relationship between PCI and PQ is shown in Plate 3 [4].

Plate 1. Salah Al-Deen Road  
Plate 2. Baghdad International Airport Road  
Plate 3. Pavement Condition Index rating [5]

4. PCI Calculation  
4.1. Steps required for manual PCI calculation

The manual calculation method depends on PCI to assess a pavement. Its calculation is based on the assessment of pavement surface condition by defining; distress type, extent and severity. The fact that the pavement assessment method is dependent on nineteen distress types and it is the most detailed for system of pavement management. Assessment process begins with field inspection in study area, dividing the road into sections or sides, these sections or sides are subdivided into sample units with equal distance. The length of roads in this study is 23.25 km. Each sample unit must be assessed by visual inspection. The computation of PCI includes the following steps:

- Segmentation of the pavement section or side into sample units (N) to determine (N) for rigid pavement by divided the number of road slabs by the sample unit area, which is (20±8 slab).
- To find (n, i and s) according Shahin, 2005. Where (n) represents the minimum number of sample units that must be surveyed (the selections of the minimum number of sample unit were
calculated using Equation (B.1), (i) represents the sampling interval value is determined by \( i = N/n \) and (s) represent Random start value \[6\].

- Determination of distress type, spreading (extend) and severity.
- Determination of the Deduct Value (DV) for each distress type and each severity level using the corresponding to DV curves according (ASTM D6433) \[7\].
- Computation of total deducts value (TDV) as the sum of DVs of all distress types.
- To find the corrected DV (CDV) account for interact among distress types using the corresponding DV curves.
- Calculation of the sample unit PCI from PCI = 100 - CDV.
- The segment or side PCI is then the average of the PCI values gotten for the segment or side sample units.
- Determination of the pavement rating.
- If all inspected sample units are selected randomly, the PCI of the pavement section is calculated by averaging the PCI of sample units. If any additional sample units are inspected, a weighted average must be used \[7\].
- Using of all equations, figures and tables for each type of distress necessary to obtain values of PCI, according (ASTM D6433).

4.2. Finding PCI using Micro PAVER software

U.S. Army Corps of Engineers (USACE) developed the Micro PAVER software program in the mid-1980s to help the Department of Defense manage the maintenance and rehabilitation repair of its vast inventory of roads \[8\]. The software permits for the record, inspection, modeling, reporting, Project planning and condition analysis. Micro PAVER is a decision-making process for identifying cost-effective maintenance repairs on roads, parking lots and airfields \[8\].

Table 1 is shows the details of each selected road in this study and includes the following information.

| No. | Road name                  | Area                  | Pavement type | No. of slab | Sample size | N   | nF. | nE. | i   | s   |
|-----|----------------------------|-----------------------|---------------|-------------|-------------|-----|-----|-----|-----|-----|
| 1   | Salah al-Deen              |                       |               |             |             |     |     |     |     |     |
|     | Side 1                     | 112000 m² (8000*14)m  | Rigid         | 5333        | 28 slabs    | 190 | 30.7 | 30.4 | 6   | 6   |
|     | Side 2                     | 112000 m² (8000*14)m  | Rigid         | 5333        | 28 slabs    | 190 | 30.7 | 30.4 | 6   | 6   |
| 2   | Baghdad International Airport |                   |               |             |             |     |     |     |     |     |
|     | Segment 2                  | 83375 m² (7250*11.5)m | Rigid         | 4350        | 24 slabs    | 181 | 30.3 | 30.2 | 6   | 6   |

Where: nF= denotes for the minimum number of sample from figure.

nE= denotes for the minimum number of sample units from equation.

5. Inventory of the Distresses and Field Measurements for Roads in the Study Area

5.1. Salah al-Deen Road

Side 1 of this road is from AL-Shaala Bridge to Baghdad International Airport road and side 2 from Baghdad International Airport road to AL-Shaala Bridge. Table 1 shows numbers of sample units in this side from Salah al-Deen road. The types of distresses, level of severity of each type and their quantities for both sides of Salah Al-Deen Road were inventoried as shown in Table A1 in Appendix A, and recorded it on the data sheet and then compute all the required variables such as; density, DV and CDV, according (ASTM D6433).

5.2. Segment 2 of Baghdad International Airport Road
It is from buildings of travelers inside the airport to the airport check point. Table 1 shows numbers of sample units of this section. Types of distresses, level of severity of each type and their quantities for segment 2 were inventoried as shown in table A2 in Appendix A, and recorded it on the data sheet and then compute all the required variables such as; density, DV and CDV, according (ASTM D6433).

6. PCI Calculation Results
6.1. Manual Calculation
6.1.1. Salah Al-Deen Road. PCI values were calculated according to (ASTM D6433) based on procedures above as shown in table 2.

6.1.2. Segment 2 of Baghdad International Airport Road. PCI values were calculated according of (ASTM D6433) based on procedures above as shown in table 3.

6.2. Using Micro PAVER software
6.2.1. Salah Al-Deen Road. Table 4 presents the values of pavement condition Indices (PCI) for each sample unit in each side of Salah Al-Deen Road using Micro PAVER method.

6.2.2. Segment 2 of Baghdad International Airport Road. Table 5 shows the values of pavement condition Indices (PCI) for each sample unit in segment 2 of Baghdad International Airport road using Micro PAVER method. Plates 4 and 5 illustrate the process within the Micro PAVER Software program starting with entering the field data collection to the final stage in order to obtain the current pavement condition index (PCI).

Plate 4. Entry of data for Salah Al-Deen Road

Plate 5. PCI value for segment 2 of Baghdad International Airport Road
Table 2. Values of the PCI for each sample unit in unit each sides of Salah Al-Deen Road using Manual calculations.

| Sample unit | Sample type | PCI-Side 1 | Rating  | PCI-Side 2 | Rating  |
|-------------|-------------|------------|---------|------------|---------|
| 2           | Additional-2 | 68.74      | fair    |            |         |
| 4           | Additional-2 | 61.87      | fair    |            |         |
| 6           | Random       | 73         | satisfactory 83.5 | satisfactory |
| 12          | Random       | 52         | poor 46 | poor       |         |
| 18          | Random       | 61         | fair 59 | fair       |         |
| 20          | Additional-2 | 68.36      | fair    |            |         |
| 24          | Random       | 52         | poor 49 | poor       |         |
| 30          | Random       | 40.5       | poor 60.5 | fair      |
| 32          | Additional-2 | 67.46      | fair    |            |         |
| 36          | Random       | 42         | poor 57 | fair       |         |
| 42          | Random       | 49.5       | poor 23 | serious    |         |
| 47          | Additional-1 | 71.48      | satisfactory |          |
| 48          | Random       | 56         | fair 58 | fair       |         |
| 54          | Random       | 56         | fair 61.65 |         |
| 60          | Random       | 47         | poor 51.5 | poor     |
| 66          | Random       | 57.2       | fair 53 | poor       |         |
| 72          | Random       | 74.5       | satisfactory 65.5 | fair |
| 78          | Random       | 82         | satisfactory 73.5 | satisfactory |
| 84          | Random       | 70         | fair 71.5 | satisfactory |
| 90          | Random       | 75.5       | satisfactory 67 | fair |
| 96          | Random       | 54.25      | poor 40 | very poor  |         |
| 102         | Random       | 79         | satisfactory 48 | poor |
| 108         | Random       | 73.5       | satisfactory 80.5 | satisfactory |
| 112         | Additional-1 | 63.93      | fair    |            |         |
| 114         | Random       | 79         | satisfactory 73.5 | satisfactory |
| 120         | Random       | 87.25      | good 80 | satisfactory |         |
| 126         | Random       | 76         | satisfactory 75 | satisfactory |
| 130         | Additional-2 | 64.05      | fair    |            |         |
| 132         | Random       | 76.75      | satisfactory 53 | poor |
| 138         | Random       | 79.5       | satisfactory 59.5 | fair |
| 144         | Random       | 37         | very poor 61 | fair |
| 150         | Random       | 68.25      | fair 75 | satisfactory |         |
| 156         | Random       | 69.5       | fair 74 | satisfactory |         |
| 162         | Random       | 75.28      | satisfactory 77 | satisfactory |
| 163         | Additional-1 | 60.88      | fair    |            |         |
| 168         | Random       | 44.6       | poor 84 | satisfactory |         |
| 174         | Random       | 71         | satisfactory 59.5 | fair |
| 180         | Random       | 76         | satisfactory 65.5 | fair |
| 183         | Additional-2 | 73.15      | satisfactory |          |
| 186         | Random       | 56.8       | fair 50 | poor       |         |

- Additional-1 represents additional sample unit in side1.
- Additional-2 represents additional sample unit in side2.

Table 3. Values of the PCI for each sample in segment 2 for Baghdad International Airport Road using Manual calculations.

| Sample unit | Sample type | PCI-Section 2 | Rating  |
|-------------|-------------|---------------|---------|
| 6           | Random      | 79.8          | satisfactory |
| 12          | Random      | 48            | poor     |
| 18          | Random      | 82.5          | good     |
| 24          | Random      | 62.6          | poor     |
| 30          | Random      | 71            | satisfactory |
| 36          | Additional-2 | 69.31      | satisfactory |
| 42          | Random      | 79            | satisfactory 48 | poor |
| 48          | Random      | 56            | fair 58 | fair       |         |
| 54          | Random      | 56            | fair 61.65 |         |
| 60          | Random      | 47            | poor 51.5 | poor     |
| 66          | Random      | 57.2          | fair 53 | poor       |         |
| 72          | Random      | 74.5          | satisfactory 65.5 | fair |
| 78          | Random      | 82            | satisfactory 73.5 | satisfactory |
| 84          | Random      | 70            | fair 71.5 | satisfactory |
| 90          | Random      | 75.5          | satisfactory 67 | fair |
| 96          | Random      | 54.25         | poor 40 | very poor  |         |
| 102         | Random      | 79            | satisfactory 48 | poor |
| 108         | Random      | 73.5          | satisfactory 80.5 | satisfactory |
| 112         | Additional-1 | 63.93      | fair    |            |         |
| 114         | Random      | 79            | satisfactory 73.5 | satisfactory |
| 120         | Random      | 87.25         | good 80 | satisfactory |         |
| 126         | Random      | 76            | satisfactory 75 | satisfactory |
| 130         | Additional-2 | 64.05      | fair    |            |         |
| 132         | Random      | 76.75         | satisfactory 53 | poor |
| 138         | Random      | 79.5          | satisfactory 59.5 | fair |
| 144         | Random      | 37            | very poor 61 | fair |
| 150         | Random      | 68.25         | fair 75 | satisfactory |         |
| 156         | Random      | 69.5          | fair 74 | satisfactory |         |
| 162         | Random      | 75.28         | satisfactory 77 | satisfactory |
| 163         | Additional-1 | 60.88      | fair    |            |         |
| 168         | Random      | 44.6          | poor 84 | satisfactory |         |
| 174         | Random      | 71            | satisfactory 59.5 | fair |
| 180         | Random      | 76            | satisfactory 65.5 | fair |
| 183         | Additional-2 | 73.15      | satisfactory |          |
| 186         | Random      | 56.8          | fair 50 | poor       |         |
**Table 4.** Values of the PCI for each sample unit in each sides of Salah Al-Deen Road using Micro PAVER method.

| Sample unit | Sample type | PCI-Side1 | Rating | PCI-Side2 | Rating |
|-------------|-------------|-----------|--------|-----------|--------|
| 2           | Additional-1 2 | 65        | fair   |           |        |
| 4           | Additional-1  | 62        | fair   |           |        |
| 6           | Random       | 65        | fair   | 86        | good   |
| 12          | Random       | 52        | poor   | 45        | poor   |
| 18          | Random       | 57        | fair   | 62        | fair   |
| 20          | Additional-1  | 66        | fair   |           |        |
| 24          | Random       | 56        | fair   | 47        | poor   |
| 30          | Random       | 35        | very poor | 57   | fair   |
| 32          | Additional-1 2 | 64        | fair   |           |        |
| 36          | Random       | 38        | very poor | 50   | poor   |
| 42          | Random       | 47        | poor   | 20        | serious |
| 47          | Additional-1  | 71        | satisfactory |    |        |
| 48          | Random       | 49        | poor   | 56        | fair   |
| 54          | Random       | 63        | fair   | 63        | fair   |
| 60          | Random       | 39        | very poor | 47   | poor   |
| 66          | Random       | 55        | poor   | 51        | poor   |
| 72          | Random       | 74        | satisfactory | 59   | fair   |
| 78          | Random       | 80        | satisfactory | 66   | fair   |
| 84          | Random       | 65        | fair   | 72        | satisfactory |
| 90          | Random       | 76        | satisfactory | 65   | fair   |
| 96          | Random       | 49        | poor   | 40        | very poor |
| 102         | Random       | 82        | satisfactory | 48   | poor   |
| 108         | Random       | 66        | fair   | 77        | satisfactory |
| 112         | Additional-1  | 64        | fair   |           |        |
| 114         | Random       | 76        | satisfactory | 76   | satisfactory |
| 120         | Random       | 88        | good   | 82        | satisfactory |
| 126         | Random       | 75        | satisfactory | 67   | fair   |
| 130         | Additional-1 2 | 64        | fair   |           |        |
| 132         | Random       | 78        | satisfactory | 52   | poor   |
| 138         | Random       | 81        | satisfactory | 58   | fair   |
| 144         | Random       | 34        | very poor | 62   | fair   |
| 150         | Random       | 68        | fair   | 73        | satisfactory |
| 156         | Random       | 64        | fair   | 71        | satisfactory |
| 162         | Random       | 73        | satisfactory | 68   | fair   |
| 163         | Additional-1  | 59        | fair   |           |        |
| 168         | Random       | 42        | poor   | 86        | good   |
| 174         | Random       | 67        | fair   | 64        | fair   |
| 180         | Random       | 76        | satisfactory | 63   | fair   |
| 183         | Additional-1 2 | 72        | satisfactory |    |        |
| 186         | Random       | 56        | fair   | 46        | poor   |

- Additional-1 represents additional sample unit in side1.
- Additional-2 represents additional sample unit in side2.
7. Analysis and Comparison between the Two Methods

7.1. Salah Al-Deen Road

This road is divided into 31 random sample units on each side, and contains 5 and 4 additional sample units for side 1 and side 2, respectively. Analysis of Salah Al-Deen road resulted in, using manual calculations method, the highest PCI value is 87.25 and 84 for Side 1 and 2, respectively and the rating of these sides are good and satisfactory, respectively, while the lowest value for PCI is 37 in Side 1 and 23 in Side 2 and the rating of these sides are very poor and serious, respectively. While when using Micro PAVER method, it is noticed that the highest PCI value is 88 and 86 for Side 1 and 2, respectively and the rating of these sides are good, while the lowest value for PCI is 34 in Side 1 and 20 in Side 2 and the rating of these sides are very poor and serious, respectively. Plates 6 and 7 illustrate comparison of PCI values between Manual calculation and Micro PAVER method for each side of Salah Al-Deen Road. The PCI value for each side is 64.3 and 61.5 for Side 1 and 2, respectively using manual calculations method and rating of these sides is fair. While when using Micro PAVER method, the PCI value is 62 in side 1 and 61 in side 2 and rating of these sides are fair also.

Plate 6. Comparison between two methods for the PCI values of Side1 of Salah Al-Deen Road

Plate 7. Comparison between two methods for the PCI values of Side2 of Salah Al-Deen Road

7.2. Segment 2 of Baghdad International Airport Road

This road is divided into 30 random sample units in this section, in addition to 3 additional sample units. Using manual calculations method, it is noticed that the highest PCI value is 100 for segment 2 and the rating of this section is good. While the lowest value for PCI is 35.6 in segment 2 and the rating of this section is very poor. Similarly, when using Micro PAVER method, it is noticed that the highest PCI value is 100 for segment 2 and the rating of this section is good, while the lowest value for PCI is 44 in
segment 2 and the rating of this section is poor. Plate 8 represents comparison of PCI values between manual calculation and Micro PAVER method for Segment 2 of Baghdad International Airport Road. The PCI value for this segment is 80.9 for using manual calculations method and the rating of this segment is satisfactory. While when using Micro PAVER method, the PCI value is 80 in segment 2 and also the rating of this segment is satisfactory.

Plate 8. Comparison between two methods for the PCI values of Segment 2 of Baghdad International Airport Road

Table 6, shows a summary for PCI values for each side and section in the study area. It appears that the lowest value of PCI in the study area, in side 2 of Salah Al-Deen Road, is 62.5 and 61 for both methods manual and Micro PAVER, respectively. This means fair condition for side 2 of Salah Al-Deen Road. This side is external and very important and suffering from the passage of heavy loaded traffic vehicles and lack to routine maintenance. While the highest value of PCI in the study area in segment 2 of Baghdad International Airport Road, which is 80.9 and 80 for manual and Micro PAVER, respectively; this means satisfactory condition for segment 2 of Baghdad International Airport Road. This segment is internal and it is constantly being maintained as an important road and the passage of heavy loaded vehicles is not allowed, and so the distresses are little.

Table 6. The PCI values and the rating for each side and section of the study area

| Study area             | Direction | PCI manually | Rating  | PCI Micro PAVER | Rating  | Length Km |
|-----------------------|-----------|--------------|---------|-----------------|---------|-----------|
| Salah Al-Deen Road    | Side 1    | 64.3         | Fair    | 62              | Fair    | 8         |
| Salah Al-Deen Road    | Side 2    | 62.5         | Fair    | 61              | Fair    | 8         |
| Baghdad International Airport Road | Segment 2 | 80.9         | Satisfactory | 80          | Satisfactory | 7.25      |

8. GIS Application

In this study, GIS program has been used as a database, for displaying and saving data more easily and readily. When using GIS, it is easy to determine the location of each distress type on any road in study area with entered complete information as shown in Plates 9 and 10. The tasks of GIS contain: data entry, data show, data managing, information analysis and retrieval. Data is accepted from a wide-range of sources, satellite image, containing maps, surveys and aerial photographs [9].
9. Maintenance priority for the Selected Roads in the Study Area

The priority of maintenance for the selected roads in the study area was as follows; the first road to be maintained is side 2 of Salah Al-Deen Road, then side 1 of the same road and finally segment 2 of Baghdad International Airport Road as presented in Table 7.

Table 7. Priority of maintenance for the selected roads in the study area

| No. | Road Name                        | Road Number | PCI value | Priority of Maintenance for Each Side and Section According Road Number |
|-----|----------------------------------|-------------|-----------|------------------------------------------------------------------------|
|     |                                  |             | Manually  | Micro PAVER                                                            |
|     |                                  |             | ---       | ---                                                                    |
| 1   | Salah al-Deen Road               | Side1       | 1         | 64.3                                                                  | 62          | 2 | 2 |
|     |                                  | Side2       | 2         | 62.5                                                                  | 61          | 1 | 1 |
| 2   | Baghdad International Airport Road| Segment 2   | 3         | 80.9                                                                  | 80          | 3 | 3 |

10. Conclusions and Recommendations

This study was conducted to assess the current condition of selected rigid pavement roads by visual surveys using the Pavement Condition Index (PCI) method (following standard ASTM D6433). The conclusions that have been accomplished by this study in order to obtain the required objectives are:

10.1. Conclusions

1. Creating a geographic map, which illustrates all distress types and the pavement condition index (PCI) values for each sample unit for the selected roads using GIS software. This map can be considered as an integrated database system for the selected roads within Baghdad governorate and considering it as a reference in the road maintenance works in future.

2. The results of the selected roads in study area showed that the PCI values are 62.9, and 80.9 for Salah Al-Deen Road and Baghdad International Airport Road, respectively, and the rating conditions for these roads are ‘fair’ for Salah Al-Deen Road and ‘satisfactory’ for Baghdad International Airport road; these results were obtained using manual calculations. While when
using Micro PAVER method, the PCI values were 61.5 and 80 for Salah Al-Deen Road and Baghdad International Airport Road, respectively, and the rating conditions for these roads are as follows; ‘fair’ for Salah AL-Deen Road and ‘satisfactory’ for Baghdad International Airport road.

3. The priority of maintenance for the selected roads in this study were as follows; the first road to be maintained is side 2 of Salah Al-Deen Road, then side 1 of the same road and finally section 2 of Baghdad International Airport Road.

10.2. Recommendations

1. Suggestions and recommendations for additional researches are: Creation of integrated database system using GIS software for all major and important roads of Baghdad governorate as the first stage and considering it as a reference in the road maintenance works in future followed by creation of an integrated database for all roads in Iraq.

2. Use of advanced measurement techniques for forecast and evaluation of the pavement condition (PCI) rather than visual inspection for roads, which reduces the percentage of errors that may occur during the visual inspection.

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Appendix A
A.1. Data Collection and Field Measurement

A.1.1. Data Collection of Salah Al-Deen Road

Table A1 represents the types, severities and quantities of distresses in each side of Salah Al-Deen Road

| Description of Distress | Unit | Side1 Severity | Side2 Severity | The Entire Road Severity |
|-------------------------|------|----------------|----------------|--------------------------|
| Blowup/Buckling         | No.  | 0 5 1 0 6 3 0 11 4 |                |                          |
| Corner Break            | No.  | 4 14 6 13 24 13 17 38 19 |                |                          |
| Divided Slab            | No.  | 12 10 7 19 14 3 31 24 10 |                |                          |
| Durability Cracking     | No.  | 2 3 1 6 4 1 8 7 2 |                |                          |
| Faulting                | No.  | 27 65 26 23 35 15 50 100 41 |                |                          |
| Joint Seal Damage       | No.  | 2 10 1 2 15 2 4 25 3 |                |                          |
| Lane/Shoulder Drop-Off  | No.  | 0 0 0 1 0 0 1 0 0 |                |                          |
| Linear Cracking         | No.  | 171 5 1 185 0 0 356 5 1 |                |                          |
| Patching, Large         | No.  | 5 22 5 15 25 13 20 47 18 |                |                          |
| Patching, Small         | No.  | 34 18 3 30 48 3 64 66 6 |                |                          |
| Polished Aggregate      | No.  | 0 3 0 7 0 0 7 3 0 |                |                          |
| Popouts                 | No.  | 0 0 0 0 0 0 0 0 0 |                |                          |
| Pumping                 | No.  | 0 0 0 0 0 0 0 0 0 |                |                          |
| Punchout                | No.  | 2 31 22 13 54 15 15 85 37 |                |                          |
| Railroad Crossing       | No.  | 0 0 0 0 0 0 0 0 0 |                |                          |
| Scaling                 | No.  | 13 13 0 3 5 0 16 18 0 |                |                          |
| Shrinkage Cracks        | No.  | 25 0 0 13 0 0 38 0 0 |                |                          |
| Spalling, Corner        | No.  | 10 30 9 10 19 7 20 49 16 |                |                          |
| Spalling, Joint         | No.  | 46 67 39 49 63 32 95 130 71 |                |                          |

Where: L= Low, M=Medium, H= High

A.1.2. Data Collection for segment 2 of Baghdad International Airport Road

Table A2 represents the types, severities and quantities of distresses in segment 2 of Baghdad International Airport Road.

| Description of Distress | Unit | Segment 2 Severity |
|-------------------------|------|--------------------|
|                         |      | L     | M     | H |
| Blowup/Buckling         | No.  | 0     | 0     | 0 |
| Corner Break            | No.  | 6     | 3     | 0 |
| Divided Slab            | No.  | 4     | 10    | 0 |
| Durability Cracking     | No.  | 1     | 0     | 0 |
| Faulting                | No.  | 12    | 18    | 9 |
| Joint Seal Damage       | No.  | 7     | 3     | 1 |
| Lane/Shoulder Drop-Off  | No.  | 5     | 0     | 0 |
Table A2 Types, Severities and Quantities of Distresses for Segment 2 of Baghdad International Airport Road (continue)

| Linear Cracking | No. | L  | M  | H  |
|-----------------|-----|----|----|----|
| Patching, Large | 18  | 22 | 12 |    |
| Patching, Small | 35  | 17 | 1  |    |
| Polished Aggregate | 0  | 0  | 0  | 1  |
| Popouts | 0  | 0  | 0  |    |
| Pumping | 0  | 0  | 0  |    |
| Punchout | 14  | 10 | 0  |    |
| Railroad Crossing | 0  | 0  | 0  |    |
| Scaling | 0  | 0  | 0  |    |
| Shrinkage Cracks | 8  | 0  | 0  |    |
| Spalling, Corner | 6  | 6  | 2  |    |
| Spalling, Joint | 3  | 14 | 12 |    |

Where: L= Low, M=Medium, H= High

A.2. Types of Distresses and the Degree of Severity in this research

LOW

![Figure A1](image1) A Variation of Severities for Blowup in the Study Area

![Figure A2](image2) A Variation of Severities for Corner Break in the Study Area

![Figure A3](image3) A Variation of Severities for Divided Slab in the Study Area
Figure A4 A Variation of Severities for Durability Crack in the Study Area

Figure A5 A Variation of Severities for Faulting in the Study Area

Figure A6 A Variation of Severities for Joint Seal in the Study Area

Figure A7 A Variation of Severities for Lane/Shoulder in the Study Area

Figure A8 A Variation of Severities for Linear Cracking in the Study Area
Figure A9 A Variation of Severities for Patching (Large) in the Study Area

Figure A10 A Variation of Severities for Patching (Small) in the Study Area

Figure A11 A Variation of Severities for Polished Aggregate in the Study Area

Figure A12 A Variation of Severities for Popouts in the Study Area

Figure A13 A Variation of Severities for Punchout in the Study Area
Figure A14 A Variation of Severities for Scaling in the Study Area

Figure A15 A Variation of Severities for Shrinkage in the Study Area

Figure A16 A Variation of Severities for Spalling Corner in the Study Area

Figure A17 A Variation of Severities for Spalling Joint in the Study Area
Appendix B

B.1. Satellite Image of the Roads within Baghdad Governorate

Figure B1 illustrates of the selected road of this research within Baghdad Governorate

![Satellite Image of the Roads in Baghdad Governorate](image)

**Figure B1** Satellite Image of the Roads in Baghdad Governorate

B.2. Some Equations are used to Find PCI (Pavement Condition Index)

\[
n = \frac{N s^2}{\left(\frac{e^2}{4}\right) (N-1) + s^2} \tag{B.1}
\]

Where:

- \(N\) = total number of sample units in the pavement section.
- \(e\) = allowable error in the estimation of the section PCI (e was equal to 5).
- \(s\) = standard deviation of the PCI between sample units in the section.

\[
m = 1 + \frac{99}{8} (100 - HDV) \leq 10 \tag{B.2}
\]

Where:

- \(m\) = allowable number of deducts, including fractions, for sample unit.
- \(HDV\) = highest individual DV.

\[
PCI_s = PCI_r = \frac{\sum_{i=1}^{K} PCI_{ri} \times A_{ri}}{\sum_{i=1}^{R} A_{ri}} \tag{B.3}
\]

Where:

- \(PCI_s\) = PCI of pavement section.
- \(PCI_r\) = area weighted average PCI of random sample units.
- \(PCI_{ri}\) = PCI of random sample unit number \(i\).
- \(A_{ri}\) = area of the random sample unit.
- \(R\) = total number of inspected random sample units.
\[ PCI_a = \frac{\sum_{i=1}^{4} (PCI_{ai} \times A_{ai})}{\sum_{i=1}^{4} A_{ai}} \]  

\[ PCI_i = \frac{ PCI_i \left( A_i - \sum_{r=1}^{4} A_{ir} \right) + PCI_a \times \sum_{r=1}^{4} A_{ir} }{A_i} \]  

Where:

PCI\(_a\) = area weighted average PCI of additional sample units.

PCI\(_{ai}\) = PCI of additional sample unit number.

A\(_a\) = area of additional sample unit.

A = total section area.