Development of a computer model to analyze and evaluate flexible pavement distresses of roads

(Case study: Ahmed Abdel Aziz Street in Toukh city)

Abstract: There are many methods to treat road distress. These methods need very intelligent people interested in road maintenance to select the most suitable treatment for each road distress. Roads must be designed and implemented according to specifications and standards. A road maintenance program is then developed to preserve roads from any distress, provide road safety and speed, and save road lifetime. The selection of a suitable distress treatment represents a major issue for people interested in road maintenance. Many factors, such as distress type and severity, control the distress treatment selection. In Egypt, no software program helps those interested in road maintenance choose the best ways to treat the distress of flexible pavement roads. Therefore, the objective of this research is to develop a model for handling the distress of flexible pavement roads, identify their severity, and propose the best ways to treat them. The model also enables the user to draw the road segments with their coordinates and cross-section, display any number of distresses on the segments, draw the distresses on the drawn road segments with specified colors, calculate the total cost to treat the distress and identify the road condition according to the pavement condition index (PCI).

Keywords: Road maintenance; Flexible pavement distresses; Distress severity; and Maintenance cost.

1. INTRODUCTION

Infrastructure components need large capital investments and ongoing maintenance. Pavement is considered one of the major infrastructure components. Deterioration of pavement occurs due to traffic loading and climate conditions. The pavement must be maintained periodically to maintain road safety and comfort and preserve the road design period. Activities related to road maintenance are considered critical during the life cycle of the pavement. Vehicle damage occurs, and fuel consumption increases because of pavement deterioration. The deterioration rate relies on many factors, such as construction conditions and traffic characteristics [1].

There is no program used to identify the severity of road distress and select the suitable treatment for these distresses, so in this study, the authors create software for selecting the treatment for each road distress. In this research, the authors study the previous studies related to road distress and maintenance, the types of road distress, and the methods to inspect these distresses. The authors also discuss the road treatment distresses related to distress severity and the methodology of the software, and explain how the software can help people in road maintenance. Finally, a practical case study is handled using the software.

2. LITERATURE REVIEW

Flexible pavement distresses include distresses due to pavement cracking, surface distortion, slippery surfaces, and surface disintegration. Distresses due to pavement cracking are fatigue cracking, block cracking, edge cracking, longitudinal cracking, transverse cracking, slippage cracking, and reflective cracking [2] [3]. Distresses due to surface distortion include corrugations, depression, shoving, rutting, swelling, bumps, sags, and lane/shoulder drop-off. Distresses due to slippery surfaces include

bleeding and aggregate polishing [2] [4]. Distresses due to surface disintegration are raveling, potholes, patching, and railway crossings [2].

Classification of surface condition relies on pavement surface distress indicators, including pavement condition index (PCI), condition survey rating scores (CSRS), condition rating survey (CRS), and international roughness index (IRI). The Egyptian code for urban and rural roads uses the pavement condition index (PCI) to classify the pavement surface condition. (PCI) is defined as a numerical index that is used to describe the pavement surface condition. Many factors affect the calculation of the pavement condition index, such as pavement type, distress type, distress density, distress severity, and the distress number of the segment. The pavement condition index (PCI) ranges from 0 to 100, where the value of 0 refers to the worst surface condition, and the value of 100 means the best surface condition. The road is divided into road segments according to its structural and geometric properties. Each segment is studied, and the pavement condition index is calculated for each segment. After the pavement condition index is calculated and the road condition is identified, the required maintenance is determined [5]. Nave Bayes is an intelligent algorithm that handles the dataset to classify the condition of the road pavement surface. The dataset uses condition survey rating scores (CSRS) such as average rut depth (cm), fatigue cracking per segment percentage area, and drainage condition in pavement surface condition classification. There are three severity levels according to rut depth: slight, which has a rut depth of 1 cm to 2 cm; moderate, which has a rut depth of 2 cm to 3 cm; and severe, which has a rut depth of more than 3 cm. There are three classes of fatigue cracking: Class I, defined as longitudinal cracks that cross between each other and separate every 2 m; Class II, defined as interconnected cracks that look like alligator skin and contain small polygons; and

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Class III, which includes separation between cracks and pieces of pavement that are lost and move under traffic [6].

Maintenance activity selection should take into account many factors, such as distress type, roadway classification, traffic volume, treatment cost, qualified staff availability, material quality availability, appropriate maintenance time, pavement quality, and records of road maintenance [3]. The Egyptian code enables methods to treat many distresses, which include fatigue cracking, block cracking, edge cracking, slippage cracking, corrugations, depression, shoving, rutting, bleeding, polishing of aggregate, raveling, and potholes [2]. Full-depth repair is used to treat many distresses, such as transverse cracking, alligator cracking, rutting, potholes, slippage cracking, and corrugations [7]. Shoving and patching are also treated by full-depth repair. Treatments for edge cracking include crack sealing, while micro surfacing is used to treat the polishing of aggregate and rutting. Seal coat is also considered a good treatment for polishing aggregate, but milling and sealing treat reflective cracking [8]. Full-depth repair also treats swelling, bumps, and sags, and a slurry seal is a good treatment for the polishing of aggregate. The treatments for rutting and depression include leveling and overlaying [9]. The seal coat and crack sealing are considered good treatments for block cracking, longitudinal cracking, and transverse cracking while bleeding and raveling are treated by the seal coat and micro surfacing. Reflective cracking is also treated by the seal coat [10]. The fog seal is used to treat fatigue cracking and raveling, while the slurry seal is considered a good treatment for bleeding, block cracking, and raveling. Fatigue cracking, transverse cracking, and longitudinal cracking are treated by the cape seal [11]. The treatments of edge cracking, longitudinal cracking, transverse cracking, block cracking, rutting, and bleeding include hot mix asphalt overlay after milling [12].

Hot mix asphalt overlay is also considered a good treatment for raveling and depression, while patching is used to treat potholes [3].

Maintenance costs differ according to road conditions, traffic volume, weather conditions, maintenance treatment methods, geographical location, and treatment equipment. A program management maintenance system (PMMS) is used to achieve better maintenance at a lower cost [13]. Four types of treatments, which include crack sealing, patching, overlay, and reconstruction, were studied in 2003 in Laos to implement the maintenance of a two-lane road. The maintenance unit cost of crack sealing, patching, overlaying, and reconstruction was 1.5, 1.5, 6.6, and 21 $/m2, respectively. The steady flow of maintenance funds cannot be achieved for a variety of reasons, including budget holders' lack of understanding of the social and economic importance of maintenance, the politicized budget process, and the fact that visible and popular construction is preferable to maintenance [14]. The unit cost of some treatments and the expected treatment life for different treatment types were reported in Mexico. The different treatments are crack sealing, seal coat, micro surfacing, and hot mix overlay, and their maintenance unit costs were 0.6, 1.02, 1.5, and 2.09 $/m^2, respectively [15]. The maintenance unit costs of crack sealing, the level and overlay, and the mill and overlay are studied in Rowan (USA). The mill and overlay had the highest unit maintenance cost, which equals 105,000 $/lane-mile. The unit maintenance cost of the level and overlay was 84150 $/lane-mile, while crack sealing had a unit maintenance cost of 4550 $/lane-mile [16]. In 2019, the maintenance unit cost of four treatments was handled in a study in Iowa (USA). The four treatments were micro surfacing, slurry seal, patching, and crack sealing and had a unit maintenance cost of 19510.06, 6841.19, 19398.87, and 2985.72 $/lane-mile, respectively [17].

The procedures for cost estimation and selection of M&R sequence for the California implementation were provided by the LCCA tool and RealCost 2.5 California version CA. Pavement life cycle cost analysis (LCCA) is defined as a technique that helps pavement engineers make decisions that balance the cost of construction with future costs, including costs of maintenance and rehabilitation M&R and traffic delays in the work zone in the life cycle. RealCost 2.5 California version (CA) refers to the California version of RealCost software that has been enhanced. The essential information sources, such as unit costs of pavement, traffic data, and pavement structures, were integrated by this software. The user can compare alternative pavement designs by using M&R sequence selection and automated pavement structure selection. M&R costs in the future are estimated by modules of automated cost calculation depending on the pavement type and scope of each construction [18]. An overview of the framework for the two-phase maintenance and rehabilitation was provided in Canada. The framework has two phases: the initial program and the management of project assets. The initial program utilizes modeling of performance, historical data, and optimization to select rehabilitation and maintenance programs for the bidding stage. After the contract is awarded, the asset management phase of the project is implemented. This phase utilizes the monitoring data on contract performance and cost estimation from phase one. The initial program is handled to implement a program for rehabilitation and maintenance during the bidding stage. The framework inputs contain the contract period, specifications of contract performance, deterioration models of maintenance and rehabilitation, generated costs and improvements, and data about the pavement [19].

As shown in the previous studies, there isn't a program that can draw the road segment, identify the severity of road distresses, draw the road distresses on the road

segment, and suggest suitable treatments for each distress, so the authors discuss new software that does what the previous programs cannot.

3. DISTRESSES TREATMENT USED IN THE DEVELOPED SOFTWARE

3.1 Distresses due to surface cracking

Distresses such as fatigue (alligator) cracking, block cracking, and slippage cracking are measured by the area, but edge cracking, longitudinal cracking, transverse cracking, and reflective cracking are measured by the length. There are three categories of fatigue cracking: low-severity cracking, medium-severity cracking, and high-severity cracking. The low-severity cracks, which are parallel to each other and have a width that doesn't exceed 0.6 cm, are treated by the Egyptian code method (1) for fatigue cracking, the Egyptian code method (2) for fatigue cracking, fog seal, cape seal, micro surfacing, slurry seal, seal coat, and hot mix asphalt (HMA) overlay after milling. The medium-severity cracks intersect with each other, forming small pieces, and have a width of 0.6 cm to 1.5 cm. The high-severity cracks of fatigue cracking are wide, intersect with each other, and have a width of more than 1.5 cm. The treatments for medium- and high-severity cracking include the Egyptian code method (1) for fatigue cracking, the Egyptian code method (2) for fatigue cracking, and full-depth repair. Block cracking has three severity categories: low, medium, and high. There are two treatments for low-severity cracking, which have a width of less than 0.6 cm, including the Egyptian code method (1) for block cracking and crack sealing. The medium, having a width of 0.6 cm to 1.5 cm, and the high severity of block cracking, having a width of more than 1.5 cm, have four treatments, which include slurry seal, seal coat, hot mix asphalt (HMA) overlay after milling, and the Egyptian code method (2) for block cracking. There are three categories of edge cracking, which include low-severity

cracking of a width that does not exceed 1 cm and has three treatments, including the Egyptian code method (1) for edge cracking, crack sealing, and HMA (hot mix asphalt) overlay after milling; medium-severity cracking of a width of 1 cm to 1.5 cm, which is treated by the Egyptian code method (2) for edge cracking; and high-severity cracking of a width of more than 1.5 cm, which can be treated by the Egyptian code method (3) for edge cracking. Longitudinal and transverse cracking include three categories: low-severity cracking, medium-severity cracking, and high-severity cracking. Low-severity cracking, which has a width of less than 0.6 cm, has six treatments, which include seal coat, crack sealing, micro surfacing, cape seal, slurry seal, and hot mix asphalt (HMA) overlay after milling. Medium-severity cracking, which has a width of 0.6 cm to 1.5 cm, and high-severity cracking, which has a width of more than 1.5 cm, are treated by full-depth repair.

Slippage cracking has three categories, which include low-severity cracking with a width of less than 0.6 cm, medium-severity cracking with a width of 0.6 cm to 1.5 cm, and high-severity cracking with a width of more than 1.5 cm. All categories of slippage cracking are treated by full-depth repair and the Egyptian code method for slippage cracking. There are three categories of reflective cracking: low-severity cracking, which has a width of less than 0.65 cm; medium-severity cracking, which has a width of 0.65 cm to 1.9 cm; and high-severity cracking, which has a width of more than 1.9 cm. Low-severity reflective cracking is treated by crack sealing, whereas milling and sealing can treat medium- and high-severity cracking.

3.2 Distresses due to surface distortion

Corrugations, depression, shoving, rutting, and swelling are measured by the area, while bumps, sags, and lane/shoulder drop-offs are measured by the length. Corrugations include three categories: low-severity corrugations, which mean simple and perpendicular corrugations to the traffic movement and don't need

maintenance; medium-severity corrugations, which mean modest corrugations perpendicular to the direction of the traffic and are treated by full-depth repair and the Egyptian code method (1) for corrugations; and high-severity corrugations, which are severe corrugations perpendicular to the direction of the traffic and are treated by full-depth repair and the Egyptian code method (2) for corrugations. There are three categories of depression: low-severity, which has a depth of 1.3 cm to 2.5 cm and doesn't need maintenance; medium-severity, which has a depth of 2.5 cm to 5 cm; and high-severity, which has a depth greater than 5cm. Medium- and high-severity depressions are treated by leveling and overlaying and the Egyptian code method for depression. Hot mix asphalt (HMA) overlay can also treat depression of medium severity. Shoving includes three categories: low severity, which is a subtle shoving in the asphalt surface; medium severity, which means a noticeable shoving in the pavement surface; and high severity, which is defined as an intense and spreading shoving. All categories of shoving are treated by full-depth repair and the Egyptian code method for shoving. Rutting has three categories: low-severity rutting, which has a depth of 0.5 cm to 1.5 cm and does not need maintenance; medium-severity rutting, which has a depth of 1.5 cm to 2.5 cm and is treated by the Egyptian code method (1) for rutting and micro surfacing; and high-severity rutting, which has a depth of more than 2.5 cm and is treated by Egyptian code method (2) for rutting. Milling and overlaying and hot mix asphalt (HMA) overlay also treat medium and high severity. There are three categories of swelling: low severity, which is an unnoticeable swelling in pavement layers; medium severity, which is defined as a noticeable swelling where vehicles are driving; and high severity, which is a visible and very noticeable swelling. Bumps and sags have three categories: low severity, which means minor bumps in the longitudinal direction of the road; medium severity, which means modest bumps in the longitudinal direction of the

road; and high severity, which is defined as severe bumps in the longitudinal direction of the road. There are three categories of lane/shoulder drop-off: low severity, which has a depth of less than 3 cm; medium severity, which has a depth of 3 cm to 5 cm; and high severity, which has a depth of more than 5 cm. All categories of swelling, bumps, sags, and lane/shoulder drop-off are treated by full-depth repair.

3.3 Distresses due to surface slippery

Distresses due to surface slippage are measured by the area and include bleeding and polishing of aggregate. Bleeding includes three categories: low-severity bleeding, which occurs a few days in the year; medium-severity bleeding, which occurs a few weeks in the year; and high-severity bleeding, which occurs many weeks in the year. All bleeding categories are treated by the Egyptian code method (1) for bleeding and the Egyptian code method (2) for bleeding. Low-severity bleeding is also treated by applying hot sand, but micro surfacing and seal coats are used for medium-severity bleeding treatment. High-severity bleeding treatments also include slurry seal and hot mix asphalt (HMA) overlay after milling. There are three categories of polishing of the aggregate: low severity, which means slight polishing of aggregate; medium severity, which is defined as a modest and scattered polishing of aggregate in multiple areas of the pavement surface; and high severity, which is severe and widespread on multiple areas of the pavement surface. Low polishing of aggregate severity is also treated by micro surfacing. The treatments for medium polishing of aggregate severity also include seal coat, where slurry seal treats high polishing of aggregate severity.

3.4 Distresses due to surface disintegration

All distresses due to surface disintegration are measured by the area, except potholes, which are measured by the number. There are three categories of raveling:

low-severity, which doesn't cause potholes; medium-severity, which causes potholes of less than 1 cm in diameter; and high-severity, which causes potholes of more than 1 cm in diameter and 1.3 cm in depth. The treatments for low-and medium-severity raveling include micro surfacing, seal coat, and the Egyptian code method (1) for raveling. High-severity raveling is treated by the Egyptian code method (2) for raveling, slurry seal, and hot mix asphalt (HMA) overlay. Potholes have three categories, which include low severity, which has a diameter between 10 cm and 15 cm and a width between 1.25 cm and 2.5 cm; medium severity, which has a diameter from 15 cm to 45 cm and a width from 2.5 cm to 5 cm; and high severity, which has a diameter between 45 cm and 75 cm and a width of more than 5 cm. Low-severity potholes are treated by surface patching and the Egyptian code method (1) for potholes. The Egyptian code method (2) for potholes can treat medium-severity potholes. High-severity potholes are treated by the Egyptian code method (3) for potholes. The treatments for medium- and high-severity potholes also include full-depth repair. Patching includes three categories: low severity, which means a well-constructed patching with good properties similar to the old paving; medium severity, which is defined as a modest and different patching from the old paving with the clarity of the location of the patching; and high severity, which is a different patching from the old paving with the clarity of the location of the patching and the appearance of cracking on it. Low-severity patching doesn't need maintenance, while medium- and high-severity patching are treated with full-depth repair. There are three categories of railway crossings: low severity, which means a minor railway crossing; medium severity, which is a modest railway crossing; and high severity, which is defined as a severe railway crossing. All categories of railway crossings are treated by full-depth repair.

A programming language called C# is used to transform the severity and treatment of distress into machine code.

4. THE METHODOLOGY OF THE MODEL BUILDING

4.1 Data entry of road segment coordinates

The user chooses the first segment type, which can be a line or a curve. Then, the start point coordinates of the segment are inserted in the form of "X1", "Y1", and "Z1". After that, the endpoint coordinates of the segment are entered in the form of "X2", "Y2", and "Z2". The user inserts the radius "R" of the curve if the segment type is a curve.

4.2 Data insertion of cross-section properties

Next, the user selects "section properties" to enter the segment's cross-section properties in the left and right directions. The cross-section properties include properties of the median, median curbs, which separate the median and inner shoulders, inner shoulders, carriageway, outside shoulder curbs, which are situated after the outer shoulder, outer separations, the curbs that are located after the outer separation, service roads, the curbs that are situated between the sidewalk and the service road, sidewalks, sidewalk's curbs, and outer shoulders. Next, to store the segment's cross-section attributes, the user selects "OK".

4.3 Data entry for the extra road segment

If the user wants to go to the next step, he should click the "Draw" button. Then, the user has two choices: clicking "Draw" to draw the first segment in AutoCAD or clicking "Add segment" to insert another segment. If the user selects "Add segment", the software will ask the user to enter the name of the second segment and click the "OK" button.

4.4 The road segment drawing

The user inserts the other road segment type, the coordinates of the start and end points, and the cross-section properties as the first segment. The software will draw the road segments in AutoCAD when the user clicks the "Draw" button.

4.5 Segment distresses data entry

The software will ask the user about the data by which the distress severity is specified, such as average width, average diameter, or average depth, when the user chooses the distresses in each segment. The distress properties will be shown after the user enters the severity data and clicks the "OK" button. The quantity of the distress and the segment distress intensity will be calculated when the user inserts the distress coordinates in AutoCAD by clicking the "Multiple Select" button. The user chooses the distress treatment from the distress treatments suggested by the software according to the distress severity and inserts the unit cost of the chosen treatment. After that, the total treatment cost will be calculated according to the unit cost and the quantity of the treatment.

4.6 Drawing of the road distresses

The user clicks on the "Draw" button, and the software draws the distress with its properties such as name, severity, and the chosen treatment with the specified color according to the distress severity, where green refers to low distress severity, yellow means that the distress severity is medium, and red refers to high distress severity.

4.7 Check the pavement condition index (PCI)

The user inserts the pavement condition index (PCI), which has a value from 0 to 100. The total distress quantity and density of the road segment are calculated when the user clicks on the "Check" button. The model shows the condition of the

pavement surface according to the pavement condition index (PCI) value and suggests reconstruction if the pavement condition index (PCI) is lower than 55%.

5. THE SOFTWARE APPLICATION FOR THE PRACTICAL CASE STUDY

The segment road of Ahmed Abdel Aziz in Toukh city is the subject of this study. A divided multi-lane street is Ahmed Abdel Aziz Street. Visual examination shows that the segment has alligator cracking, longitudinal cracking, and depression as road distresses. Before anything else, the software needs to have the kind of road section and the coordinates for the start and end points, as shown in Fig. 1.

FIGURE 1. The start and end point coordinates of the segment.

Then, the section properties are entered by clicking on "section properties" and the segment is drawn in AutoCAD using the "Draw" button. The software shows the properties of each distress, which include name, severity, quantity, treatments, unit cost, and total cost, after inserting the segment distress, as shown in Fig. 2.
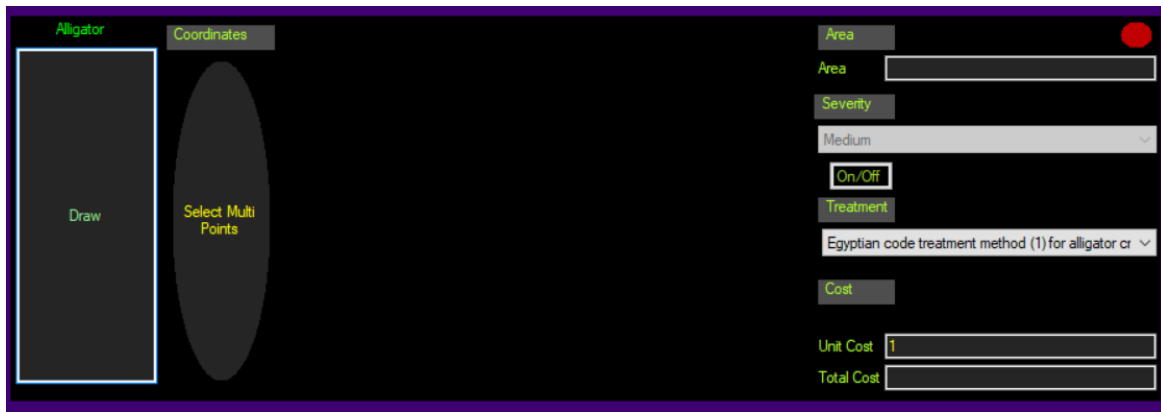
FIGURE 2. The properties of segment distress.

The segment distresses are drawn with the specified colors on the segment according to distress severity in AutoCAD after entering the distress coordinates, as shown in Fig. 3.
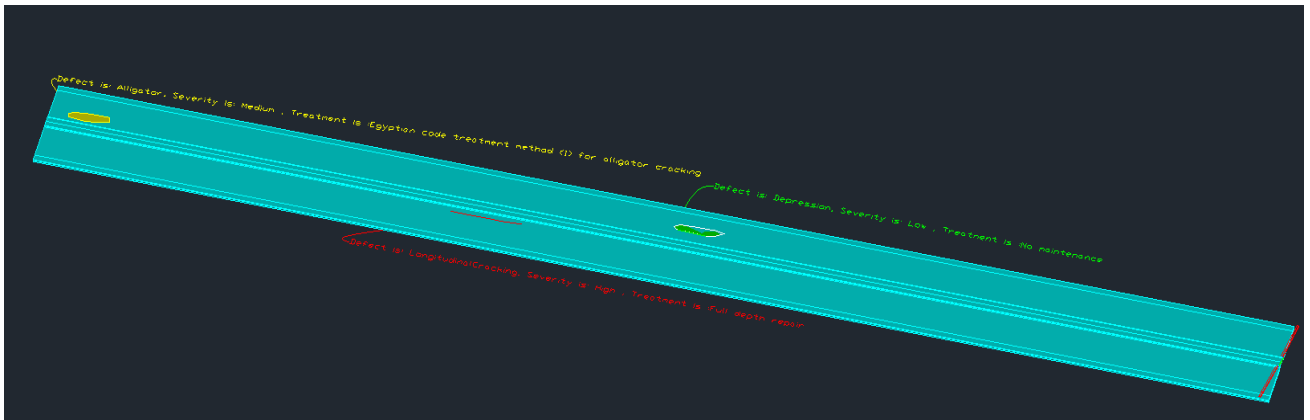

FIGURE 3. The drawn road distresses.

After the software calculates the quantity of the distress and the distress severity, these data are applied in PAVER 5.2 to calculate the pavement condition index (PCI). PAVER 5.2 asks for the network ID and name and the branch properties such as name, ID, use, and number of sections. Then, the branch area is calculated after the user inserts the section ID, start station, end station, surface type, length, and width. After the inspection date, distress type, distress severity, and distress quantity

are inserted, the pavement condition index is calculated. Then, the PCI value is inserted in the model, and the road condition, total distress quantity, and density are displayed by clicking on the "Check" button, as shown in Fig. 4.

FIGURE 4. Check of the segment pavement condition index (PCI).

6. CONCLUSION AND RECOMMENDATIONS

In this research, a model that helps people who are interested in road maintenance is studied. This model can draw any number of road segments, which can be a line or a curve after the user inserts their coordinates. The user can also enter the properties of the cross-section of each road segment, and the model adheres to this. Then, the user enters the distress in the road segments, gives the model the data by which the distress severity is specified, and inserts their coordinates in AutoCAD. The model can identify whether the distress is measured by area or length and calculate it. The model also specifies the severity of the distresses, and draws the

distresses on the road segment with specified colors according to the severity in AutoCAD. The model can suggest the treatments for each distress. The cost of the treatment is calculated after the user chooses the treatment from the suggested treatments and inputs the unit cost of the treatment. Then, the pavement condition index (PCI) of the segment is entered, and the model calculates the total distress quantity and density and suggests reconstruction when the pavement condition index (PCI) is lower than 55%.

The research recommends that:

1- People who are interested in flexible pavement maintenance should use the suggested model because it reflects reality.

2- The suggested treatments should be used because they are detailed and specified according to the distress severity.

3- Use PAVER 5.2 to calculate the pavement condition index (PCI) instead of the manual calculations.

4- In the future, a model that can draw road distresses in 3D should be suggested.

5- A model that can suggest road distress treatments with a detailed video should be programmed.

6- The rigid pavement, its distresses, and treatment should be handled in the future.

7- Laser scanners should be used to detect road distress.

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