# Diagnosis of Flexible Pavement Road Deterioration By Using Expert System

**By**

**Dr. Ali M. Sagheer**
**College of Computer,**
**Al-Anbar University, Iraq**

**Asist. Lec. Yousif A. Mansour Al-Kubaisy**
**College of Engineering,**
**Al-Anbar University, Iraq**

**Asist. Lec. Hamed A. Awad**
**College of Engineering,**
**Al-Anbar University, Iraq**

**الخلاصة**

شهدت العقود الاربعة الاخيرة حالات فشل كثيرة في الطرق الاسفلتية المرنة وللاسباب متعددة كزيادة احمال الخدمة، تكرر الأحمال المرورية على الطرق والتأثيرات البيئية التي تحصل على الطرق. يعتبر نظام الخبير اداة قرار تعتمد على الحاسوب مبنية على الحقائق والخبرات لحل مشاكل القرار الصعب مستندةً على المعرفة المكتسبة من الخبرة العملية . لجعل متطلبات التصليح اكثر واقعية استخدمت البرامج الحاسوبية لتكون اكثر قابلية للتنفيذ مع التقنيات العملية، هذا وقد بنيت البرامج على الحقائق ومجالات المعرفة العملية والنظرية . أن برنامج تشخيص الاضرار الاسفلتية باستخدام نظام الخبير **(DFPRD)** والمستخدم في البحث هو لتشخيص التشوهات الخاصة بالطريق الاسفاتي المرن وقد طور للتشخيص من خلال استخدام برنامج حاسوبي بلغة برولوك "Prolog " وللاستخدام كبديل عن الخبير "الشخص الخبير" وذلك لاعطاء قرار تقني في التشخيص لاضرار الطريق ..

## Abstract

During the last four decades, incidence of failure of flexible pavement road has been seen widely for many reasons, such as increasing service axial loads, repetition of traffic loads and the environmental effects. An expert system is an interactive computer-based decision tool that uses both facts and heuristics to solve difficult decision problems based on knowledge acquired from an expert. To realize these requirements, a logic programming Prolog language was utilized together with diagnosis technology. The logic programming language formalizes the domain knowledge. The expert system Diagnosis of Flexible Pavement Road Deterioration **(DFPRD)** developed in this paper is a diagnostic advisory system, which can be used as an alternative to the human expert, to give technical decisions in diagnosing deterioration in flexible pavement.

**Keywords:** Expert System, Pavement Road Deterioration

## Objective:

The main objectives of this study are formulated as follows:

1. Classification of deteriorations likely to occur in flexible pavement road, according to available literatures and the expert's opinions.

2. Construction of a knowledge base that incorporates the gathered information in a form of rules suitable to be implemented in an expert system environment of a diagnostic advisory nature.

## 1. Introduction

A road pavement continuously deteriorates under the combined actions of traffic loading and the environment. The ability of the road to satisfy the demands of traffic and the environment over its design life is known as performance. The most common indicators of pavement performance are: fatigue cracking, surface rutting, riding quality, and skid resistance. The change in the value of these performance indicators over time is referred to as deterioration [1].

The major problems in accessing a human expert in a particular field are unavailability and scarcity of real experts and if the human expert is available then there may be problem for common people in making contact with him. Consultation may be very expensive and human expert may feel the repetitive job uninteresting. This in turn may affect expert's efficiency, day by day, new knowledge in enormous amount is being added in every discipline and thus more relevant and accurate advice can be taken from a human expert if his own knowledge is updated which is not an easy task. Human experts are bounded by limitations and it is quite difficult for a human expert to consider all the essential factors while taking decision. Something is always escaped and remains unattended. Thus some tool or assistance is needed even for an expert to update his knowledge and get help in decision making process. In the researches and developments in science and technology, attempts have been always made to overcome the problems of people. The advancements made in the discipline of Artificial Intelligence and Computer Science and Engineering. Have tackled the problems related to mental and intellectual processes of the people. Gradual advancements in these disciplines have enhanced our cognitive capabilities. From very beginning scientists and researchers of have been trying to produce systems that can behave like an intelligent being. The program asks series of questions about the concerned problem and gives appropriate advice based on its store of knowledge. The knowledge, the expert system uses is made up of either rules or experience information about the behavior of elements of a particular subject domain. Such systems can be designed for specific hardware and software configurations, or they can be software systems that are designed to run on a general-purpose computer [2].

## 2. Expert Systems (ES)

Since the World War II, computer scientists tried to develop techniques that would allow computers to act more like humans. The entire effort including decision-making systems, robotics, and various approaches to computer speech is usually termed Artificial Intelligence (AI). A collection of Artificial Intelligence techniques that enables computers to assist people in analyzing problems and making decisions, called "Knowledge-Based Systems". Expert system is a part of the knowledge-based systems family. Expert systems are developed to assist people in many fields, for example (Engineering, Trouble shooting, diagnosing… etc.) [3].

Expert systems are developed to support end users in accessing a domain expert's domain knowledge whenever an expert is not available in person. These systems focus on simulating the domain experts' problem solving abilities, i.e., they simulate human reasoning in performing some portion of the relevant tasks. Furthermore, they perform reasoning about the representations of human knowledge and solve problems by heuristics or approximate methods [4].

The benefit of these systems is their performance of many different functions. The use of expert systems can improve production operations, increase output and help to standardize approaches to problems that require expertise and utilize incomplete and uncertain information [4].

## 3. Deteriorations in Flexible Pavement Asphalt:

The flexible pavement distresses are classified in the following categories [5]:

**A. Cracking**

It includes fatigue cracking, block cracking, edge cracking, longitudinal cracking, reflection cracking at joints & transverse cracking.

**B. Patching and Potholes**

It includes the patch deterioration & potholes.

**C. Surface Deformation**

It includes rutting & shoving.

**D. Surface Defects**

It includes the bleeding, polished aggregate & raveling.

### 3-1 Crack deterioration

This section includes the following distresses:

**1. Fatigue Cracking**

- **Description**

Occurs in areas subjected to repeated traffic loadings (wheel paths). Can be a series of interconnected cracks in early stages of development. Develops into many-sided, sharp-angled pieces, usually less than 0.3 meters (m) on the longest side, characteristically with a chicken wire/alligator pattern, in later stages. Must have a quantifiable area. as shown in figure (1). [6, 7].

- **Severity Levels**

**Low**

An area of cracks with no or only a few connecting cracks; cracks are not spalled or sealed; pumping is not evident. [6, 7].

**Moderate**

An area of interconnected cracks forming a complete pattern; cracks may be slightly spalled; cracks may be sealed; pumping is not evident. [6, 7].

**High**

An area of moderately or severely spalled interconnected cracks forming a complete pattern; pieces may move when subjected to traffic; cracks may be sealed; pumping may be evident. [6,7].

- **How to Measure**

Record square meters of affected area at each severity level. If different severity levels existing within an area cannot be distinguished, rate the entire area at the highest severity present. [6, 7].

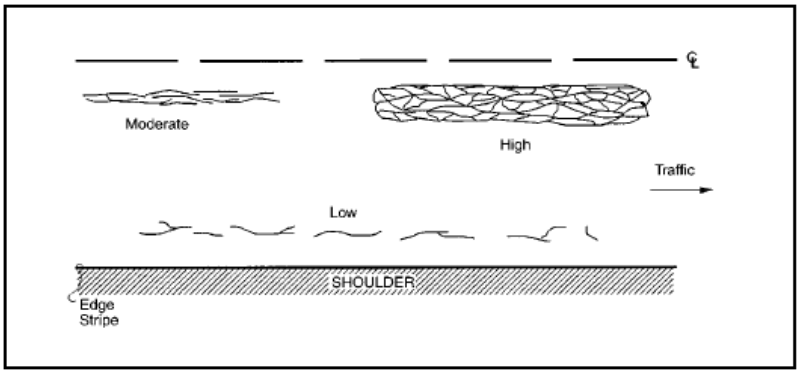



**Figure No.(1) Distress Types—Fatigue Cracking**[5].

**2. Block Cracking**

- **Description**

A pattern of cracks that divides the pavement into approximately rectangular pieces. Rectangular blocks range in size from approximately 0.1 m2 to 10 m2.as shown in figure (2). [6, 7].

- **Severity Levels**

**Low**

Cracks with a mean width ≤6 millimeters (mm); or sealed cracks with sealant material in good condition and with a width that cannot be determined. [6, 7].

**Moderate**

Cracks with a mean width > 6 mm and ≤19 mm; or any crack with a mean width ≤19 mm and adjacent low severity random cracking. [6, 7].

**High**

Cracks with a mean width > 19 mm; or any crack with a mean width ≤19 mm and adjacent moderate to high severity random cracking. [6, 7].

- **How to Measure**

Record square meters of affected area at each severity level. If fatigue cracking exists within the block cracking area, the area of block cracking is reduced by the area of fatigue cracking.

Note: An occurrence should be at least 15 m long before rating as block cracking. [6, 7].

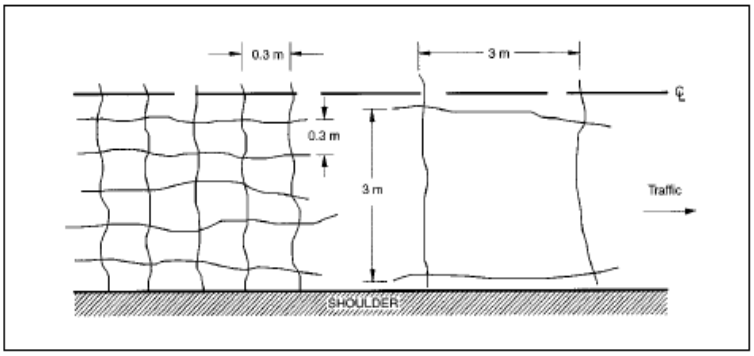



**Figure No. (2) Distress Types—Block Cracking** [5].

## 3. Edge Cracking

- **Description**

Applies only to pavements with unpaved shoulders. Crescent-shaped cracks or fairly continuous cracks which intersect the pavement edge and are located within 0.6 m of the pavement edge, adjacent to the shoulder. Includes longitudinal cracks outside of the wheel path and within 0.6 m of the pavement edge as shown in Figure No.(3). [6, 7].

- **Severity Levels**

**Low**

Cracks with no breakup or loss of material. [6, 7].

**Moderate**

Cracks with some breakup and loss of material for up to 10 percent of the length of the affected portion of the pavement. [6, 7].

**High**

Cracks with considerable breakup and loss of material for more than 10 percent of the length of the affected portion of the pavement. [6, 7].

- **How to Measure**

Record length in meters of pavement edge affected at each severity level. The combined quantity of edge cracking cannot exceed the length of the section. [6, 7].

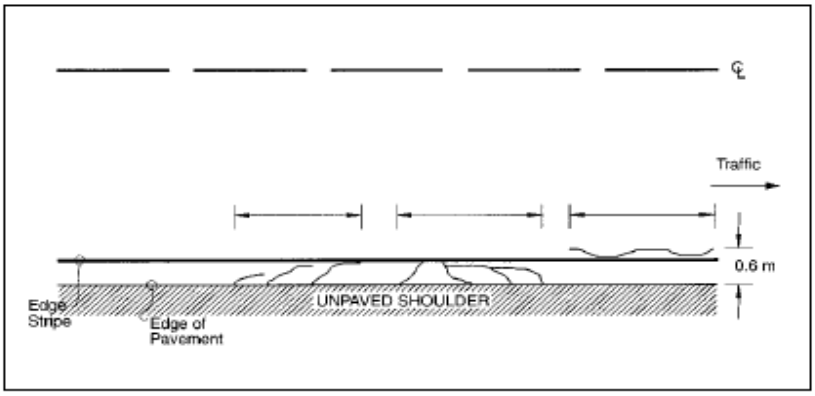



**Figure No.(3) Distress Types—Edge Cracking**[5].

**4. Longitudinal Cracking**

- **Description**

Cracks predominantly parallel to pavement centerline. Location within the lane (wheel path versus non-wheel path) is significant as shown in Figure No.( 4). [6, 7].

- **Severity levels**

**Low**

A crack with a mean width ≤6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined. [6, 7].

**Moderate**

Any crack with a mean width > 6 mm and ≤19 mm; or any crack with a mean width ≤19 mm and adjacent low severity random cracking. [6, 7].

**High**

Any crack with a mean width > 19 mm; or any crack with a mean width ≤19 mm and adjacent moderate to high severity random cracking. [6, 7].

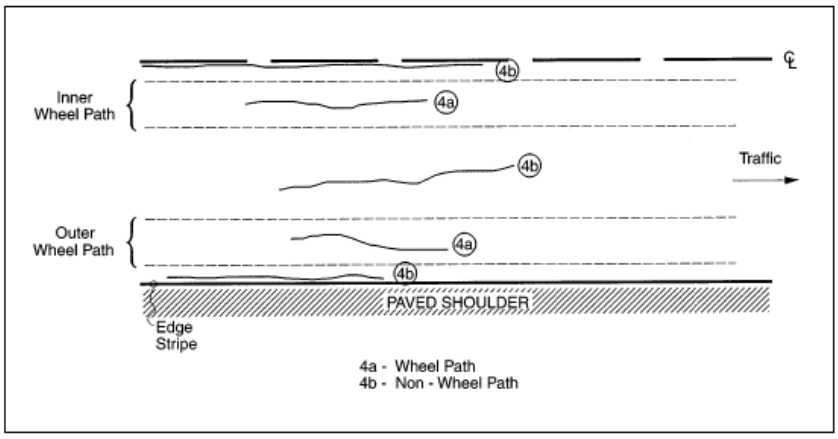



**Figure No.(4) Distress Types— Longitudinal Cracking**[5].

- **How to Measure**

Record separately:

**5. Reflection Cracking At Joints**

- **Description**

Cracks in asphalt concrete overlay surfaces that occur over joints in concrete pavements. As shown in Figure No.( 5) [6, 7].

Note: The slab dimensions beneath the Asphalt Concrete (AC) surface must be known to identify reflection cracks at joints.

- **Severity Levels**

**Low**

An unsealed crack with a mean width ≤6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined. [6, 7].

**Moderate**

Any crack with a mean width > 6 mm and ≤19 mm; or any crack with a mean width ≤19 mm and adjacent low severity random cracking. [6, 7].

**High**

Any crack with a mean width > 19 mm; or any crack with a mean width ≤19 mm and adjacent moderate to high severity random cracking. [6, 7].

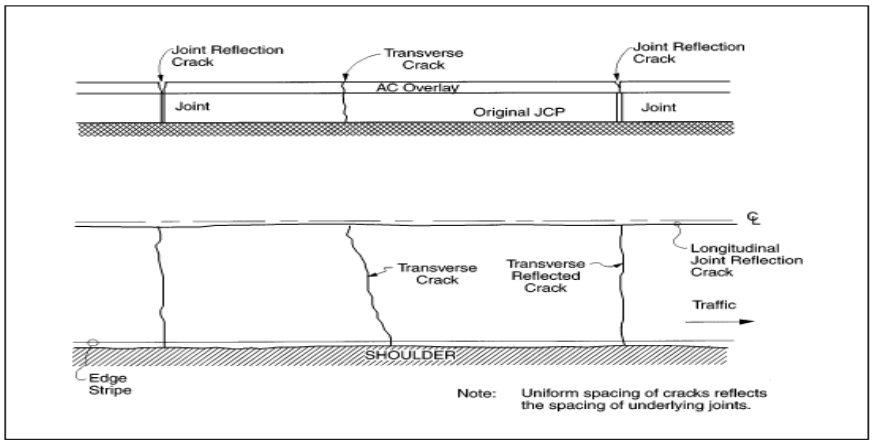



**Figure No.(5) Distress Types- Reflection Cracking At Joints**[5].

## 6. TRANSVERSE CRACKING

- **Description**

Cracks that are predominantly perpendicular to pavement centerline as shown in Figure No.(6). [6, 7].

- **Severity Levels**

**Low**

An unsealed crack with a mean width ≤6 mm; or a sealed crack with sealant material in good condition and with a width that cannot be determined. [6, 7]

**Moderate**

Any crack with a mean width > 6 mm and ≤19 mm; or any crack with a mean width ≤19 mm and adjacent low severity random cracking. [6, 7].

**High**

Any crack with a mean width > 19 mm; or any crack with a mean width ≤19 mm and adjacent moderate to high severity random cracking. [6, 7].

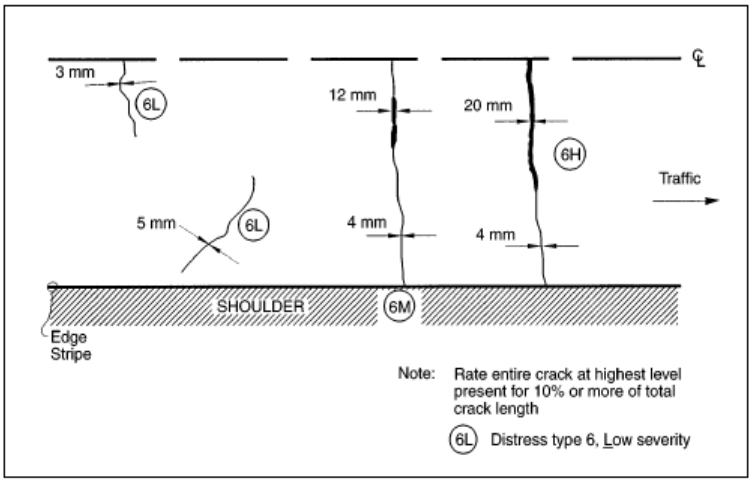



**Figure No.(6) Distress Types- Transverse Cracking** [5].

- **How to Measure**

Record number and length of transverse cracks at each severity level. Rate the entire transverse crack at the highest severity level present for at least 10 percent of the total length of the crack. Length recorded, in meters, is the total length of the crack and is assigned to the highest severity level present for at least 10 percent of the total length of the crack.

Also record length in meters of transverse cracks with sealant in good condition at each severity level. [6, 7].

Note: The length recorded is the total length of the well-sealed crack and is assigned to the severity level of the crack. Record only when the sealant is in good condition for at least 90 percent of the length of the crack. If the transverse crack extends through an area of fatigue cracking, the length of the crack within the fatigue area is not counted. The crack is treated as a single transverse crack, but at a reduced length. Cracks less than 0.3 m in length are not recorded. [6, 7].

## 3-2. PATCHING AND POTHOLES DETERIORATION

This section includes the following types of surface defects

1. **Patch/Patch Deterioration**

- **Description**

Portion of pavement surface, greater than 0.1 m2, that has been removed and replaced or additional material applied to the pavement after original construction as shown in Figure No.(7). [6, 7].

- **Severity Levels**

**Low**

Patch has, at most, low severity distress of any type including rutting < 6 mm; pumping is not evident. [6, 7].

**Moderate**

Patch has moderate severity distress of any type or rutting from 6 mm to 12 mm; pumping is not evident. [6, 7].

**High**

Patch has high severity distress of any type including rutting > 12 mm, or the patch has additional different patch material within it; pumping may be evident. [6, 7].

- **How to Measure**

Record number of patches and square meters of affected surface area at each severity level.

Note: Any distress in the boundary of the patch is included in rating the patch. Rutting (settlement) may be at the perimeter or interior of the patch. [6, 7].

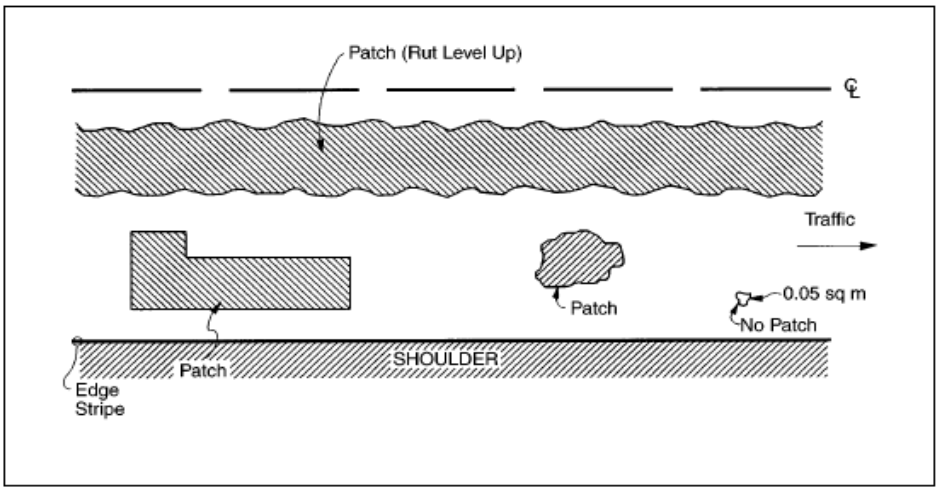



**Figure No.(7) distress types-patch/patch deterioration**[5].

**2. POTHOLES**

- **Description**

Bowl-shaped holes of various sizes in the pavement surface. Minimum plan dimension is 150 mm.as shown in Figure No.(8) [6, 7].

- **Severity Levels**

**Low**

< 25 mm deep. [6, 7].

**Moderate**

25 mm to 50 mm deep. [6, 7].

**High**

> 50 mm deep. [6, 7].

- **How to Measure**

Record number of potholes and square meters of affected area at each severity level. Pothole depth is the maximum depth below pavement surface. If pothole occurs within an

area of fatigue cracking the area of fatigue cracking is reduced by the area of the pothole[6, 7]..

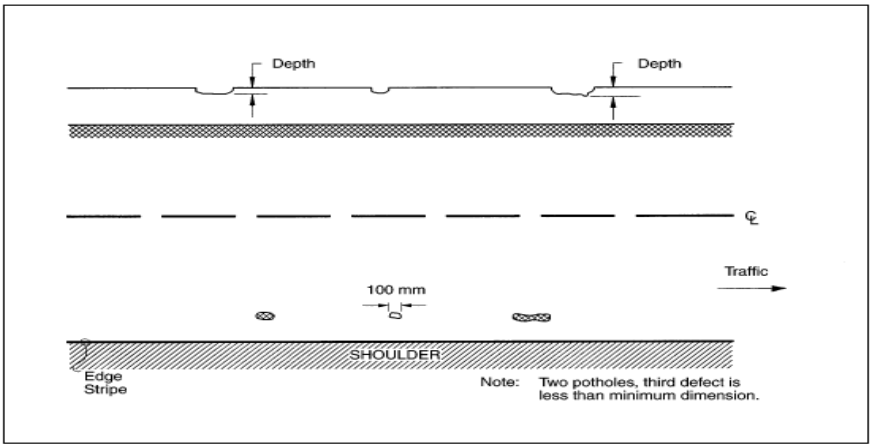



**Figure No.(8) distress types-potholes deterioration** [5].

### 3-3 Surface Deformation

This section includes the following types of surface defects:

1. **Rutting**

- **Description**

A rut is a longitudinal surface depression in the wheel path. It may have associated transverse displacement as shown in Figure No.(9). [6, 7].

- **Severity Levels**

Not applicable. Severity levels could be defined by categorizing the measurements taken. A record of the measurements taken is much more desirable, because it is more accurate and repeatable than are severity levels. [6, 7].

- **How to Measure**

Record maximum rut depth to the nearest millimeter, at 15.25-m intervals for each wheel path, as measured with a 1.2-m straight edge[6, 7]..

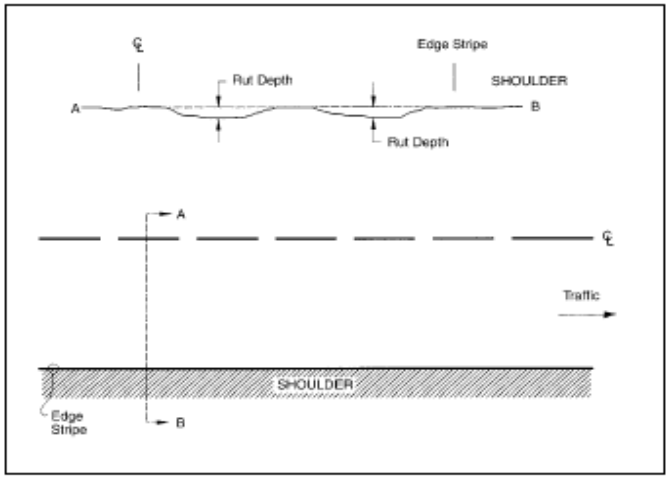



**Figure No.(9) distress type-Rutting deterioration[5].**

**2. Shoving**

- **Description**

Shoving is a longitudinal displacement of a localized area of the pavement surface. It is generally caused by braking or accelerating vehicles, and is usually located on hills or curves, or at intersections. It also may have associated vertical displacement as shown in Figure No.10. [6, 7].

- **Severity Levels**

Not applicable. However, severity levels can be defined by the relative effect of shoving on ride quality. [6, 7].

- **How to Measure**

Record number of occurrences and square meters of affected surface area. [6, 7].

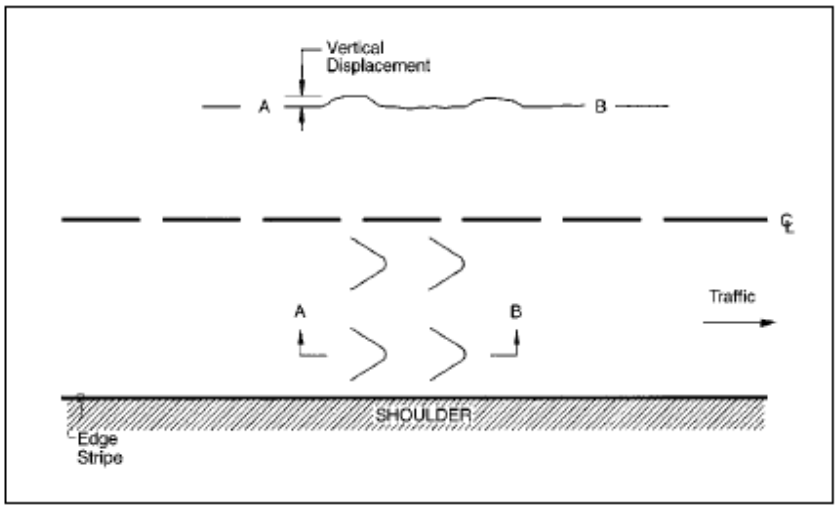



**Figure No.( 10) distress type-Shoving deterioration [5].**

## 3-4 Surface Defects

This section includes the following types of surface defects:

**1. Bleeding**

- **Description**

Excess bituminous binder occurring on the pavement surface, usually found in the wheel paths. May range from a surface discolored relative to the remainder of the pavement, to a surface that is losing surface texture because of excess asphalt, to a condition where the aggregate may be obscured by excess asphalt possibly with a shiny, glass-like, reflective surface that may be tacky to the touch. [6, 7].

- **Severity Levels**

Not applicable. The presence of bleeding indicates potential mixture related performance problems. Extent is sufficient to monitor any progression. [6, 7].

- **How to Measure**

Record square meters of surface area affected.

Note: Preventative maintenance treatments (slurry seals, chip seals, fog seals, etc.) sometimes exhibit bleeding characteristics. These occurrences should be noted, but not rated as bleeding. [6, 7].

**2. Polished Aggregate**

- **Description**

Surface binder worn away to expose coarse aggregate. [6, 7].

- **Severity Levels**

Not applicable. However, the degree of polishing may be reflected in a reduction of surface friction. [6, 7].

- **How to Measure**

Record square meters of affected surface area. Polished aggregate should not be rated on test sections that have received a preventive maintenance treatment that has covered the original pavement surface. [6, 7].

**3. Raveling**

- **Description**

Wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder. Raveling ranges from loss of fines to loss of some coarse aggregate and ultimately to a very rough and pitted surface with obvious loss of aggregate. [6, 7].

- **Severity Levels**

Not applicable. The presence of raveling indicates potential mixture related performance problems. Extent is sufficient to monitor any progression. [6, 7].

- **How to Measure**

Record square meters of affected surface. Raveling should not be rated on chip seals. [6, 7].

## 4. Identification of the Problem

Many questions may arise about the use of expert system for the limited of damaged Flexible pavement road, which are:

- Do damages in flexible pavement road exist?
- Is it necessary to give the attention to these damages and this technique?
- Is the expert system technique suitable for this domain?
- What are the results of applying such technique to this domain?

In order to answer these questions the following justifications are stated:

- Damages in Flexible pavement road may arise for many reasons even in well-pave road.
- The nature of domain problems is suitable for expert system technology since the problem-solving method does not use or need an explicit algorithm.
- The result of applying the selected technique to domain problems is a diagnostic-advisory expert system, which is an effective tool in providing consultation in different sites.

## 5. Knowledge Acquisition

Expert systems derive their power from knowledge, and it is the effective use of knowledge that makes its reasoning successful [8].

Knowledge acquisition is the collection of information from one or more domain expert, as well as any other sources, leading to the production of a number of documents, which form the basis of a functioning knowledge base [8, 9].
The three basic approaches are as follows [10]:

**a. Interviewing:** In this approach a knowledge engineer obtains knowledge from the human expert through a series of interviews and encodes it in the expert system. Here the knowledge engineer plays a central role in the knowledge acquisition process, and the quality of the expert system greatly depends on the skills of the knowledge engineer.

**b. Learning by Interaction:** This approach often relies on computer-assisted knowledge acquisition. Experts directly interact with a computer program that helps to capture their knowledge. The need for a knowledge engineer can be significantly diminished here and the program often helps experts clarify their own thoughts.

**c. Learning by Induction*:*** In this approach a computer program distills knowledge by examining data and examples. Here the dependence on both the expert and the knowledge engineer is again diminished. The main problem here is the identification of the suitable characteristics or attributes on which induction would be performed.

The process is performed in two stages. The first is collecting knowledge from literature, whereas, the second is collecting knowledge from Iraqi experts in the domain of concrete structure repair. The two stages are explained in the following articles.

## 6. Investigation of Flexible pavement Road Deterioration

Experience has shown that a number of testing methods are of proven value in determining the extent of deterioration of a flexible pavement road and in identifying those areas where remedial measures are necessary.

### 1. Stage Approach

Any investigation can conveniently be split into two stages:-
Stage 1 - An initial survey to identify the cause of the problems.
Stage 2 - An extension of the stage 1 survey, perhaps using a limited number of techniques to identify the extent of the defects revealed by stage 1.

### 2. Visual Survey

After collecting as much background data as possible, any testing problem should begin with a thorough visual survey of the structure. This may conveniently be recorded on a developed elevation giving particular attention to the following defects:

1- Cracks
2- Rutting
3- Bleeding
4- Shoving
5- Stripping

## 7. Knowledge Analysis

The analysis process to the acquired knowledge has been done continuously together with acquisition process. The process of the diagnosis of the damages is applied as a menu-driven and question-and-answer, where from the menu we choose the type of the

Pavement Road Deterioration, then from submenu choose the type of the cracks may be occur in the element, finally, the execution is done as question-and-answer, into reach to the diagnostic damage. The process is composed of all steps as abstracted in the data flow diagrams in the Appendix A.

## 8. Knowledge Representation

The knowledge used by an expert system needs to be represented and employed in a form that can be used for reasoning. This is in contrast to most computer programs that work with data. Thus, knowledge structures are used to store knowledge and reason with it, just as data structures are used to store and deal with data [7, 8].

In this study, rules are used because they are the most common forms of statement in representing the knowledge. Each rule consists of one or more conditions, which, if satisfied, gives rise to one or more actions [9]. A rule can be expressed in the general form:

IF (condition)
THEN (conclusion or action)

Such rules are sometimes called "Production Rules" since they produce a result. For example:-

IF the type of damages in the beam is "cracking" AND the cracks appear on both the "side and the bottom faces of the beam" AND the cracks are "longitudinal" AND the cracks "follow the pattern of the reinforcement" THEN CAUSES.

This flowchart starts with the main menu that includes the main types of Pavement Road structural elements to be repaired. Each type of structural element leads to a branch menu that contains the damages possibly happen in this element. For every type of these damages there are several choices and questions from which the type of the happened damage is specified. These steps or methods in chaining used from the beginning of the flowchart to the end are known as "backward chaining". This method begins from the conditions or events until reaching the goals. See Appendix A.

## 9. Study Case

The data was been take from the highway traffic Fallujah office.

### 1. Location

Expressway No.9 section 1. From station 0+00 to station 63+00 (Km) (from Abo Ghraeeb Intersection to Al-BoAbead Intersection. Toward Al_Ramadia city ) see Appendix B

### 2. Description of the Road

**Geometric description**

- Two way , three lane in each direction for traffic and one lane for emergence stopping
- Median width 10 meter
- Acceleration and deceleration lane for ramps , interchange and parking
- One interchange bridge and 10 overpass , 10 under pass
- Expressway width 45 meter from edge to edge .
- Parking

**Flexible Pavement Asphalt layer description**

- Sub base layer thickness 20-35 cm
- Base asphalt layer thickness 18-20 cm
- Binder Asphalt layer thickness 8 cm
- Surface Asphalt layer thickness 4 cm

## 10. Results of the System

The user interacts with the system through a user interface that simplifies communication and hides much of the complexity, such as the internal structure of the rule base. Expert system interfaces employ a variety of user styles, including question-and-answer, menu-driven, or graphics interfaces. The final decision on the interface type is a compromise between user needs and the requirements of the knowledge base and inferencing system.
The heart of the expert system is the knowledge base, which contains the knowledge of a particular application domain. In a rule-based expert system this knowledge is represented in the form of if... then... rules. The knowledge base contains both general knowledge as well as case-specific information.
The knowledge of the DFPRD expert system is represented as tree of rules contain all questions that user may be ask it to lead to the solution. The constructed tree is the space of problem of the DFPRE expert system. The inference engine applies the knowledge to the solution of actual problems. It is essentially an interpreter for the knowledge base. In the production system, the inference engine performs the recognize-act control cycle. The procedures that implement the control cycle are separate from the production rules themselves.
The following photos represent the displayed screens for applying the presented expert system to the problem of the study case.
In this DFPRD expert system we considered the Expert System Lifecycle. The procedure of the execution is begun with menu-driven to select the type of the flexible pavement road. After this step there are a submenu used to select the type of the damage occur in the road. The next step represents the scenario and dialog between the DFPRD expert system and the user. The scenario is done by the question-and-answer, where the expert system asks and the user answer until reach to the goal of the diagnosis. The interfaces of the implementation of the DFPRD expert system are obtained in Appendix C.

## 11. Conclusions

From the present theoretical study and depending on its results the following points are concluded:

1. The expert system (DFRD) developed in this work is a diagnostic advisory system, that can be used as an alternative to the human expert, to give technical decisions in diagnosing deterioration in flexible paved road.
2. The most difficult stage of expert system development is knowledge acquisition because the effectiveness, efficiency and reliability of the developed system highly depend on the quality and quantity of its knowledge base.

4. The using of the DFPRD expert system is easy, fast and give successful answer for engineer, because we take almost the perhaps damages in consideration.
5. The development of the DFPRD expert system may be done by updating the knowledge base in the system without changing the inference engine.

## Reference

1- Jorge. A. P." Modeling pavement performance by combining field and experimental data ," Ph. D Thesis , Engineering – Civil and Environmental Engineering , University of California ,Berkeley, 2001.

2- K. Parsaye and M. Chignell, "Exper Systems for Experts," John Wiley & Sons Inc., 1988.

3- G. S. Tuthill and L. J. Levy, "Knowledge-Based System, A manager's Perspective", TAB Professional and References Books, tab Books, a division of McGraw-Hill, Inc., 332 pp, 1991.

4- R. J. Allwood," Techniques and application of Expert Systems in the Construction Industry", Ellis Harwood Series in Civil engineering, 1st Edition, England, 133pp, 1989.

5- FHWA RD 03-031 "Distress identification manual for long term pavement performance program" ,2003

6- Dr. Christos Drakos " Flexible pavement distress " lectures, Florida university, 2000.

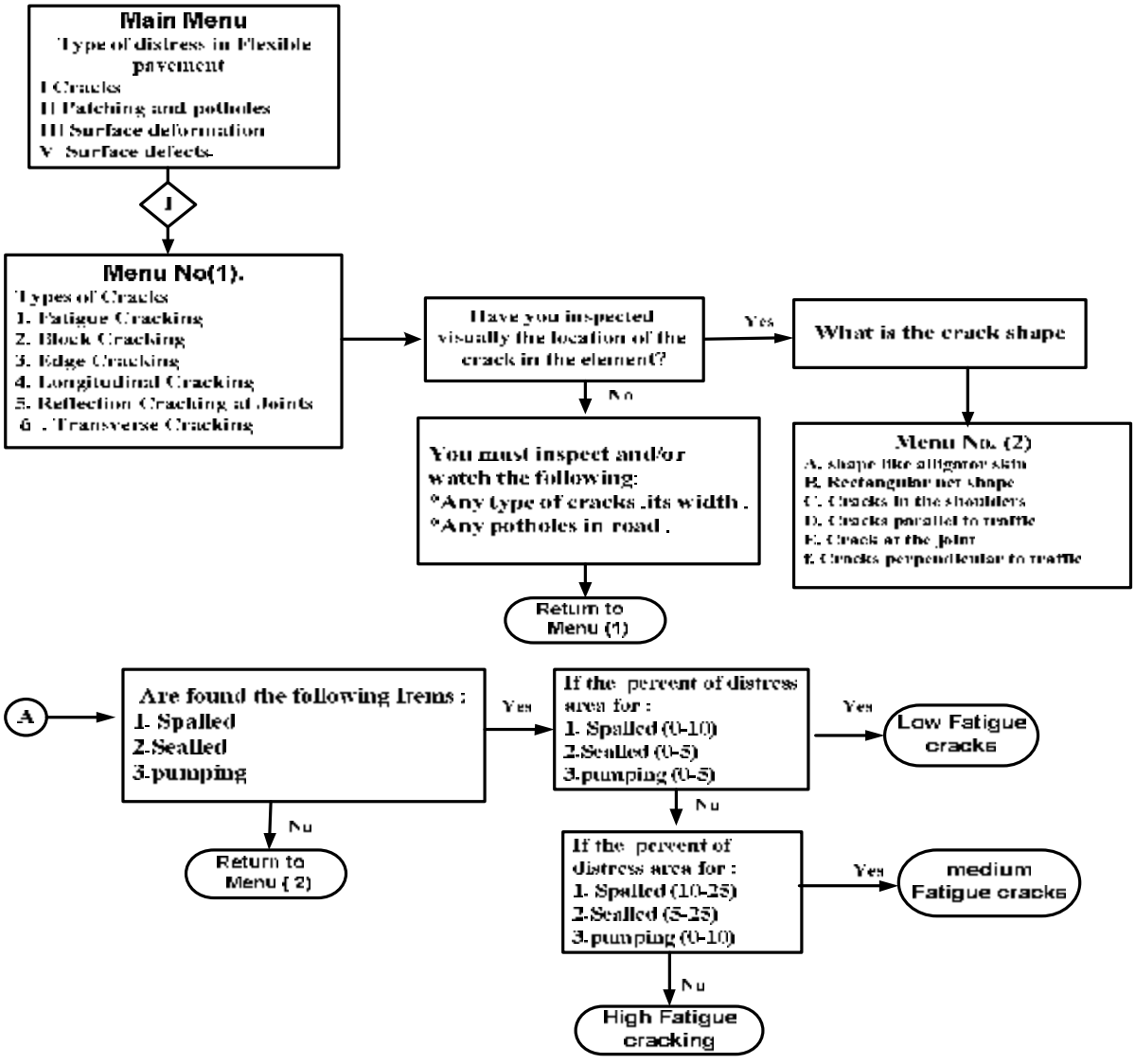
7- FY 2003 UDOT "Distress Manual" September, 2002.
8- E. Rich," Artificial Intelligence", McGraw-Hill Book Co., New York, 436 pp, 1983.

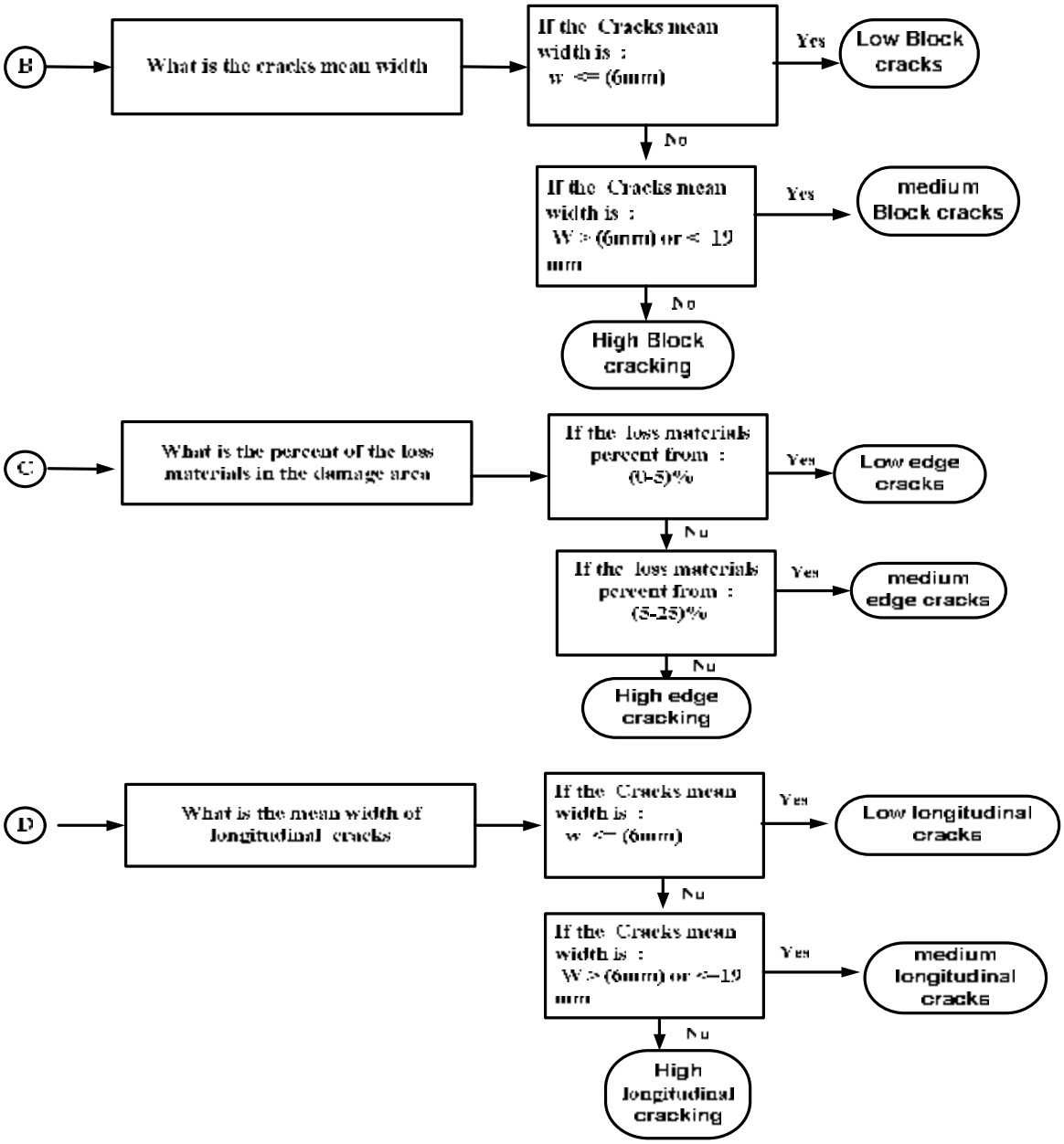
9- T. J. Ross, F. S. Wang, S. J. Savage, and H. C. Sorensen, "An Expert System for damaged Assessment of Protective Structures", Expert System in Civil Engineering, Proceedings of a Symposium Sponsored by the Technical Council on Computer Practices of the American Society of Civil Engineers in Conjunction With the ASCE Convention in Seattle, Washington, pp.109-120, April 8-9, 1986.

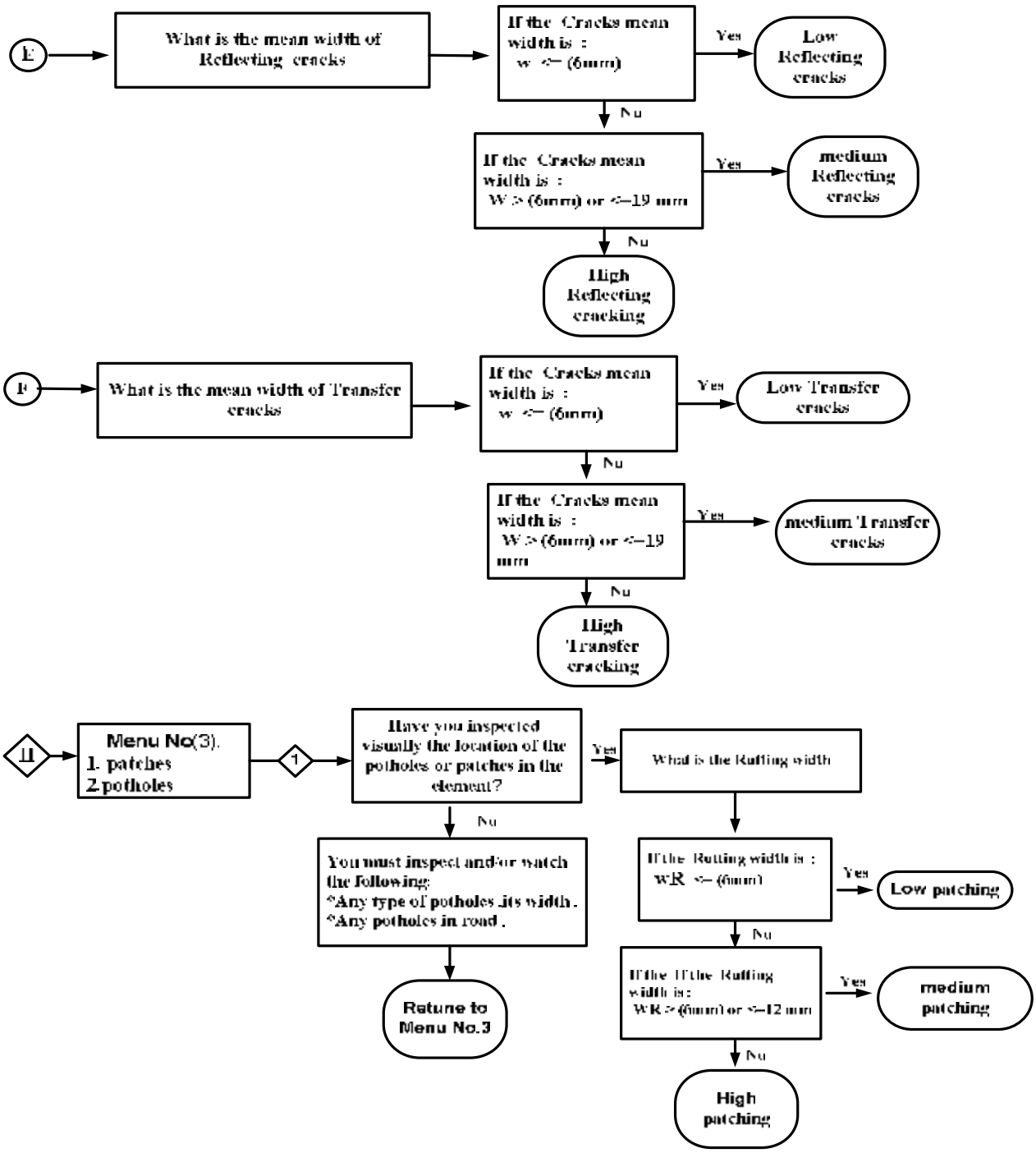
10- I. Graham and P. L. Jones," Expert System, Knowledge, Uncertainty and Decision ", Chapman and Hall Inc., 1988.

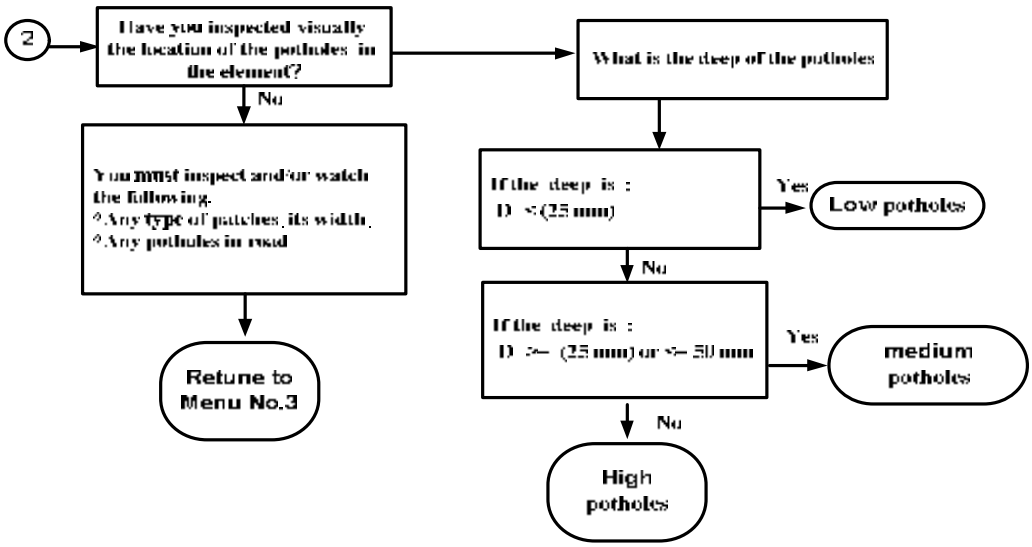
## Appendix A

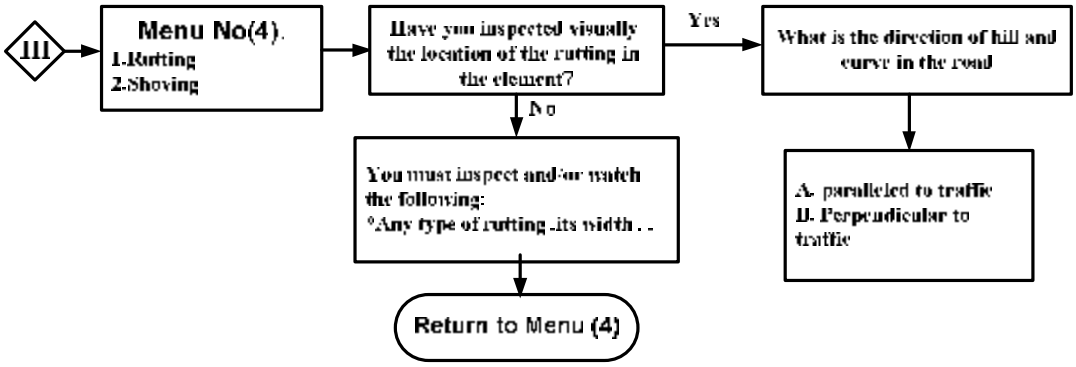
This appendix shows the flow chart for the Diagnosis of Flexible Pavement Road Deterioration Using Expert System program .

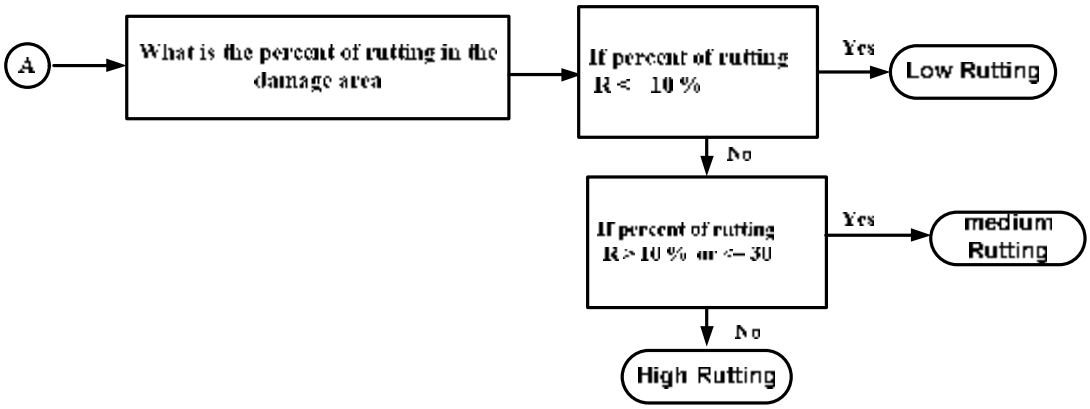


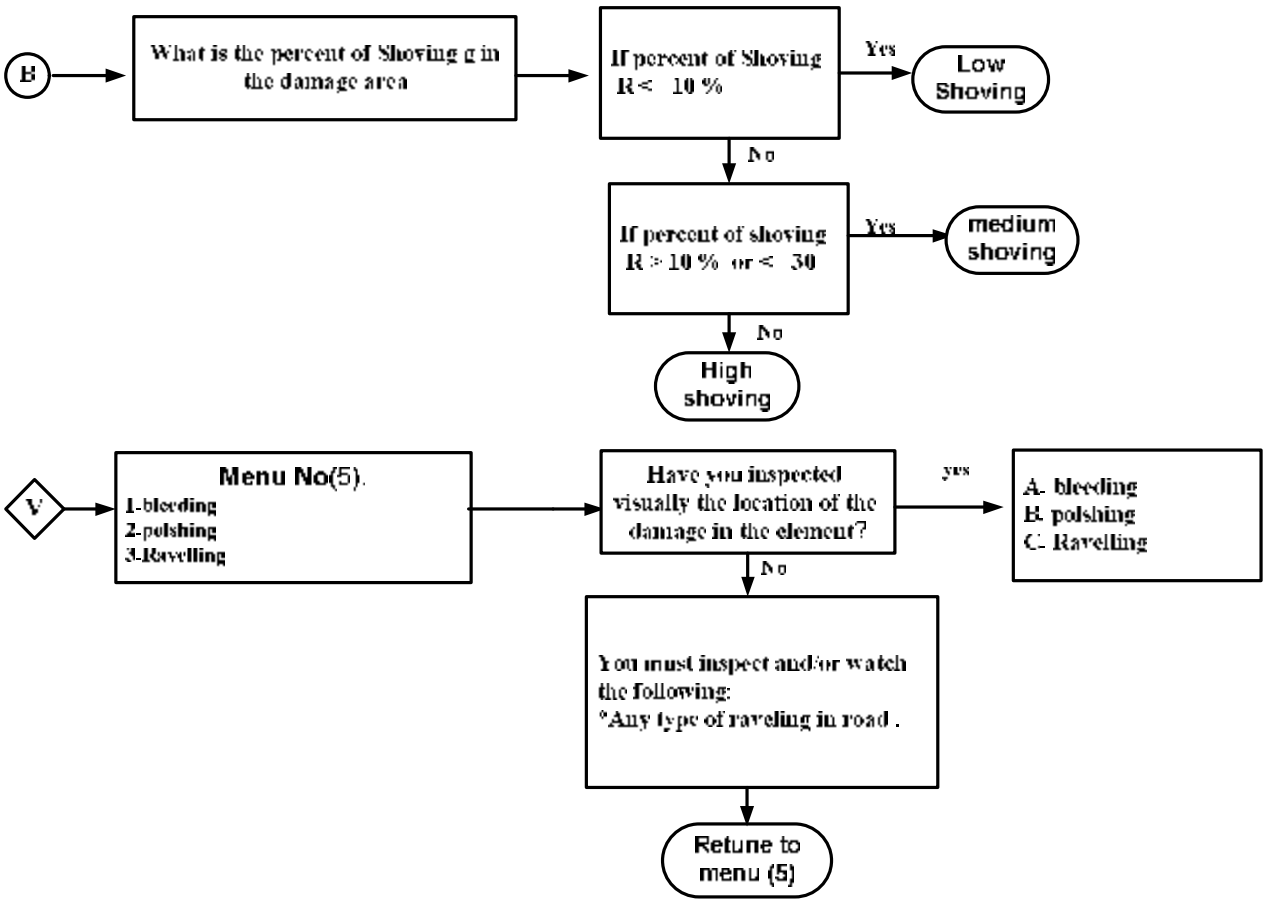

B
What is the cracks mean width
If the Cracks mean width is : w <= (6mm)
Yes
Low Block cracks
No
If the Cracks mean width is : W > (6mm) or < 19 mm
Yes
medium Block cracks
No
High Block cracking
C
What is the percent of the loss materials in the damage area
If the loss materials percent from : (0-5)%
Yes
Low edge cracks
No
If the loss materials percent from : (5-25)%
Yes
medium edge cracks
No
High edge cracking
D
What is the mean width of longitudinal cracks
If the Cracks mean width is : w <= (6mm)
Yes
Low longitudinal cracks
No
If the Cracks mean width is : W > (6mm) or <=19 mm
Yes
medium longitudinal cracks
No
High longitudinal cracking

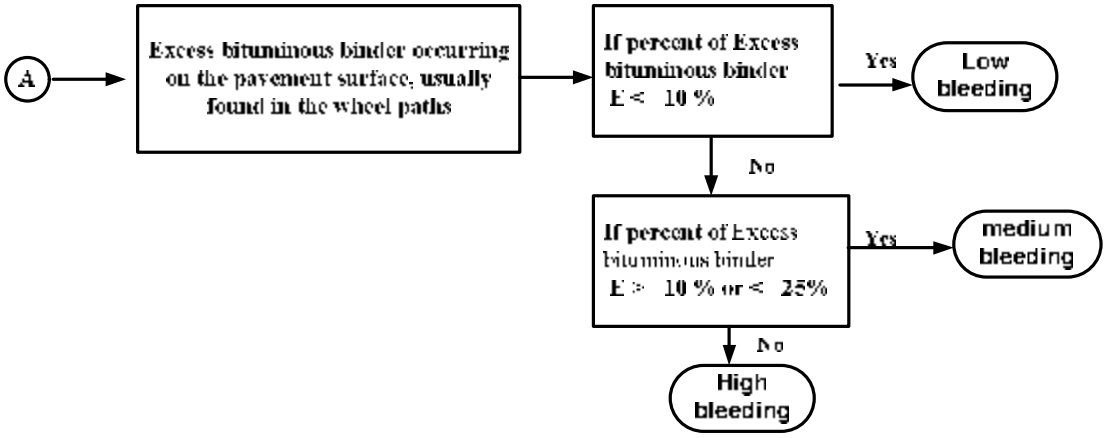

E
What is the mean width of Reflecting cracks
If the Cracks mean width is : w <= (6mm)
Yes
Low Reflecting cracks
No
If the Cracks mean width is : W > (6mm) or <=19 mm
Yes
medium Reflecting cracks
No
High Reflecting cracking
F
What is the mean width of Transfer cracks
If the Cracks mean width is : w <= (6mm)
Yes
Low Transfer cracks
No
If the Cracks mean width is : W > (6mm) or <=19 mm
Yes
medium Transfer cracks
No
High Transfer cracking
H
Menu No(3). 1. patches 2.potholes
I
Have you inspected visually the location of the potholes or patches in the element?
Yes
What is the Rutting width
No
You must inspect and/or watch the following: *Any type of potholes ,its width . *Any potholes in road .
Retune to Menu No.3
If the Rutting width is : WR <= (6mm)
Yes
Low patching
No
If the If the Rutting width is : WR > (6mm) or <=12 mm
Yes
medium patching
No
High patching

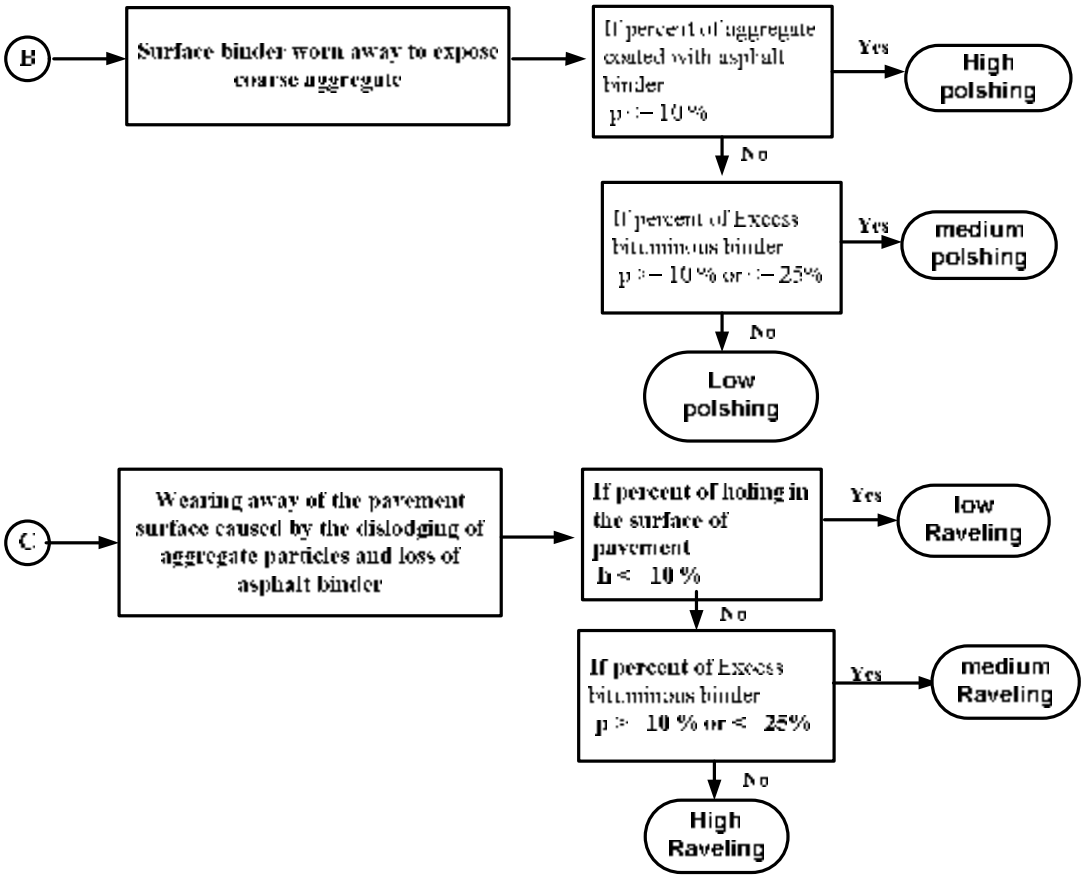

2
Have you inspected visually the location of the potholes in the element?
No
You must inspect and/or watch the following.
*Any type of patches, its width.
*Any potholes in road
Retune to Menu No.3
What is the deep of the potholes
If the deep is :
D <=(25 mm)
Yes
Low potholes
No
If the deep is :
D >= (25 mm) or <= 50 mm
Yes
medium potholes
No
High potholes


III
Menu No(4).
1-Rutting
2-Shoving
Have you inspected visually the location of the rutting in the element?
Yes
No
You must inspect and/or watch the following:
*Any type of rutting ,its width . .
Return to Menu (4)
What is the direction of hill and curve in the road
A- paralleled to traffic
B- Perpendicular to traffic


A
What is the percent of rutting in the damage area
If percent of rutting
R < 10 %
Yes
Low Rutting
No
If percent of rutting
R > 10 % or <= 30
Yes
medium Rutting
No
High Rutting


B
What is the percent of Shoving g in the damage area
If percent of Shoving R < 10 %
Yes
Low Shoving
No
If percent of shoving R > 10 % or < 30
Yes
medium shoving
No
High shoving
V
Menu No(5).
1-bleeding
2-polshing
3-Ravelling
Have you inspected visually the location of the damage in the element?
yes
A- bleeding
B- polshing
C- Ravelling
No
You must inspect and/or watch the following:
*Any type of raveling in road .
Retune to menu (5)


A
Excess bituminous binder occurring on the pavement surface, usually found in the wheel paths
If percent of Excess bituminous binder E < 10 %
Yes
Low bleeding
No
If percent of Excess bituminous binder E > 10 % or < 25%
Yes
medium bleeding
No
High bleeding


B
Surface binder worn away to expose coarse aggregate
If percent of aggregate coated with asphalt binder
Yes
High polishing
No
If percent of Excess bituminous binder
Yes
medium polishing
No
Low polishing
C
Wearing away of the pavement surface caused by the dislodging of aggregate particles and loss of asphalt binder
If percent of holing in the surface of pavement
Yes
low Raveling
No
If percent of Excess bituminous binder
Yes
medium Raveling
No
High Raveling

**Appendix B:**

The appendix shows the flexible pavement high way deterioration

Figure No.B-1 high Transverse Cracking (St. 40+00)

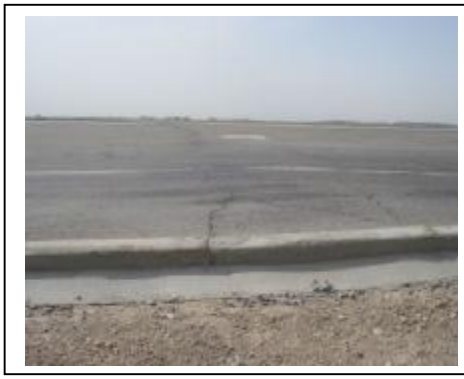


Figure No.B-2 high longitudinal crack (St 52+00)

Figure No.B-3 moderate edge crack (St. 30+00)

Figure No.B-4 high bleeding (St. 13+00)

Figure No.B-5 high rutting (St. 22+00)

Figure No.B-6 high edge crack (St. 34+00)

Figure No.B-7 high patches (St. 8+00)

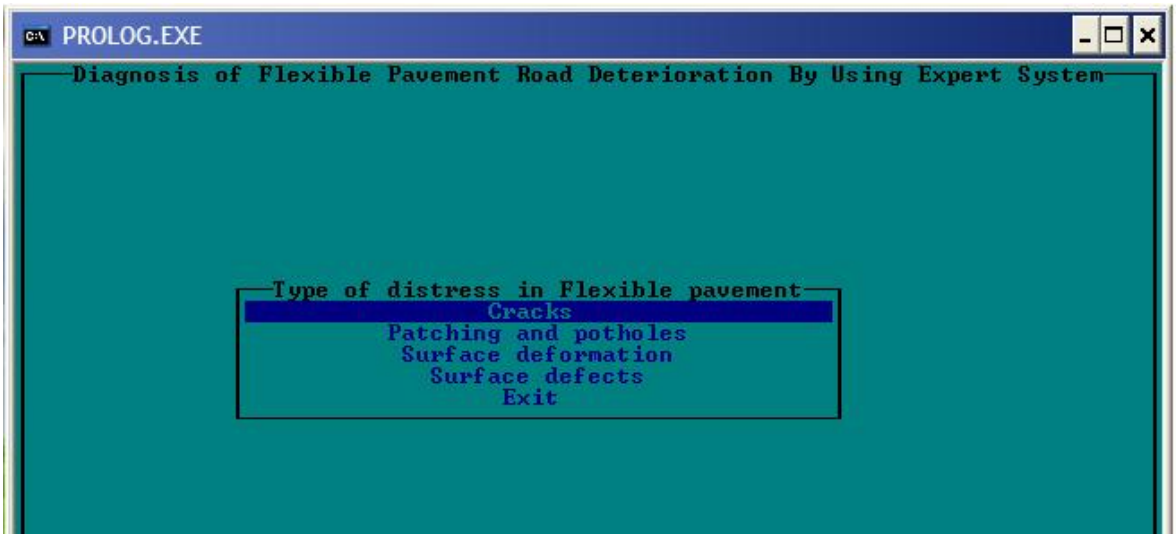
Figure No.B-8 moderate longitude crack and high patches (St. 18+00)

**Appendix C:**

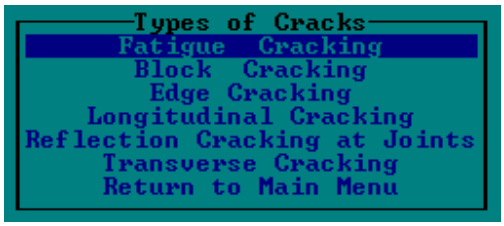
This appendix shows the Diagnosis of Flexible Pavement Road Deterioration Using Expert System, it is programmed by Turbo Prolog programming Language. The program takes all cases and questions as shown as in appendix A.

The system is work as follows:

The Main Menu of the system is shown in the following figure:

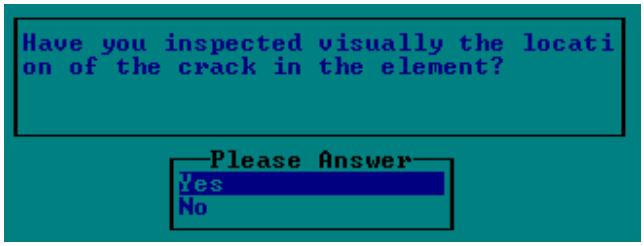



There are four choices (Cracks, Patching and potholes, Surface deformation, Surface defects, and Exit), we select one of them according to the type of element which is effect or exit from the system. If we select Cracks. The following figure is shown:

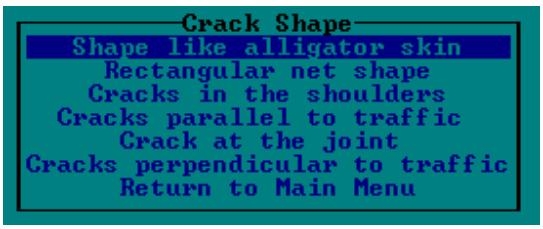



There are seven choices also (Fatigue Cracking, Block Cracking, Edge Cracking, Longitudinal Cracking, Reflection Cracking at Joints, Transverse Cracking, and Return to Main Menu), we select one of them according to the cracking type.

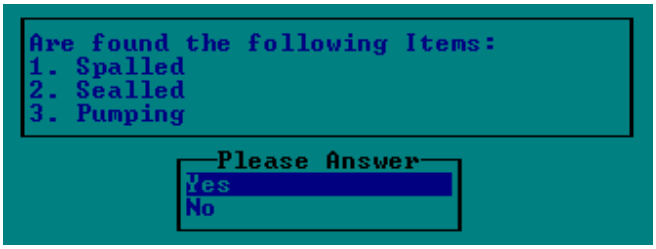
If we select Fatigue Cracking the following figure is shown:



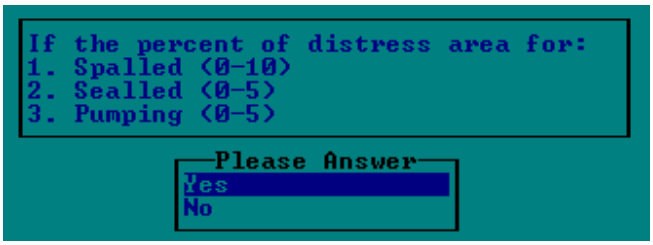
If we select Yes the following figure is shown:




We must select one of the crack shape, if we select Sshape like alligator skin, the following figure is shown:




If we select Yes the following figure is shown:




If we select Yes the following figure is shown:


So on, for other cases according to the flowcharts showing in appendix A.