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# PROTOTYPE WEB-BASED EXPERT SYSTEM FOR FLEXIBLE PAVEMENT MAINTENANCE

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## Abstract

The paper describes the development of a prototype web-based expert knowledge system that can be used to maintain flexible pavement within a tropical region. This prototype system provides the advantages of using existing web-based expert system technology. Currently, deterioration of asphalt pavement layers is one of the biggest problems in Malaysia and requires maintenance to ensure that the roads remain open and able to guarantee the regularity, punctuality, and safety of all transport services. According to this process, the knowledge collection that has acquired and the date concerning to domain expert system of the development web-based system was launched with knowledge representation IF and THEN rules and coded by PHP programming. The web pages that support the user interface are created using a framework consisting of HTML, CSS, and J-Query. The prototype web-based expert system uses the knowledge of a pavement maintenance expert, or a specialist in pavement problem remediation, to emulate a portion of their professional reasoning abilities, which it can then use to assist with the maintenance of existing roads and enhance the efficiency and accuracy of the professional engineers tasked with the assessment of all available remedies. Thus, the system increases the performance level of the engineers in analysing, discerning and customising the information that will assist decision makers throughout the project, so the probability that the right decision and treatment are implemented at the right time is increased.

Keywords: Prototype system, Road maintenance, Expert system, Remedies, Techniques.

**Abbreviations**

| | |
|---|---|
| CSS | Cascading Style Sheets |
| DC | Density of Crack |
| FHA | Federal Highway Administration |
| GUI | Graphical User Interface |
| HTML | Hyper Text Mark-up Language |
| ISA | International Standard Atmosphere |
| IT | Internet Technology |
| ITD | Idaho Transportation Department |
| Jquery | JavaScript Library |
| NACA | National Advisory Committee for Aeronautics |
| PC | Pavement Condition |
| PHP | Programming Hypertext Pre-processor |
| PWBKES | Prototype Web-Based Knowledge Expert System |
| RF | Road Functional Class |
| RPS | Rapid Prototype System |
| RT | Remedy Techniques |
| SC | Severity of Crack |
| SQL | Structured Query Language |
| TRB | Transportation Research Board |
| UWM | University of Wisconsin-Madison |
| VCTIR | Virginia Centre for Transportation Innovation and Research |
| WHO | World Health Organization |
| WSDOT | Washington State Department of Transportation |

## 1. Introduction

In Malaysia, substantial amounts of time and money are spent on a yearly basis for the maintenance and rehabilitation of major and minor roads with evidence of distress, such as cracking and rutting [1]. However, there exists a deficit of skilled individuals with specialised training and expertise in the area of pavement evaluation [2].

This lack of adequate labour has resulted in a situation, wherein maintenance workers lack the craft of maintaining urban and rural road infrastructure, and possess limited knowledge of road construction or pavement maintenance. As a result, these workers require consultation from experts before selecting appropriate treatments during the maintenance of distressed asphalt pavement [3].

The maintenance of distressed pavement, and the process of returning it to a serviceable state is one of the most challenging problems faced by pavement engineers and executive decision makers within the highway sector [4]. A diagnosis of pavement distress requires a significant amount of engineering judgment, and individuals with the skills to make such judgements are in scarce supply, particularly when it comes to the maintenance of flexible pavements in Malaysia and other tropical regions. At the same time, pavement maintenance is one of the most cost-effective, socially and environmentally sustainable ways to achieve deteriorating roadway systems, when utilised in a suitable way [5]. Moreover, pavement maintenance is one of the most substantial components of a complete road network, and should be granted due significance for priority analysis. Priority analysis is a multi-criteria process for determining the appropriate classification list of candidate sections for maintenance and is based on several factors [6].

Road maintenance and rehabilitation of pavement models have been developed throughout the world, where an expert system is adapted to sustain the pavement maker of choice. Prediction of future pavement performance of a road network is a crucial step in a pavement management system equipped with a corresponding annual budget. Researchers used soft computing, i.e., fuzzy logic, neural network, and so on in enhancing the pavement management systems [7 - 9] and pavement deterioration modelling [10].

The development of web-based expert systems for assistance in remediation of flexible pavement deterioration has received increasing attention in the literature over the last few years [11]. Currently, hundreds of millions of users can access several billion documents on the Web, and even larger datasets reside within organisations' intranets and Web-accessible databases (the so-called Deep Web) [12]. As the amount of available data continues to grow rapidly, it becomes increasingly difficult for users to organise, find, access, and maintain the information required [13].

By involving pavement engineers and other officials due to the lack of easily available systems that allow access to critical information relevant to flexible pavement maintenance technologies and may assist an engineer or a planner in deciding which technologies are potentially applicable to their projects [14]. When utilised in an intelligent manner, pavement maintenance is a cost-effective and environmentally effective technique for managing a deteriorating roadway system and is necessary for long-term planning of anticipated maintenance requirements needed to satisfy the users of the roadway systems [5].

## 2. The Importance Factors Considered in the Prototype System

This study focuses on the following factors that contribute to distress type:

- the observed distress;
- the cracking severity;
- the cracking density;
- the road function class;
- the climate region;

These factors were considered by the system in the development and selection of pavement treatments. Each factor was divided into particular categories, identified by existing documents and through interviews with selected experts in asphalt pavement. Most of the interviews were conducted with selected asphalt pavement experts, as it was considered inappropriate to gather group and class input from every worker.

## 3. Development of ESTAMPSYS Prototype

At the point in time when pavement condition surveys are conducted, the knowledge engineer requires a minimum amount of information in order for him/her to make wise decisions about the level of need for rehabilitation, and the strategy by which to achieve the rehabilitation. These data requirements identify firstly the pavement distress types, as either single distress or combined distress, and secondly the category of the problem. The distress types are categorised according to their causal mechanisms and assigned a distress severity that measures the level of severity of each observed distress type. The distress severity measures the degree of deterioration, the amount of distress density and the relative percentage of the area of the project affected by each combination of distress type and severity. In addition, consideration is given to the degree to which the road is functional, as this may be impacted by the regional climate. A technically sound engineering condition survey must address each one of these needs, although the parameters of each category may vary from agency to agency. Table 1 shows an example of a distress type description, its associated severity, and density groups that can be used as criteria to choose remediation techniques that will correct the condition.

**Table 1. Criteria of pavement maintenance for transverse cracking**.

| Type of Distress | Evaluation | | RF | RT | PC |
|---|---|---|---|---|---|
| | SC | DC | | | |
| **Single Transverse Cracking** | **Low** | **Rare** | Minor | Routing and seal >6mm | Corrective |
| | | | Major | Routing and seal >6mm | Corrective |
| | | **Intermittent** | Minor | Routing and seal >6mm | Corrective |
| | | | Major | Routing and seal >6mm | Corrective |
| | | **Frequent** | Minor | Burn and Seal | Corrective |
| | | | Major | Clean and seal | Corrective |
| | | **Extensive** | Minor | Crack filling | Corrective |
| | | | Major | Crack filling | Corrective |

## 3.1. The approach to resolving engineering problems

Within the domain of engineering, problems and solutions are identified from two types of knowledge. The first is deterministic knowledge, characterised by a body of well-accepted and proven information that is available to engineers working in the field. The second is heuristic knowledge or personal information developed by individual engineers characterised by beliefs, opinions, and rules-of-thumb [15]. Typically, challenging engineering problems cannot be solved based merely on deterministic knowledge; there are two reasons for this. First, the problem may be so severe that the available deterministic knowledge is incomplete. Second, occasionally, the solution to an engineering problem cannot be classified as entirely correct or fully incorrect. In many cases, the knowledge engineer must select the best option from among a set of alternatives such that it is cost-effective and “good enough.” As these decisions must be made on-location, the engineer must be adaptable to the domain, and he/she must possess excellent evaluation skills and good judgment acquired from previous experience in solving similar issues. Additionally, this selection process also requires that the engineers possess excellent technical skills.

### 3.2. Knowledge acquisition

The process by which an expert knowledge base is acquired is a critical component of knowledge engineering. The knowledge acquisition process consists of gathering relevant information about a domain, usually from an expert who already possess substantial knowledge in highway pavement construction and maintenance, and who then aggregates further knowledge obtained from documented sources and human expertise Sources of knowledge can be partitioned into two classes. The first class consists of documented knowledge such as professional journals, manuals, and books written in the field of pavement maintenance. The information extracted from these sources becomes the knowledge foundation and is used principally by the proposed web-based expert system. Written sources in the domain of flexible pavement maintenance consist of studies that address various subjects and structures with documented exposure to pavement maintenance activities, as shown in Table 2.

The second class of knowledge consists of undocumented sources that are integrated within expert systems by domain experts. The selection of domain experts is one of the most important components of any expert system development. Domain experts must be both knowledgeable of and have sufficient experience (theoretical, practical, or a combination) in their field. Moreover, the multiplicity of knowledge sources and types increases the complexity of knowledge acquisition. In addition, the time requirements for knowledge acquisition increase the difficulty in creating the knowledge base.

**Table 2. The majority of sources knowledge acquisition**.

| No | Title | Publisher | Year Version |
|---|---|---|---|
| **1** | Treatment for Virginia Pavements | VDOT | 2015 |
| **2** | Pavement Patching Practices | TRB | 2014 |
| **3** | Pavement Rating Manual | ITD | 2011 |
| **4** | Pavement Distress Identification Manual | FHA | 2006-2009 |
| **5** | Pavement Surface Evaluation and Rating | UWM | 2001 |
| **6** | Asphalt Pavement Maintenance | WSDOT | 2000 |
| **7** | Pavement Surface Condition Field Rating | WSDOT | 1999 |

### 3.3. Selection of building tool

The development of a web-based expert system is largely dependent upon the design of the end-user interface (GUI) and server-side programming language employed (i.e., the web-based program in which the knowledge-based rules are encoded). The end-user interface manages all user input and, therefore, is designed for simplicity and ease of use. In this paper, the web pages that support the user interface are designed using a framework consisting of HTML, CSS, and J-Query. Additionally, a responsive web interface, for facilitating browsing from mobile devices, is ensured by utilising the Bootstrap framework. On the server side, the data extracted from the web page is processed by a proxy or agent process. This processing is executed on the server side using PHP, a high-level programming and scripting language that is easy-to-use and does not require the extensive knowledge of object oriented programming necessary when using C++, C# or Java. The relational database used to store the acquired knowledge is MySQL, a proprietary, non-standard implementation of entry level SQL. The expert system supports a GUI, thus making it more accessible for users with minimal expertise in data management. Users are not aware of the dependency on the MySQL database and need not have any knowledge of SQL. Novice users can, therefore, learn and improve their knowledge in flexible pavement maintenance.

## 3.4. Knowledge representation

The structure of the ESTAMPSYS prototype, as shown in Fig. 1, consists of the relationships between the main components of the expert system and includes working memory, the inference engine, the knowledge base, and the user interface. Moreover, the expert system consists of two main parts, described as follows.

- The development environment includes the part that is used to inject the expert's knowledge into the expert system environment.
- The consultation environment consists of the part that is used by non-expert users to gain knowledge.

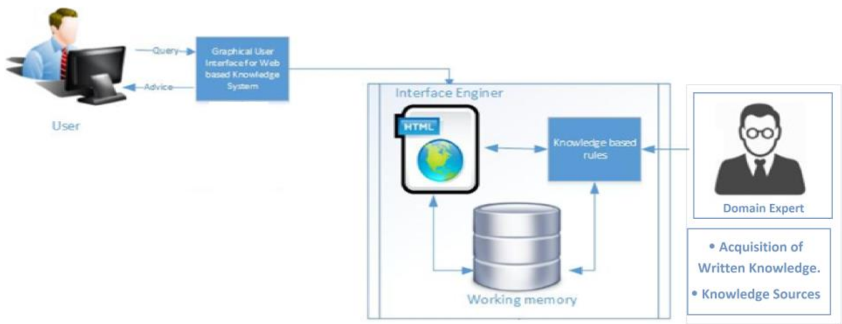


**Fig. 1. Architecture of web-based expert system**.

## 3.5. Graphical user interface

Graphical User Interface (GUI) design focuses on interactions with users obtaining expert knowledge. The GUI provides screens, boxes, action buttons and other primitive input/output elements that are easy to access, understand, and use so as to facilitate the user actions. Making expert systems as user-friendly possible and avoiding the creation of a complicated design makes expert systems attractive to users in many fields. Expert systems must enable users to identify their problems while minimising any confusion or frustration that the user may encounter. The ESTAMPSYS web-based expert system provides a variety of different and useful user functions. The primary category of the system is displayed as toolboxes within the user interface. Toolboxes for flexible pavement distress are provided to assist end-users. Figures 2 and 3 show a screenshot of the main menu. In this section, the function of the toolboxes for single distress and combined distress, problems, and solutions are discussed and include practical examples.

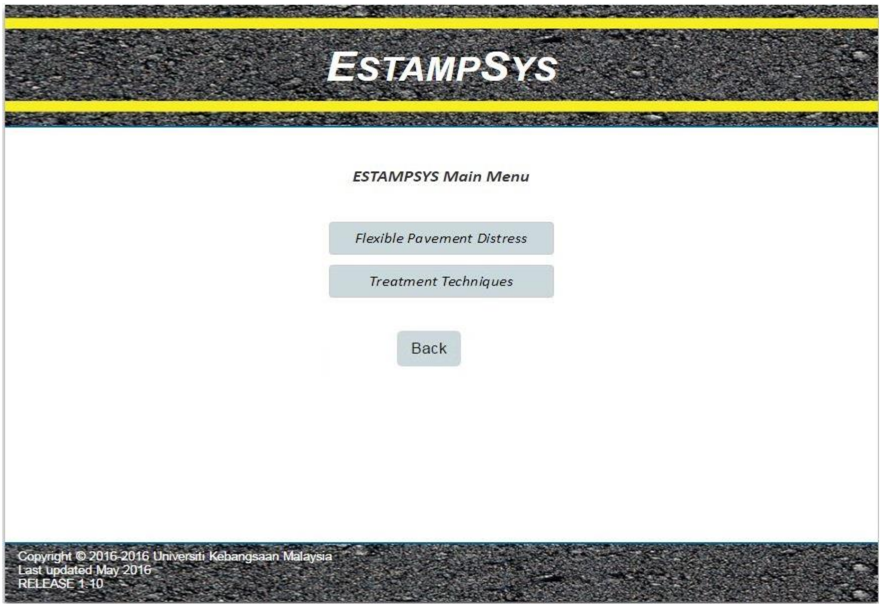


**Fig.2. A screenshot of the main menu**.

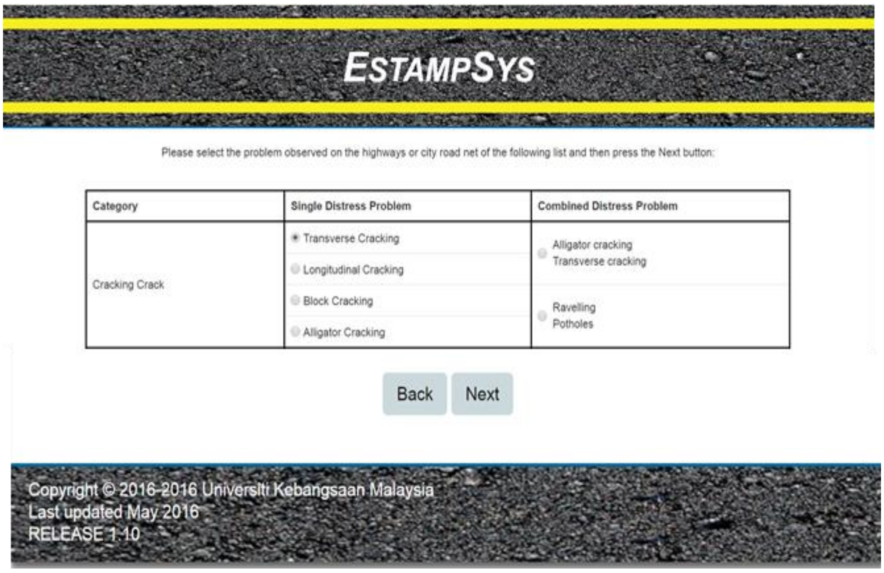


**Fig. 3. A screenshot of the problems**.

## 3.6. Toolbox for problems selection with solution

At this stage, the toolbox for problems asks the user to select parameters based on the deterioration of pavement, as shown in Fig. 4, and presents a list of five categories, which were described previously, representing different criteria relating to a single instance of pavement distress. On this page, users can select the problems they have faced and the amount of distress observed, as it relates to severity, density, functional road class, and climate users of the expert system. Descriptions of such problems can help both users and engineers know the cause of problems and the effect these problems on the maintenance of roads. For example, if single pavement distress is observed, its severity is low, density is rare, the functional road class is minor, and climate is tropical rain, then the next page will inform the user that Crack Routing and Sealing is the appropriate solution, as shown in Fig. 5.

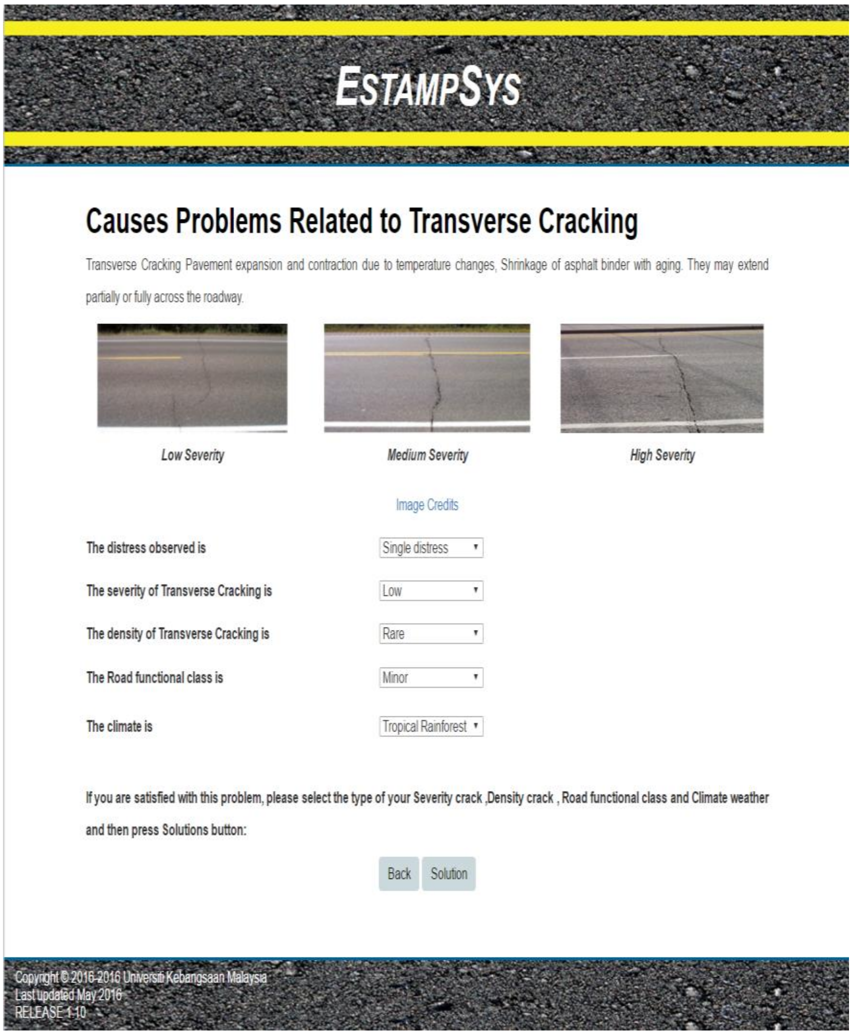


**Fig. 4. A screenshot of problems and solutions**.

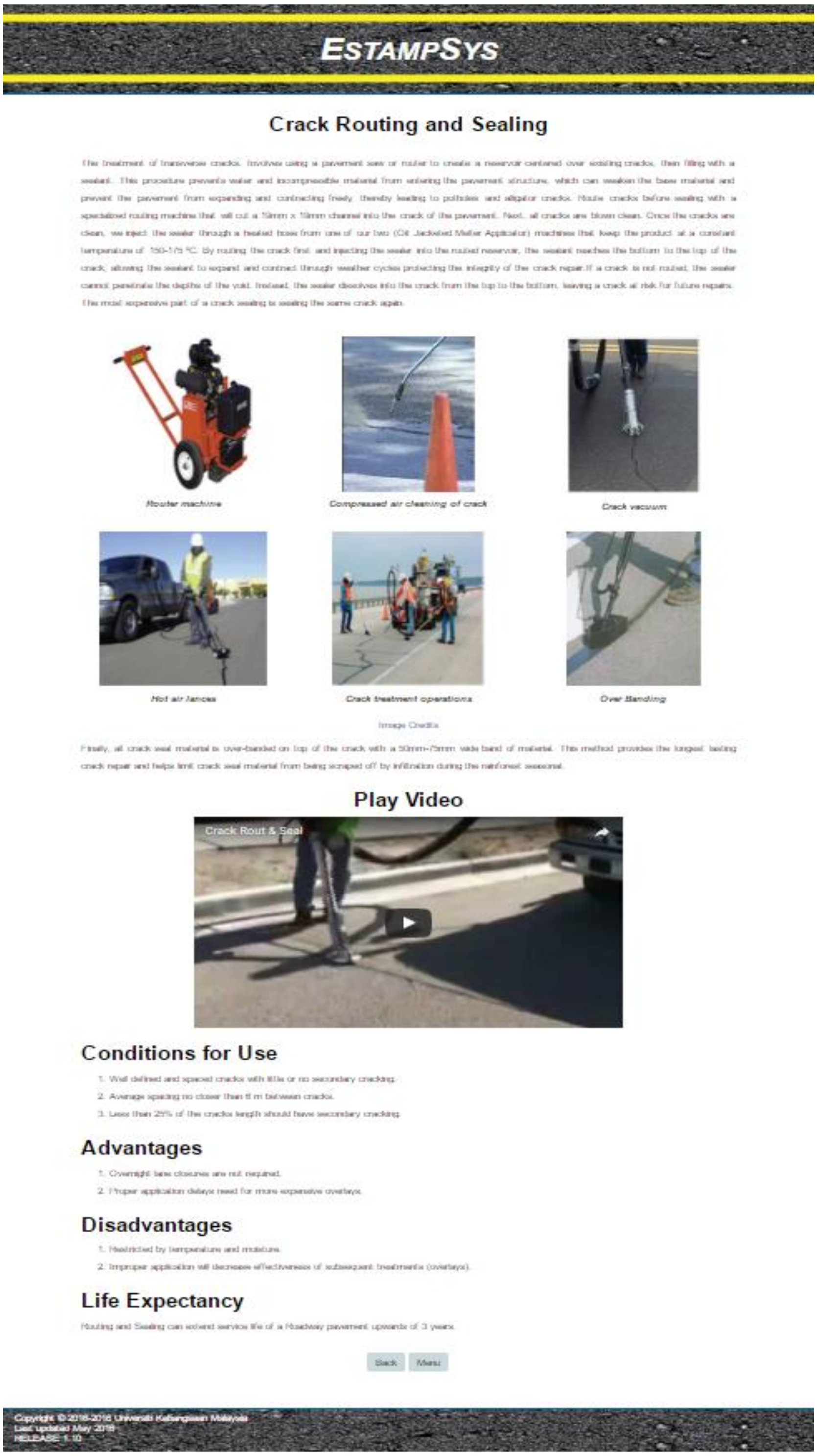


**Fig. 5. A screenshot of solution**.

## 4. Evaluation of the System

Evaluation of expert systems is a very complicated task. It is a fundamental one, however, if the expert system is to be put in practice [16, 17]. Moreover, evaluations are useful in determining whether an expert system is meeting its intended aims. The evaluation methods are classified into two groups. Ten entrants were chosen and divided among two groups to test the satisfaction reported by the ESTAMPSYS users. The first group included five domain experts, while the second group included five computer engineers. The users evaluated ESTAMPSYS, assigning a mean value above five if they were satisfied. Evaluation deals with building the correct expert system by ensuring that the system precisely integrates human expertise. Therefore, the satisfaction of experts represents a significant factor in the evaluation process. The group of experts within the domain of pavement engineering produced a system verification mean value of (4.4000) i.e. (4.4000/5) = (88%), which represents the percentage of the sample that agrees that the system is functioning correctly. The group of computer scientists produced a system evaluation mean value of (4.5750), i.e., (4.5750/5) = (91.5%), and represents the percentage of the sample that agrees that the system is working correctly. The data from our questionnaires was analysed via an independent t-test over the sample space such that the value of the t statistic was (-1.297) with (8) degrees of freedom, so the p-value of this test is (0.231). Thus there is no statistical difference between these groups at a value of alpha=0.05. In this study, no significant difference between the groups was found for any questions, as shown in Table 3. Moreover, Fig. 6 explains the result questionnaire with the factors of evaluation, learnability of the ability of system application to authorise end-users learning how to work with the prototyping, overall assessment, quickness in running, lack of bugs, and ease to use.

**Table 3. Expert responses for evaluation statistically by t-test.**

| Group | N | Mean | SD | t | DF | P value |
|---|---|---|---|---|---|---|
| **Pavement Engineering** | 5 | 4.400 | 0.231 | -1.297 | 8 | 0.231 |
| **Computer science** | 5 | 4.575 | 0.190 | | | |

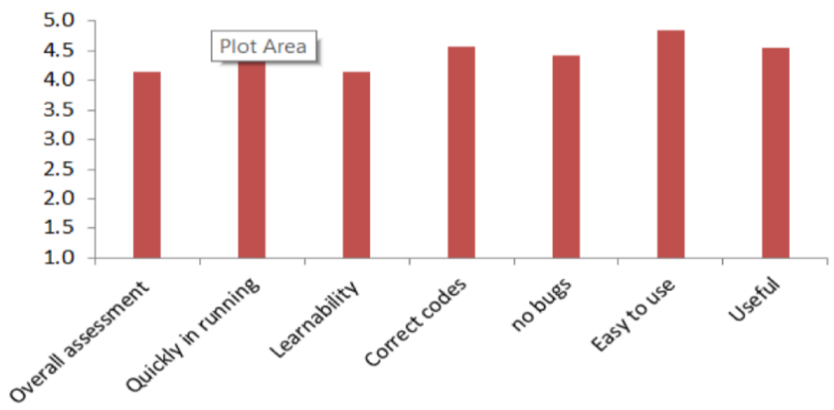


**Fig. 6. Results of prototype system evaluation**.

## 5. Maintain and Update the System

In this step, the maintenance and update stage of the web-based expert system is considered. The first stage is to discover bugs as well as problems that may appear during the web-based running of the system with adaptation to user requests. The second stage is to ensure that the system is up to date and possessing the most accurate as well as recent knowledge concerning the domain of application in the new integration of new modified knowledge. The modifications to the knowledge-base are documented and attached to the design document accordingly; these amendments may reflect some changes to the implementation. Furthermore, the required modifications are made to the development version of the system, and all modifications are documented and attached to the user manual of the next release of the complete system [18]. To achieve the second stage, an arrangement for periodical meetings with domain experts are required, where domain knowledge is reviewed, and the latest updates in the field are discussed, and the requisite knowledge is acquired and augmented into the knowledge-base. Prototyping can be maintained by a knowledge engineer or by any qualified user, competent in PHP programming, under the supervision of a highway pavement engineer. The source code of prototyping includes remarks to simplify the update operation, especially when the user carrying out the update is not the developer (the knowledge engineer).

## 6. Conclusions

This paper explains the development of a prototype web-based expert system to manage flexible pavement maintenance. The expert system, named ESTAMPSYS, implements suggestions for remedies that occur from pavement damage. We also document the effects resulting from the suggestions with the intent to assist practising engineers in identifying required repairs. The ESTAMPSYS inference engine analyses the input data parameters and recommends a set of solutions for each problem, such that the specific recommended solutions depend on the severity and density of the damaged pavement. If more than one solution is recommended, the inference engine requests further data, consisting of factors or conditions of the damage to allow the inference engine to identify the optimal solution. The extracted knowledge is not infallible but provides good to excellent documentation about pavement damage, particularly their effects, their causes, preventive actions, and remedies. The expert system can help road maintenance workers improve their professional ability to evaluate available treatments. The following conclusions were obtained in this study:

- Single pavement distress problems were identified and classified according to multiple sources, such as manuals, journals and field experts.
- Prototype, a web-based expert system for flexible pavement maintenance in tropical regions, has been developed by computerization of acquired knowledge using PHP programming.
- Web pages that support the user interface were created using a framework consisting of HTML, CSS, and J-Query. ESTAMPSYS possesses an advanced knowledge base consisting of single distress module.
- The graphical interface of the system accepts input to guide the user to agree on an input data selection to avoid user mistakes.

- ESTAMPSYS was verified, validated and evaluated. ESTAMPSYS verification required unit testing.
- Updating ESTAMPSYS to include new experiences is an easy operation because the system includes help facilities within the source code.

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