An Advisory Computerized Rule-Based System for Defects of Joints in Rigid Pavement

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Abstract: Rigid pavement is preferable over other types of pavements where traffic loads are high due to its high rigidity. However, joints are unavoidable when rigid pavement is adopted, as they control thermal movements that can cause severe damage to concrete. Although they have advantages, joints are weak points, as they may be affected by traffic or other external conditions, such as environmental factors. If joint defects occur, they may reduce the driving comfort or lead to structural damage on pavements. Therefore, controlling problems in joints is highly required. However, this process requires significant expertise, which is not always available when and where required. Therefore, providing a practical alternative is greatly recommended. Hence, this study aims to provide the required alternative by constructing a computerized rule-based system capable of diagnosing defects and advising an appropriate solution. To attain the study aim, several steps were adopted. First, the domain knowledge was collected from various references through extensive extraction and from experts through several interviews and questionnaires. The collected knowledge was analyzed, classified, and represented in a rule-based form. Afterward, the represented knowledge was converted into a computer program using Visual Basic. The built system was evaluated by highway engineers with varying levels of expertise and was found to be valid to about 90%. The constructed system is available to the pavement engineer to treat defects with minimal effort and time. It can also be adopted as an archive for domain knowledge. In addition, it can be used as a foundation for future systems in similar areas.

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1. Introduction

Pavement represents the most functional component in a highway [1, 2] which in turn represents the main facility in the transportation modes [3, 4]. Although flexible pavements (pavements constructed with a layered system with an asphaltic layer on the surface) have a great share [5, 6]Rigid pavement (pavement constructed of a Portland cement concrete slab resting on a subbase or subgrade layer) is required for a long service life. [7, 8], resistance to distortions, high traffic loading, and resistance to some substances are highly required [9-11]. These needs increase demand for rigid pavements, especially with the rapid rise in traffic volumes and truck loads. [12]. However, rigid pavement is an expansive-contractive material, as its volume increases at high temperatures and decreases at low temperatures. [13]. This property is a significant weakness in rigid pavement, as it leads to severe damage if not controlled. [14]. Fortunately, the construction of suitable joints within the pavements can control these damages. [15]. However, these joints themselves involve inherent weaknesses. [16]. First, the joint can fail and become functionless if blocked. [17]. Second, these joints are weak points that can spall, ravel, or lose their sealant. [18]. Such defects can cause uncomfortable riding or allow water to infiltrate the pavement's underlying layers, leading to severe structural damage. [19]. Such problems can occur during construction or in service. [20]. Whenever they occur, effective action must be taken to solve the problem, limit its effects, prevent further deterioration, and prevent it from causing additional problems on the pavement surface or structure. [21]. However, diagnosing joint defects, estimating their severity, and suggesting effective actions require substantial expertise, which is not always available when and where required, or at least providing such expertise is costly. [22]. Therefore, providing an effective, practical, and economical alternative is in high demand. Computer-based programs are an attractive alternative due to their advantages. However, the required alternative (a computer-based program capable of diagnosing and solving problems in joints of rigid pavements) is not available. To determine its availability, a literature review was conducted. A number of the most recent review articles in this domain were examined, as they typically cover a broad body of research. [13, 21, 23-26]. However, no such research has been conducted in this domain, highlighting a knowledge gap and underscoring the significance of this study. Therefore, there is a high demand for a computerized, rule-based system to diagnose and address defects in rigid pavement joints.

2. Knowledge Collection

To attain the objectives of the study, several steps are adopted: rule-based building, communication, and system testing. The first step comprises two sub-steps: knowledge acquisition and knowledge representation. Two methods were implemented for knowledge acquisition. First, the elicitation of knowledge from written sources. This activity consumes time and effort to review a huge number of references to cover the entire topic and focus on the intended parts (defects in joints). Afterward, the elicited knowledge was refined and calcified. Second, acquiring the human expertise from the field experts. This method was adopted to facilitate human expertise within the computerized system. To attain this aim, several experts were selected based on their reputation in the field. Afterward, several interviews were held with each one of them to document their domain knowledge. The interviews included unstructured and structured interviews, based on the intended goal of each. Unstructured interviews cover general discussions, whereas structured ones focus on specific details. After that, a detailed questionnaire was prepared in a classified format based on the knowledge acquired. Copies of that questionnaire were submitted to the experts. Later, the completed questionnaires were collected, and the answers were analyzed and classified to be suitable for representation as a rule base, as described in section 3.

3. Knowledge Representation

The following subsections abstract the problems and their suitable solutions. The knowledge was represented in rules in an (IF-THEN) manner. Table 1 shows the abstract domain problems, their diagnostic criteria, and the solutions.

3.1 Dowels are Out of Alignment

When the dowels are installed incorrectly, movement is restricted, which may cause cracks in various forms. A visual test can discover this defect during construction. If so, the dowles should be brought to correct alignment. In addition, it can be detected by advanced methods, such as radar induction, later (after construction). If so, two cases are to be noted. First, no cracks or spalling have occurred yet. In this case, no action is required, but the issue is to be registered for review in 5 years. Second, if cracks have already occurred, repair them.

3.2 Concrete around the groove is disrupted

The fresh groove exhibits a hump due to the incorrect extraction of the strip former. Two cases can be noted here first, if the groove is noted when the concrete is still fresh. In this case, a straightedge can be used to remove the hump and straighten the groove. Second, if the concrete hardened before noting the groove. In this case, diamond grinding is the best treatment.

3.3 Joint Raveling

This defect may occur if aggregates at the grooves begin to be dislodged at the early stages of sawcutting. Two cases can be noted. First, if raveling is noted during sawcutting, stop sawcutting until the concrete attains adequate strength. Second, the defect is noted later. In this case, the severity level is the controller: neglect the low, correct the medium level by widening the groove, and adopt grinding for highly severe raveling.

3.4 Joint Spalling

In case of long spalled portions (longer than 1/10 of the joint length), the entire panel must be reconstructed. In the case of short ones, partial-depth treatment is to be adopted.

3.5 Improper Sealing of Joint

This defect can be easily treated by filling the joint with sealant, following the correct procedures.

Table 1 Joint defects

Defect	criteria	treatment
Misaligned Dowels	Observations Non-destructive testing	Preventive measures Recording
Concrete disruption around the wet-formed groove	Visually Appearance	Precautionary actions Plastic restoration
Joint ravelling	Times Visual inspection Appearance Severity levels	Precautionary actions Ignoring / Renovation
Joint spalling	Observations Shape Severity level	Preventive measures Rectification / Panel removal
Improper joint sealing	Observations	Resealing

4. System computerization

To simplify the end user's (highway engineer) mission, the rule-based knowledge was converted into a computer program using Visual Basic. This programming language is a powerful tool for producing effective, flexible, attractive, and user-friendly programs. The computerization process can be described in the following subsections.

4.1 Interface Design

The interface serves as a medium that connects highway engineers to the brain of the built system. [27]. The highway engineer feeds the system inputs through the interface. [28]. Moreover, the interface provides the highway engineer with outputs and instructions for inputs. [29]. It can be considered as the channel of contact. Therefore, it must be facilitated with all tools that simplify communication processes to ensure effective use. An unfriendly interface can cause failure of good systems with effective inference engines. Therefore, the built system in this study was designed to be attractive and to include several tools to simplify users' mission, as shown in Figures 1 and 2.

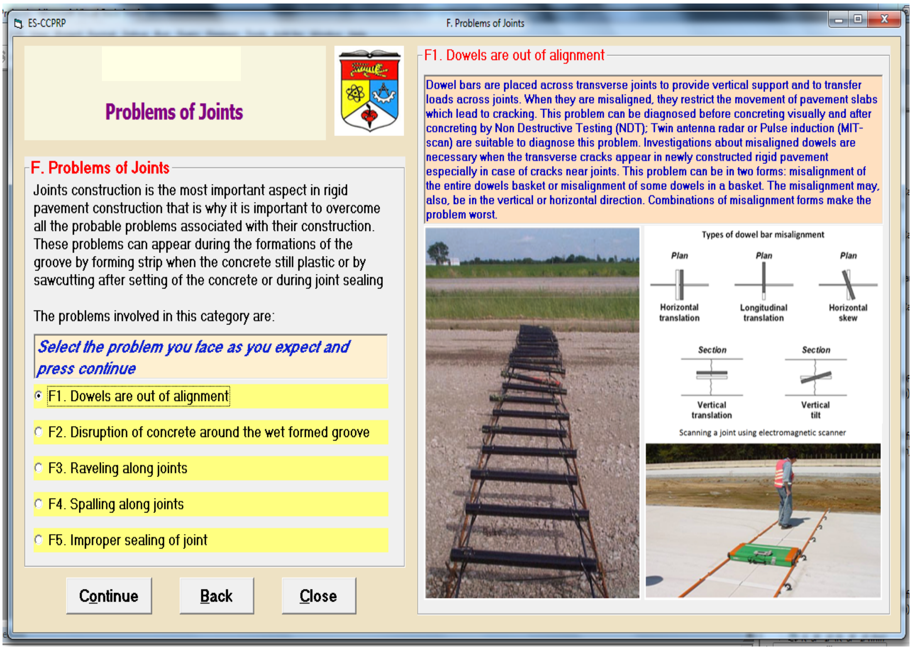

Figure 1: Use interface (Example 1)

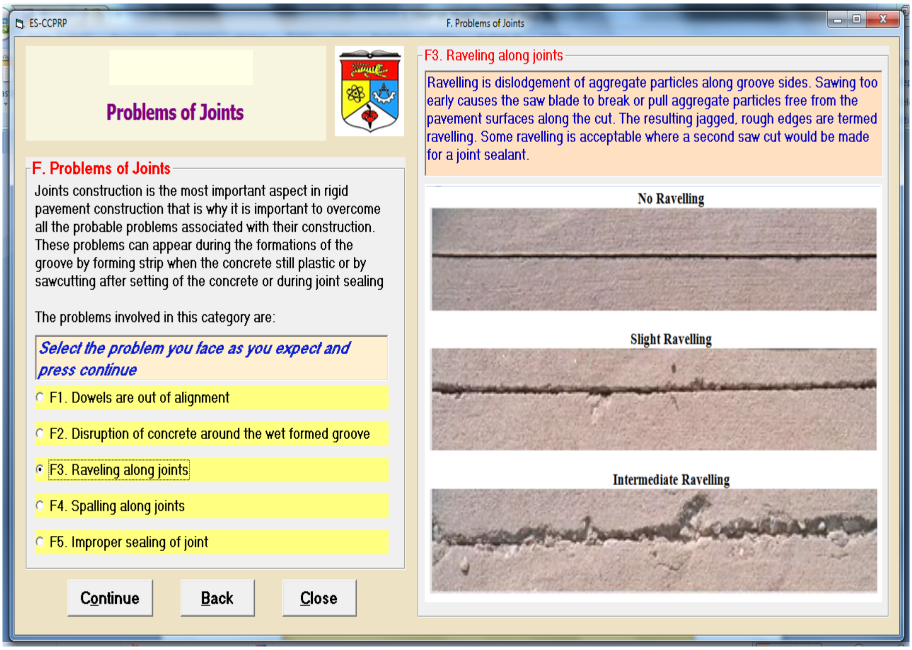

Figure 2: Use interface (Example 2)

4.2 Code writing

VB was utilized to implement this step. It offers high flexibility to apply any action. This process converted the rules into code that the computer could understand. Generally, IF-THEN is the main rule. However, the combined rules and a complex set of rules were connected using (AND) and (OR). IN addition, (EQUAL), (GREATER THAN), (SMALLER THAN), and (NOT EQUAL) are the main tools utilized in rule coding. Many notes, hints, and comments were embedded in the tools to simplify updaters' future work. Figure 3 displays a code screen.

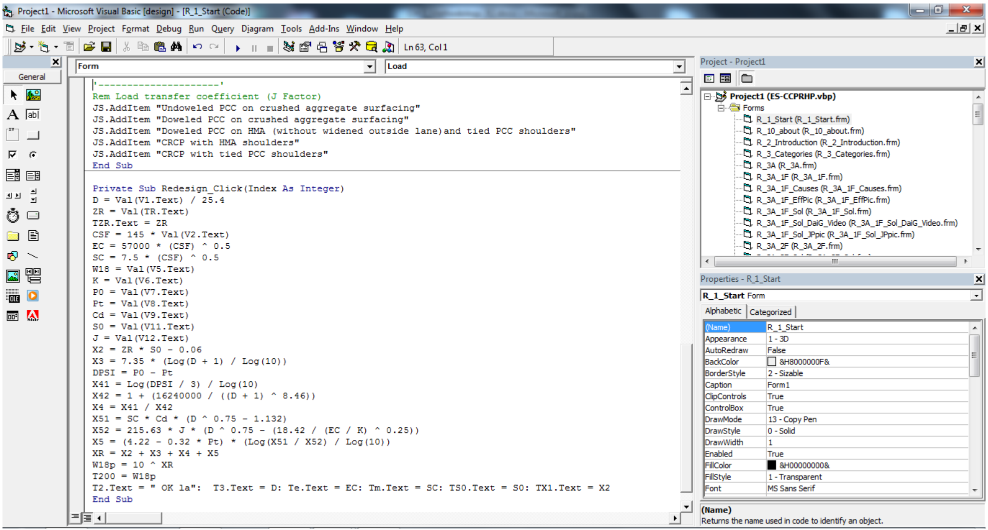

Figure 3: Code screen

4.3 Code Debugging

This step is important to ensure the built system works. [30, 31]. To implement this step, significant effort was devoted to tracing all types of errors and correcting them individually. This step was not implemented in a single batch (after completion). However, it was implemented continuously during the coding process. In addition, another debugging iteration was implemented at the final stage of coding to trace the remaining errors. The system was reoperated after each debugging sub-step. At last, the system was clean 100%. An example of the debugging process is illustrated in Figure 4.

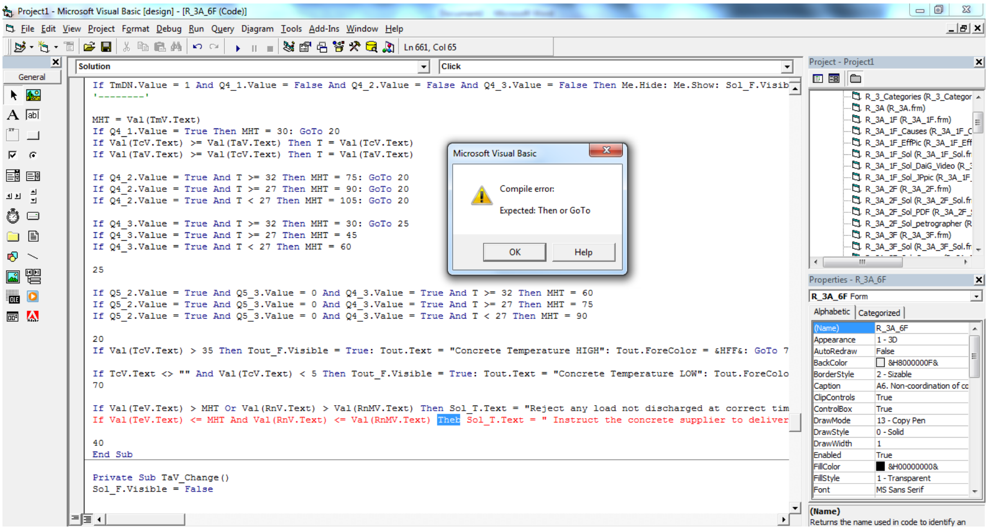

Figure 4: Example of syntax (compiler) error

4.4 Completion of the inference engine

After correcting errors, the inference engine is checked to ensure it is functioning properly. The inference engine is the control mechanism that organizes the problem data and searches the database for the appropriate rules. After matching the relevant rules from working memory with the facts available for the problem, obtained from the user's data, the inference engine concludes. The inference engine in the system essentially operates as follows: the correct rule assumption yields a correct result. The user uses the graphical interface to easily input data by selecting options or typing values. The interpretation mechanism provides explanations for the inference engine's results. These explanations are usually clear and straightforward, retracing the steps of the reasoning process and explaining how the result was reached.

5. System evaluation

To evaluate the system's efficiency, questionnaires were administered to four experts in pavement engineering and ten novices. They used the system and then gave their evaluation by filling out the questionnaires, as revealed in Table 2—their evaluation exposed high satisfaction, as they gave high scores (higher than 3/5).

Table 2 Questionnaire Scoring

	Questions	Evaluation average (Av) and standard deviation (SD)			
		By Experts		By Non-Experts	
		Av	SD	Av	SD
Q1	The built system is easy to use	3.71	0.46	3.75	0.43
Q2	It can run fast	5.00	0	5.00	0
Q3	It is user-friendly	4.20	0.75	3.75	0.43
Q4	The questions are helpful	4.50	0.5	4.25	0.43
Q5	The questions are clear	4.50	0.5	4.25	0.43
Q6	The terms are clear	3.80	0.4	4.50	0.5
Q7	It presents the results clearly	4.10	0.54	4.50	0.5
Q8	Obtaining an explanation from the system is easy	4.30	0.64	3.75	0.43
Q9	Generally, I am satisfied with the system	4.50	0.5	4.50	0.5

6. Conclusions

This study covered the development of a rule-based system to control joint defects in rigid pavements. Several conclusions can be extracted from this study.

1. Acquiring the domain knowledge from literature and expertise in a classified form saves it and facilitates reaching it by the highway engineers with less time and efforts
2. Using a rule-based frame in knowledge representation simplifies its usage, especially when embedded within a computer-based environment.
3. The constructed system can be used to control the domain problems when human expertise is not available or costly.
4. The system can suggest effective solutions for the domain problems with their causes for future avoidance.
5. The evaluation process showed a high level of system validity, which is about 90%.
6. Due to its flexibility, the system is updateable when new knowledge appears, or corrections are needed.
7. The system is to be extended to cover different problems related to the field of rigid pavements.

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نظام استشاري قائم على القواعد المحوسبة لمعالجة عيوب الفواصل في الرصف الصلب

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المستخلص: يُفضل استخدام الرصف الصلب على أنواع الرصف الأخرى في المناطق ذات الأحمال المرورية العالية نظرًا لصلابته العالية. ومع ذلك، فإن وجود الفواصل أمر لا مفر منه عند استخدام الرصف الصلب، حيث تتحكم هذه الفواصل في التمدد والانكماش الحراري الذي قد يُسبب أضرارًا جسيمة للخرسانة. وعلى الرغم من مزاياها، تُعد الفواصل نقطة ضعف، إذ قد تتعرض للتلف نتيجة حركة المرور أو أي ظروف خارجية أخرى. وفي حال تلف الفواصل، قد يقل مستوى راحة القيادة أو قد يؤدي إلى أضرار هيكلية في الرصف. لذا، فإن معالجة مشاكل الفواصل أمر بالغ الأهمية. إلا أن هذه العملية تتطلب خبرة كبيرة، وهي غير متوفرة دائمًا في كل مكان وزمان. لذلك، يُوصى بشدة بتوفير بديل عملي. ومن ثم، تهدف هذه الدراسة إلى توفير البديل المطلوب من خلال بناء نظام حاسوبي قائم على القواعد، قادر على تشخيص مشاكل المجال واقتراح حلول مناسبة. ولتحقيق هدف الدراسة، تم اتباع عدد من الخطوات. أولًا، جُمعت المعرفة المتعلقة بالمجال من مصادر مكتوبة من خلال استخلاص شامل، ومن خبراء بشريين من خلال المقابلات والاستبيانات. ثم حُللت المعرفة المُجمعة، وصُنفت، وعُرضت في شكل قاعدة قواعد. بعد ذلك، تم تحويل المعرفة المُمثلة إلى نظام حاسوبي باستخدام لغة البرمجة فيجوال بيسك. وقد تم تقييم النظام المُنشأ من قبل مهندسي الطرق السريعة ذوي مستويات خبرة مختلفة، وثبتت دقته بنسبة 90% تقريبًا

الكلمات المفتاحية: العيوب، الفواصل، الرصف الصلب، نظام قواعد محوسب, الاحمال المرورية.

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