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PROTOTYPE DEVELOPMENT OF KNOWLEDGE-BASED SYSTEM FOR LOW-VOLUME RURAL ROADS IN SARAWAK

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Abstract: The value of rural roads cannot be overstated in terms of a society's economic and social development. Road construction has the potential to alter natural terrain, cause widespread environmental damage and result in significant land-use and cultural changes. Roads must be constructed in accordance with appropriate design specifications in order to balance the needs, costs and environmental impacts of road users. There are several reasons for scarcity in technical skills and technological development of Low-Volume Rural Roads (LVRRs). Universities, colleges, polytechnics and technical schools do not provide LVRR-focused education. Low-tech LVRRs skills are often acquired through years of experience and are lost due to retirement and downsizing. This article discusses the development of a conceptual knowledge-based system for low-volume rural road design. The prototype system has been developed for demonstration purposes and is not ready for implementation. This prototype system simulates a portion of a pavement expert's or specialist's technical reasoning skills, which it can then use to help with road design and improve the efficiency and precision of engineers tasked with evaluating all potential designs. As a result, the system increases the engineers' efficiency in evaluating, assessing and modifying information that will aid decision makers throughout the project, thereby increasing the effectiveness of making the right decision at the right time.

Keywords: Low-Volume Rural Roads, knowledge-based system, rural roads, sustainability.

Introduction

Roads are critical for rural development. Not only in urban areas, but in rural areas. Roads provide the foundation for sustainability of economic activity and growth. However, rural road construction is complicated by difficult topography and unstable geology. Even so, due to the pressing need to increase productivity and the standards of living for rural inhabitants, pressure is mounting to build all these connections in rural areas in order to open them up to facilitate initiate and rekindle economic activity. The general approach to the pavement design of Low-Volume Rural Roads (LVRRs) differs in several aspects to that of High-Volume Roads (HVRs). Typical pavement designs, for example, are generally aimed at a relatively higher level of service, necessitating multiple layers of carefully chosen materials. Significant cost savings for LVRR pavements can be realised by reducing the number of pavement layers or the thicknesses of each layer, utilising more locally available and less expensive materials as well as employing more appropriate surfacing options and construction techniques (Cook *et al.,* 2015).

Unfortunately, adequate and flexible design standards for lower-speed LVRRs which are frequently single-lane and even gravel-surfaced LVRRs are not widely accepted. Furthermore, LVRRs present additional design difficulties such as adequate width for large trucks to turn on such narrow lanes, sharp curves, single-lane roads, road markings and bridge and guardrail standards. Considerable existing technical expertise on pavement materials, stabilisation and surfacing design can be applied directly to LVRR construction issues. However, the reality of inadequate LVRR funding necessitates the consideration of methodologies and solutions that may be sufficient but could be less than ideal or desirable (Jaarsma, 1997; Jaarsma & Van Dijk, 2002; Gallego *et al.,* 2008; Khandker *et al.,* 2009; Gallego *et al.,* 2016; Franzen & Thorpe, 2020; Pasindu *et al.,* 2020). A well-designed road considers mobility and safety while considering economic, sustainability and environmental considerations (Mannering *et al.,* 2005).

Several factors contribute to the shortage of LVRR technical skills and limited technological development. Universities and colleges do not offer training tailored to the needs of LVRRs. Low-tech aspects of LVRRs frequently necessitate years of experience, which is lost due to staff retirements and downsizing (Coghlan, 2000).

Traditionally, LVRRs do not attract engineers or researchers because they lack the glamour and funding of larger highway projects. The fundamental low-technology skills required for LVRRs system operation and management have been insufficiently reported in scientific and professional journals. As a result of this situation, many fundamentals, creative experiences, educational tools and other things are lost and more time is spent reinventing these things. Designing roads should be simple yet economically feasible.

However, the process of designing rural roads is problematic since engineers need to refer to the guidelines and standards provided by the relevant authorities to get exact data and precise steps for the relevant calculations (Coghlan, 2000).

Conventional roadway and pavement design methods are often inefficient and time-consuming. It prevents users such as junior road engineers, technologists, junior technical personnel and students from getting a holistic view of the design process. Commercial software packages have been developed to improve the availability and access to information on roadway design and planning processes by integrating the 3D-design models, active digital mapping and virtual reality walkthroughs. These commercial methods are typically complex and costly.

An Internet-based Low-Volume Rural Roads (ES-LVRRs) advisory system was developed by using PHP Script Language which is an open-source scripting language that can be incorporated into HyperText Markup Language (HTML) to assist end-users with understanding the design process. The development work on the knowledge-based system has no intention of duplicating or even competing with commercial packages.

The aim of the system is to give users a simple web-based tool that would provide them with the necessary features to better understand the LVRRs design process without having to pass the steep, commercial parquet learning curve as mentioned before. Furthermore, the final design process will be presented in a graphical form so that the final design could be checked and examined for reference purposes.

Thus, this study discusses the conceptual development of a knowledge-based system for the design of low-volume rural roads. The prototype system designed by this research team is for demonstration purposes only and is not yet ready for use.

The Knowledge-based System's Markup

A knowledge-based system or expert system is a type of computer-aided decision-making system that utilizes an expert's knowledge, experiences and skill to make appropriate inferences using a rule-base (Duan *et al.,* 2005; Milad *et al.,* 2016; Munaiseche *et al.,* 2018; Chatterjee *et al.,* 2020; Chan *et al.,* 2021). A knowledge-based system is a computer program that simulates the decisions and actions of a skilled practitioner in a particular field.

It requires both a knowledge base of accumulated experience and a set of rules. The knowledge-based program emphasises experience, knowledge of the subject-matter, heuristic application, forward or backward reasoning, incoherence and one's capabilities to elucidate the details to run the program effectively. The rule-based expert framework includes a knowledge base, inference engine, knowledge acquisition, description facility and user interface.

Forward and backward chaining rules are used for knowledge representation strategies. The purpose of the knowledge-based system is to simulate an expert in a particular field of knowledge such as engineering or in any other domain, where expert know-how is limited. The knowledge base is made up of data and rules that are used to reach conclusions. The information can be factual, heuristic or empirical. The expert system's problem-solving component is the inference engine. It consists of a set of processing procedures for examining data-using rules.

Knowledge-based System Characteristics

Knowledge is the most important component of any knowledge-based system. The system's competence is proven by its comprehensive, superior knowledge of the task domains. The knowledge base and the inference engine are divided into expert systems while the traditional program includes a data processing system and a knowledge database (Efraim & Aronson, 2001; Chatterjee *et al.,* 2020, Chan *et al.,* 2021).

Any alterations to the code directly impact both its knowledge and processing, this mingling makes it difficult to understand and review the programme code. The expert framework comprises of a knowledge base containing accrued expertise and a set of rules to apply it to each unique situation outlined in the program. Additional to the collection of rules, sophisticated expert structures may be enhanced. A "tool" or "shell" are terms that describe development software used to build a knowledge-based system from scratch or using what is known as "scratch development".

A shell is a complete development platform for developing and upholding knowledge-based applications. It follows a step-by-step procedure and has an extremely user-friendly interface such as a graphical interface which enables domain experts to contribute directly to the structuring and encoding of knowledge (Janakiraman & Sureshi, 2003). The cumulative output of a knowledge worker on a problem-solving challenge cannot be replaced by a knowledge-based system. These systems instead can drastically reduce the amount of work required of a person to solve a problem while still allowing people to engage in creative and inventive problem-solving.

Some of the main characteristics of knowledge-based system include:

(1) The provision high-quality performance, solving difficult programmes as well as or better than human experts in a domain.
(2) A broad range of detailed and specialised knowledge.
(3) Utilising heuristics to guide reasoning and thus narrowing down the solution search area.
(4) An explanatory capability, which enables the expert system to scrutinise and validate the reasoning behind its actions and decisions.
(5) The use of symbolic reasoning to solve problems. Numerous types of knowledge are represented by symbols, including facts, concepts and rules.
(6) Providing guidelines, modify and augment existing data, as well as deal with uncertain or irrelevant data.

Development of Prototype ES-LVRRs

The main steps in the development of an ES-LVRRs is the acquisition and representation of knowledge, the selection of building tools for development and lastly the development of a successful operating system. The initial stage is to ascertain demand and utility of the system through literature reviews and using a questionnaire survey of human specialists in the fields of flexible pavement design and rural road design. Secondly, the concerns and obstacles associated with pavement design that road designers may encounter through the knowledge acquisition process.

The next stage is to develop a detailed the generic knowledge representation. Finally, the system is verified, validated and evaluated. A main questionnaire survey is used in this step to assess the demand for a web-based knowledge system. This survey was carried out among ten road design engineers with varying levels of experience in rural road development. Seven specific research questions were applied for this research:

Q1: It is important for an expert/knowledge-based system to be available through the Internet.

Q2: It is important to develop an expert/knowledge-based system for pavement design, engineering and evaluation as a reference resource.

Q3: The proposed web-based system will be useful for engineers, junior engineers, technical staff, students and anyone interested to learn about pavement design, engineering and evaluation.

Q4: The proposed web-based system will assist novice engineers in solving domain problems.

Q5: There are currently inadequate number of domain experts. Furthermore, the numbers are decreasing.

Q6: The proposed web-based system will be used as an archive to document domain problems.

Q7: The proposed web-based system can be used as a shareable knowledge bank among engineers in the domain of the study.

Respondents were asked to rate their responses on a five-point Likert scale, with one representing "strongly disagree" and five representing "strongly agree." Table 1 summarises the responses, displaying the mean values and standard deviations of the questionnaire statements.

The results indicate that the mean values for the research questions are 4.50, 4.50, 4.50, 4.40, 4.20, 4.60 and 4.60. As demonstrated, the participants agreed on and confirmed the importance of establishing a web-based knowledge-based system.

The objective of the ES-LVRRs is to collect and provide design variable input data to further process the flexible pavement design. The output will then be received automatically by the user and the system will recommend the materials needed with options for the variable thickness for each layer.

In this study, the *Guidelines for the Design of Low-Volume Rural Roads (LVRRs), GL01. 2015*, (JKR Sarawak, 2015) was used in the system. This standard was produced by the Public Works Department (JKR) Research

Table 1: Results for the importance and needs of the system

Question No.	Mean Value	Standard Deviation (SD)
Q1	4.5	0.7071
Q2	4.5	0.8498
Q3	4.5	0.7071
Q4	4.4	0.8433
Q5	4.2	0.9189
Q6	4.6	0.5139
Q7	4.6	0.5164

Centre in collaboration with Universiti Malaysia Sarawak (UNIMAS) in 2015.

The standard is suitable for this study because it met the requirements of the Roads of Engineering Association Malaysia (REAM) and *Arahan Teknik* (JKR, 1985; JKR, 1993; JKR, 2013) for JKR R1 and R2 road standards which can be used as a reference tool for students and engineers as well as the first manual produced by JKR Sarawak (JKR Sarawak, 2015). The expert system was also evaluated as a comparison based on the domain knowledge from the Public Works Department (JKR) and the *Manual for the Structural Design of Flexible Pavement,* design method (JKR, 2013).

Methodology for Flexible Pavement Design

A typical flexible pavement structure is shown in Figure 1. The finest materials are typically located near or on the surface. The wearing surface is usually a bituminous seal or asphalt, but it could also be untreated or surface-treated soil for low-cost roads. Multiple layers of material may be present in the base or sub-base. To distribute the stresses imposed on the wearing surface by the wheel loads, the base material must be of superior quality.

This would reduce the amount of stress transmitted to the subgrade while still ensuring that the subgrade deforms as little as possible.

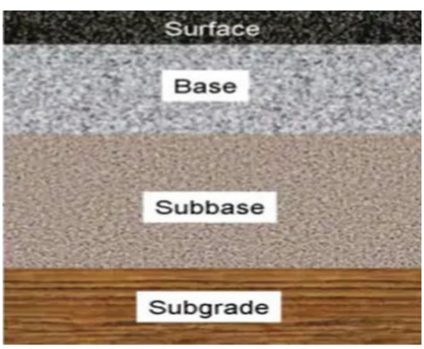


Figure 1: Typical flexible pavement

Because locally available materials are frequently used for the base course, the materials chosen for the base can vary significantly between countries and locations within a country. Pre-defined materials may also require lime or cement treatments to improve the overall engineering properties prior to being used as a base course. Gravel, crushed rock and granular materials stabilised with cement are all common base course materials.

The support provided by the subgrade is often regarded as one of the most critical variables in defining the thickness, composition and performance of the pavement. The amount of support as defined by the subgrade strength or modulus, is affected by soil type, density and moisture conditions, as well as traffic during service.

If the subgrade soil is relatively poor or if more cost-effective subbase materials are available than higher-quality base materials, a granular or stabilised subbase may be used. Choosing the surface and base materials, calculating the required minimum thickness and conducting an economic analysis are all components of the general methodology used in pavement design. The following key information is required for the design of flexible pavements when using the *Manual for the Structural Design of Flexible Pavement*, design method (JKR, 2013).

(1) The types and volumes of commercial vehicles for which the pavement structure is designed.

(2) Design life.

(3) Sub-grade type and strength.

(4) Pavement material types and properties.

(5) The surrounding environment to which the pavement structure will be subjected.

Prior to the completion of the pavement structure, the above information must be gathered and carefully evaluated. Furthermore, the goal of the pavement design is to select the most cost-effective pavement thickness and composition that will provide a satisfactory level of service for the expected traffic. To achieve this goal, the designer must have a thorough understanding of the materials, traffic and local environment - as well as their interactions - in order to predict the performance of any pavement composition.

Additionally, the designer must understand what level of performance and pavement quality will be deemed acceptable under the conditions for which the pavement structure is being designed. Because of the numerous variables and interactions that influence the results, a systematic approach to pavement design is recommended. A pavement design procedure can either be very complex or very simple depending on the amount of data that must be provided or, the number of assumptions that must be made (Austroads, 2010).

Approach to the Solution of Road Design Issues

Engineers have two different ways of finding issues with their designs and constructions and resolving those issues. The first method involves deterministic knowledge, which is defined as a collection of information, which has been accepted and proven, that field engineers have access to. The second method of acquiring knowledge is heuristic knowledge that is unique to each engineer and is defined by beliefs, opinions and rules of thumb (Lu, 1986; Milad *et al.,* 2017). The pavement layers' thickness and material characteristics must be carefully chosen to accommodate anticipated traffic loads throughout the pavement's lifespan. Most of the research on infrastructure investment is concentrated on high-volume highways as a result it is difficult to establish a cost-effective design for LVRRs using low-cost materials and techniques.

Even though LVRRs traffic volumes are relatively low, the environmental impact of the pavement of such roads persists over time. Typically, technically challenging problems cannot be solved solely on the basis of deterministic knowledge for two reasons.

Firstly, the issues may be severe enough that current deterministic knowledge is incorrect. Secondly, an engineering solution is not always completely correct or entirely incorrect. Often, the practicing engineer must select the optimal solution from a collection of worthwhile and "good enough" alternatives. Because these pronouncements need to be made on-site, the engineer's adaptability to the field is critical, they need to possess superior assessment skills and sound judgement based on prior experience resolving similar issues. Furthermore, this selection process necessitates that engineer have exceptional technical skills.

Acquisition of Knowledge

The establishment of an expert knowledge base is an important element in the process of knowledge engineering. The process of acquiring knowledge begins with the collection of domain-specific data, typically from an expert with experience in road pavement and design, construction, maintenance and the process continues with the accumulation of additional knowledge gleaned from primary sources and human expertise.

Two types of knowledge exist. The first class is devoted to books, manuals and professional journals on pavement design, construction and maintenance. This data is used to lay the foundation for the proposed web-based knowledge system. Printed sources with documented exposure to pavement design activities includes studies addressing numerous subjects and structures related to pavement design activities such as flexible pavement design, construction and maintenance, as depicted in Table 1. The second type of knowledge is that which originates from undocumented sources and is incorporated into knowledge-based systems by subject matter specialists.

When developing a knowledge-based system, one of the most critical aspects to consider is the selection of subject matter experts. Subject matter experts must be knowledgeable in their field, as well as possess ample expertise (theoretical, practical or a combination of the two). The diversity of sources and types of knowledge complicates the process of acquiring knowledge. Furthermore, time constraints for gathering information complicate the process of developing a knowledge base.

Table 2: Example of acquiring knowledge sources

No.	Title	Publisher	Year Published
1	Manual on Pavement Design, *Arahan Teknik (Jalan)* 5/85	JKR Malaysia	1985
2	Manual on Pavement Design, *Arahan Teknik (Jalan)* 5/85 *(Pindaan 1/1993)*	JKR Malaysia	1993
3	Manual on Pavement Design, *Arahan Teknik (Jalan)* 5/85 *(Pindaan 2013)*	JKR Malaysia	2013
4	Guidelines for the Design of Low-Volume Rural Roads (LVRRs), 1st Edition	JKR Sarawak	2015

Building Tool Selection

Both the design of the User Interface (UI) and the programming language used on the server to develop the web-based knowledge-based system are critical (i.e., the web-based application that contains the knowledge-based rules). The end-user interface is optimised for usability and simplicity of use by processing all user inputs.

The web pages that comprise the article's user interface are based on a framework comprised of HTML, CSS and J-Query. Also, Bootstrap framework ensures a mobile-friendly web interface. The extracted data is processed on the server by a proxy or an agent. This is accomplished on the server by using PHP, a high-level programming and scripting language that is simple to learn and requires only a basic understanding of object-oriented programming languages such as C++, C# or Java. MySQL, a proprietary, non-standard entry-level SQL implementation is used to store acquired knowledge in a relational database.

The expert system supports the Graphical User Interface (GUI), which makes it more accessible to users with little data management expertise. Users are unaware of the MySQL database's dependency and are not needed to be familiar with SQL. As a result, amateur users can gain knowledge about flexible pavements and improve their skills.

Representation of Knowledge

Figure 2 illustrates the structure of the prototype ES-LVRRs which defines the relationship between the primary components of an expert system such as the working memory, the inference engine, the knowledge base and the user interface. Two major components comprise the knowledge-based system which are as follows:

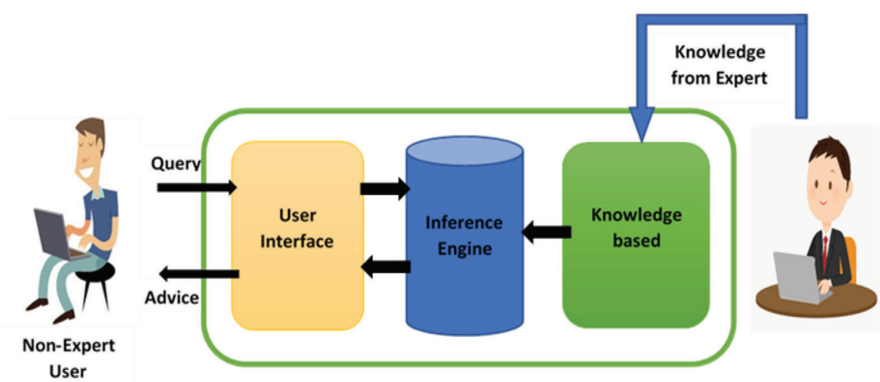


Figure 2: The web-based expert system's architecture

(1) The component of the expert system environment that is used to incorporate expert knowledge.

(2) Novice users utilise a portion of the consulting environment to gain experience.

The System Graphical User Interface (GUI)

A graphical user interface (GUI) is intended for use by users who have attained expert knowledge. The GUI is simple-to-access, comprehensive and uses screens, boxes, buttons and other primitive input/output elements. Knowledge-based systems appeal to users in a wide variety of fields because they are designed to be as simple to use as possible and avoid the use of complex designs. Users must be able to identify their problems with the least amount of confusion or frustration possible. The web-based knowledge management system for ES-LVRRs provides a slew of unique and useful features for users. The primary category of the system is presented as a toolbox within the user interface. End-users can get help from flexible pavement distress toolboxes. Figures 3, 4 and 5 show a screenshot of the main menu as well as some sample topics.

Figure 3: Screenshot example of introduction page

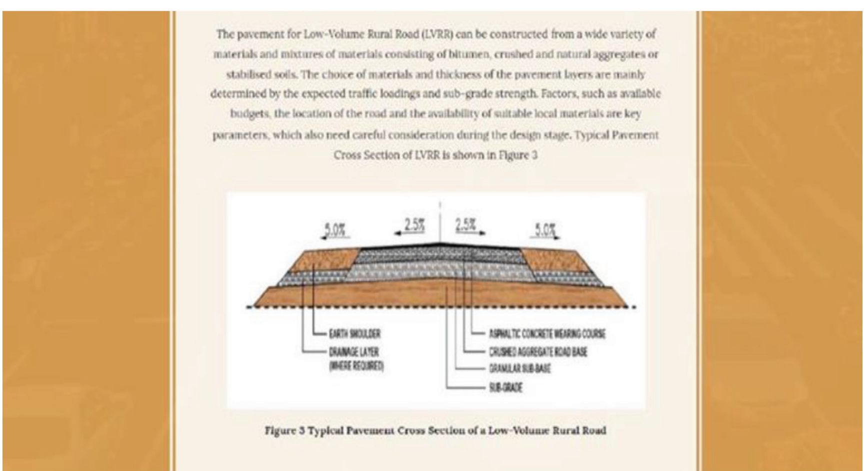


Figure 4: Screenshot example information from the guideline

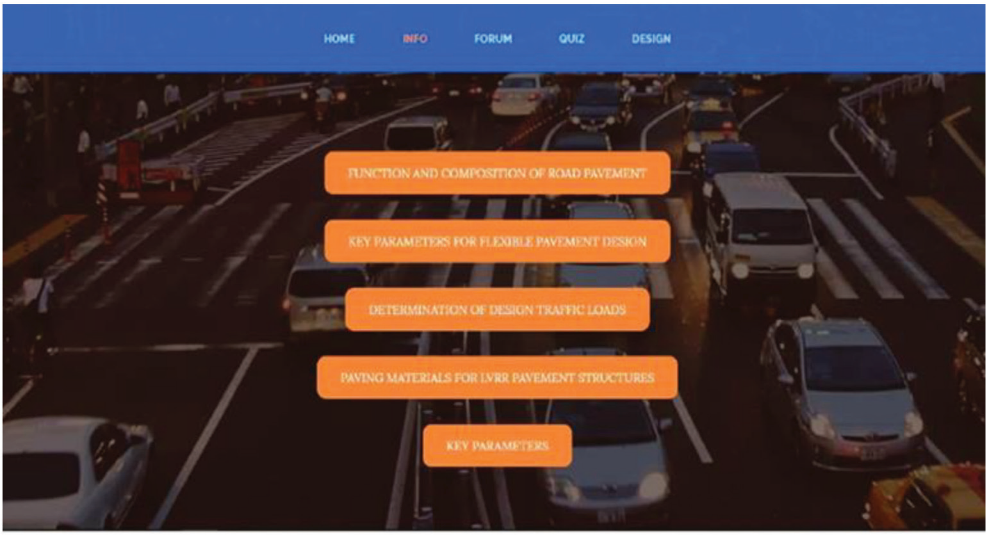


Figure 5: Screenshot example of topics

Toolbox for Design Selection and Solution

There will be a design form for the user to complete on the design page. This design form will help to calculate the output needed for the design of the pavement according to the data entered in the form as illustrated in Figure 6 and Figure 7 respectively. The form will allow the user space to enter the data according to the criteria and radio buttons that the user will need to choose. The form will also contain a table as a reference for the user.

Once the input or data has been submitted, the output with the calculation and the pavement options based on the guidelines will be presented as illustrated in Figures 8 and 9 respectively. This also enables users to double-check their design, especially the manual design, for further verification and comparison.

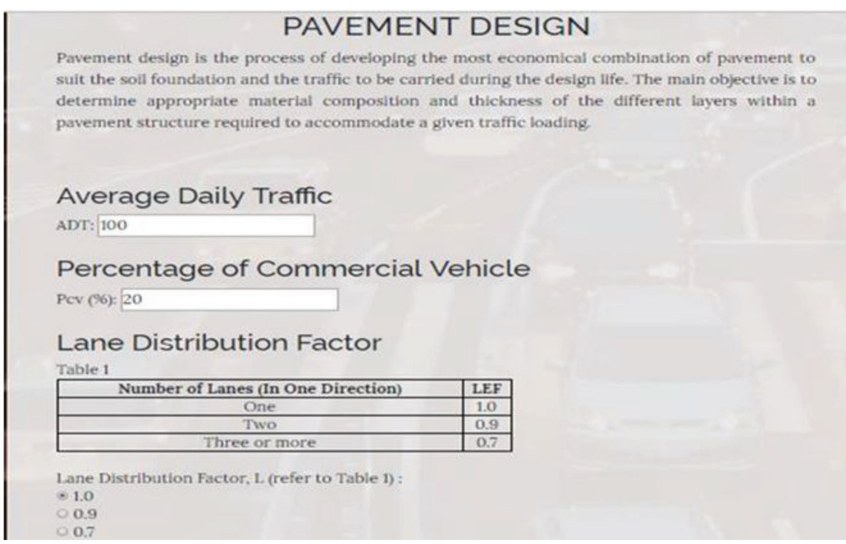


Figure 6: Screenshot of design parameters

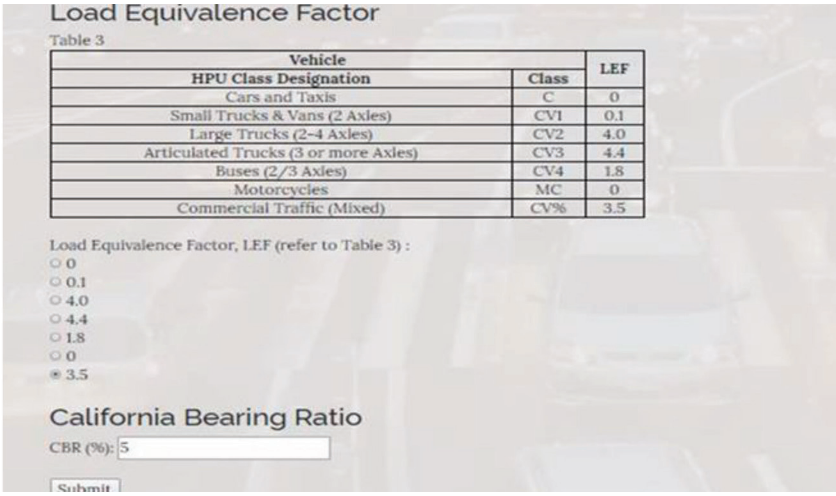
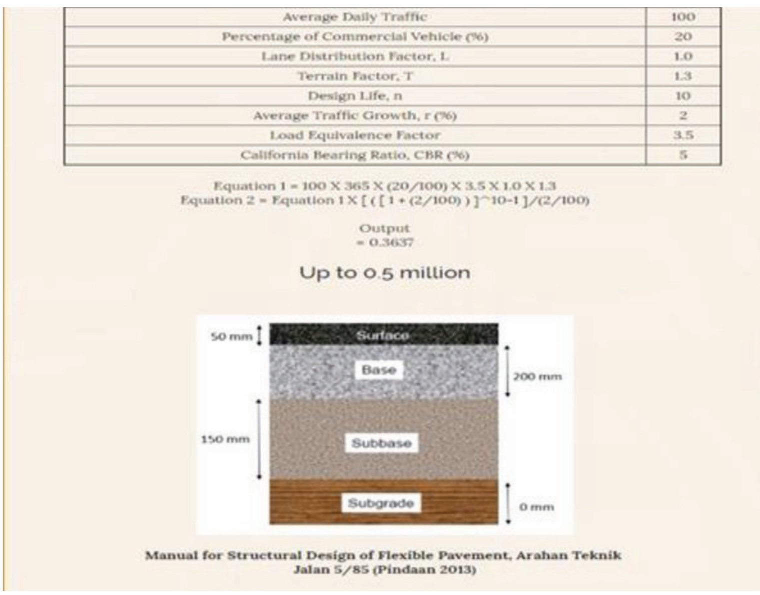

Load Equivalence Factor

Table 3

Vehicle		LEF
HPU Class Designation	Class	
Cars and Taxis	C	0
Small Trucks & Vans (2 Axles)	CV1	0.1
Large Trucks (2-4 Axles)	CV2	4.0
Articulated Trucks (3 or more Axles)	CV3	4.4
Buses (2/3 Axles)	CV4	1.8
Motorcycles	MC	0
Commercial Traffic (Mixed)	CV%	3.5

Figure 7: Screenshot of input design parameters



Average Daily Traffic	100
Percentage of Commercial Vehicle (%)	20
Lane Distribution Factor, L	1.0
Terrain Factor, T	1.3
Design Life, n	10
Average Traffic Growth, r (%)	2
Load Equivalence Factor	3.5
California Bearing Ratio, CBR (%)	5

Figure 8: Screenshot of sample output

Evaluation of the System

It is a difficult task to evaluate knowledge-based systems. This is necessary, however, if the system is going to be applied (Mosqueira-Rey & Moret-Bonillo, 2000; Aguilar *et al.,* 2008). Evaluations can also be used to determine whether an expert system accomplishes its stated objectives. The purpose of evaluation is to create the best knowledge-based system possible by ensuring that human expertise is precisely integrated. As a result, expert satisfaction is an important factor in the evaluation process. The system was evaluated by two groups of experts, the first of which consisted of five information technology (IT) specialists competent in computer science and able to make comments or proposals for system improvement.

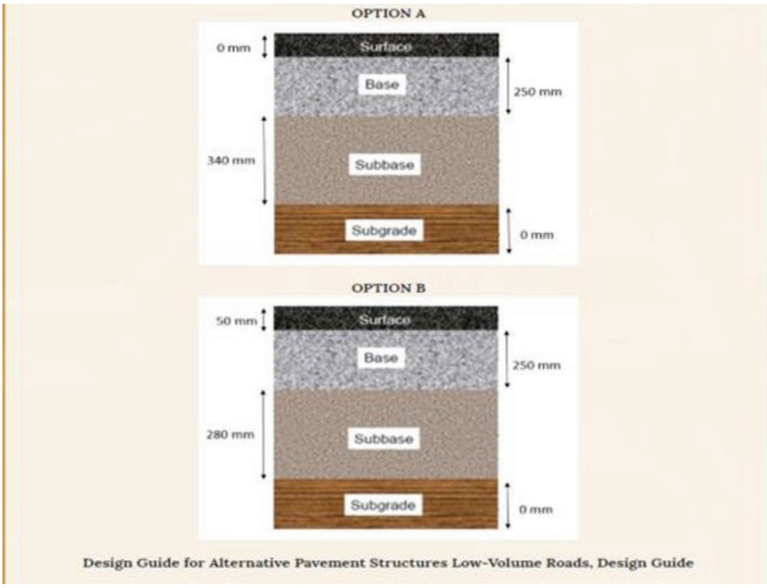


Figure 9: Screenshot of sample options

Another group included five road professionals with over a decade of experience in rural road development. We asked the IT experts and road experts to rank parameters on a 5-point Likert Scale ((1) strongly disagree to (5) strongly agree) such as the quality of user interface, ease of use, speed of running commands, bug-free and accessibility to various parts of the system. For road experts, questions included user interface quality, usability, problem expression, strategy, description of measures and solutions and system utility.

As indicated in Table 3, road specialists arrived at a mean value of 4.4000 for system verification from the questionnaire responses which equals (4.4000/5) = (88%), showing that majority of respondents agree that the system is running properly. The IT professionals generated a system assessment of (4,5750 = (4,5750/5)), which is the mean value of (91,5%), the sample proportion of respondents who agree that the system functions as intended.

Additionally, the P-value for both groups was calculated and found to be 0.230, indicating that the responses for both groups were comparable and significant, as the P-value was greater than 0.05.

To capture the knowledge from local engineering practitioners with experience in LVRs and for system evaluation, a workshop on Guidelines for the Design of Low-Volume Rural Roads was conducted in collaboration with JKR Sarawak. A total of 45 participants from local consultants, contractors, government departments and local government authorities attended. Participants were introduced to the prototype system and given a QR code to access the system during the workshop.

Table 3: Statistical evaluation responses from experts

Cluster	No.	Mean Value	Standard Deviation	*P*-value
Road experts	5	4.401	0.230	0.230
IT experts	5	4.575	0.190	

Later, a questionnaire form was distributed to the participants and they were asked to rate the prototype system overall on a 5-point Likert Scale ((1) strongly disagree to (5) strongly agree), based on factors such as ease of use, easy access via web or Internet, improved calculation reliability, potential cost savings, decision-making assistance and the ability to generate sample reports.

According to the results shown in Table 4, majority of respondents agreed that the system is easily accessible via the web or Internet and that the availability of the generated report is also a very useful tool for documentation purposes, with the highest mean values of 4.066 and 4.266, respectively. On the other hand, convenience of use and the ability to be used as a reference to aid in decision making is a significant factor for the system's adoption.

Conclusion

As demonstrated by the development of this prototype, a knowledge-based holistic approach to pavement design for LVRRs may be feasible. The knowledge-based system, called ES-LVRRs, implements suggestions for the design of pavement.

The output of the selection criterion and alternatives to help practising engineers, junior road engineers, technologist, junior technical staffs and students to evaluate their design. Additionally, the prototype ES-LVRRs inference engine can process the parameters of the dataset and recommending a set of answers for each issue, allowing for the evaluation of recommended pavement-specific solutions.

While the extracted knowledge is not infallible, it does provide adequate to excellent documentation of the layer thickness, materials and wearing course for consideration and optimisation during design. The following conclusions can be drawn in this study:

(1) Various sources such as manuals, papers and field experts were used to identify and classify the design of low-volume road layer thickness.

(2) The prototype web-based knowledge-based system for low-volume road pavement design was developed by computerising acquired knowledge with PHP programming.

(3) A framework comprised of HTML, CSS and J-Query was used to create the web pages that support the user interface.

(4) To minimise human error, the graphical interface provides explicit instructions and guidance that direct the user to an agreed-upon data selection.

(5) Verification, validation and evaluation of ES-LVRRs were performed. The system was evaluated by experts and modifications were made in response to recommendations and feedback.

Table 4: Results of prototype system evaluation

Questions	No.	Mean Value	Standard Deviation (SD)
Ease of use	45	3.955	0.2084
Easy access via web or Internet	45	4.066	0.2522
Improved reliability in calculations	45	3.444	0.5025
Potential cost savings	45	3.222	0.5173
Help in decision-making	45	3.800	0.4045
Generate a sample report for comparison studies	45	4.266	0.4472

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