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Research Article

A Knowledge-Based System to Overcome Problems of Rigid Pavements Construction During Bad Conditions

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Keywords

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Bad conditions,
Knowledge base,
Computerized system,
Construction problems.

Abstract

Pavement represents the main component of the road as it provides a comfortable and safe riding surface for vehicles. Rigid pavements are sometimes preferred over flexible pavements due to its long service life and its capability to accommodate heavy traffic loading. Therefore, constructing rigid pavements with high quality is an essential concept. However, if bad conditions occur during the construction process, they can reduce the quality of pavements and lead to sever damages in its structure which may require costly remedies sometimes reaches to removal and reconstruction. Understanding of all conditions, their effects, their precautions, and effective actions to overcome their influences is a complicated process which require wide expertise. Such expertise may not always available in the site of construction. Therefore, providing an advisory system to help the novices in the site of construction can control such problems. This study aims to develop this system. The domain knowledge was extracted from written sources and domain experts. The extracted knowledge was refined and represented in form of rules. Afterward, the represented knowledge was coded in software. The software included 3 main components. First, the graphical interface which is responsible of communication with the user (pavements engineer) via input-output process to evaluate the problem and to suggest the effective actions. Second, the working memory which represents the data structure; it changes with each problem situation, which makes it the most dynamic component of the system, assuming that it is updated. Third, the inference engine which controls the mechanism that organizes the problem data and searches the knowledge base for applicable rules. The inference engine reaches a conclusion by matching appropriate rules under a set of specific facts. The developed system can be used by site engineers to overcome domain problems which can save efforts and money. It can be adopted as a media to archive and to transfer knowledge.

1. Introduction

Efficient transportation may represent the backbone of modern life [1-4]. Highways which represents the main facility in transportation network [5, 6] depends mainly in its service on pavements [7, 8]. Flexible pavements are mostly used in highways [9, 10]; however, when heavy traffic is excepted, rigid pavements must be adopted [11, 12]. However, construction of rigid pavements encounters several difficulties that can reduce its quality and decrease its serviceability [13]. Among these difficulties, construction under bad conditions can arise. This category of construction problems includes concreting during rainy, cold, hot, and/or dusty weather, and machine failure, non-coordination of concrete feeding, and/or change of raw material properties during construction. Rainwater has very harmful effects on plastic concrete because it resolves a concrete structure and eliminates its strength. Cold weather and hot weather concreting also affect concreting process which in turns adversely affects the quality of rigid pavements. Air temperature, concrete temperature, wind speed, pavement thickness, and other conditions must be identified to attain suitable recommendations. Concreting during dusty weather may result in contamination of concrete with dust, which may reduce the strength and durability of concrete. Suitable actions must be recommended to avoid the effects of dust and to remedy the contaminated parts. Problems that may interrupt the construction include machine failure during concreting, non-coordination of concrete feeding during construction, and raw material changes can cause other problems. Emergency plans must be implemented to manage these problems. Handling these problems, their characteristics, their effects, their correct solutions, and effective precautions to avoid them in the future require wide knowledge and deep reasoning which is rarely available in the site of construction in the suitable time. Absence of expert who able to diagnose the problem and take the suitable actions can lead to costly problems which sometimes require removal and reconstruction a wide area of newly constructed pavements due to its insufficiency [14, 15]. The significance of this study can be exposes by providing such knowledge and reasoning strategy can be implemented in tem of knowledge-based program capable to recommend the suitable actions based on available data. Such knowledge-based program can be very helpful for non-expert pavement engineers to control domain problems. Therefore, this study aims to develop a computerized knowledge base to control problems occur during bad conditions of rigid pavement construction process. The proposed knowledge base capable to provide the end user (pavement engineer) with detailed description about encountered problems with their solutions. Adopting the proposed knowledge base can be very helpful in the domain of rigid pavements construction projects due to its efficiency in diagnosing of the domain problems and proposing the suitable solution which saves time and money and prevents similar problems reoccurrence. To capture the gap pf knowledge in this domain, seven recent literature review papers in the domain of rigid pavements were reviewed to expose if the present approach was covered previously. However, the review revealed that this

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domain was not covered and no study adopted construction of a computerized knowledge base to overcome problems of bad conditions in rigid pavements construction [16-22]. This finding emphases the need for the proposed study and reveals its significance.

2. Knowledge Engineering

Knowledge engineering is the main stage in constructing the proposed system. This stage mainly involves two steps: knowledge acquisition and knowledge representation. The first step includes acquisition of the domain knowledge from the proper sources; namely, references and experts. This step was implemented by sub-steps. First, extraction of documented knowledge by extensive literature review. Several books, journal and conference papers, reports, manuals, guides, and other references were reviewed to attain this objective effectively. Second, elicitation of human knowledge from experts. This sub-step was implemented by questionnaires and interviews with 6 experts in pavements engineering (see Table 1). Using multiple sources ensures an acceptable agreement on ideas and procedures. The advantages of relying on multiple sources include the exclusion of bias towards a single view, less reliance on a single domain expert for knowledge elicitation, and representation of the real situation in the field in case of conflicting views in which further research is often required. The acquired knowledge includes the descriptions of the domain problems, their reasons, their solutions, and their effects on other constructions stages and on the pavements in service. Through extensive review and repeated analysis of the acquired knowledge, domain problems were identified. In doing so, inspectors can visually diagnose a problem or via tests and measurement results. In addition, the description of problems, their likely causes, preventive actions, instantaneous solutions, and possible effects if they remained uncontrolled are stated. Problems were identified depending on their characteristics, which could be visually diagnosed according to their appearance or through measurements and tests. The name of each problem summarizes its description. Experts can note such problems and quickly come up with solutions whereas novice engineers cannot. Avoiding these problems through preventive actions can save time, money, and effort. Decisions to identify as well as prevention measures must be made to control these problems. The second step in this study called knowledge representation. The analyzed and classified knowledge was represented in form of rules that can be easily set up in a worksheet or coded in a computerized software. Figure 1 illustrates the system architecture The following subsections describe the represented domain knowledge.

Table 1. Experts involved in expertise acquisition

No.	Academic Degree	Organization	Current position	Years of experience
1	PhD	Ministry of Construction and Housing/Company for Construction	Head of Pavement Engineering Department	27
2	Master	Ministry of Construction and Housing/Organization of Roads	Head of Research and Development Unit	24
3	Master	Ministry of Construction and Housing/National Centre for Engineering Consultations	Head of Highway Department	21
4	Master	Ministry of Construction and Housing/Company for Construction	Project Manager	20
5	Master	Department of Public Works (JKR)/ Branch of Road/Headquarter	Unit Manager	20
6	Master	American Concrete Pavement Association	President	24

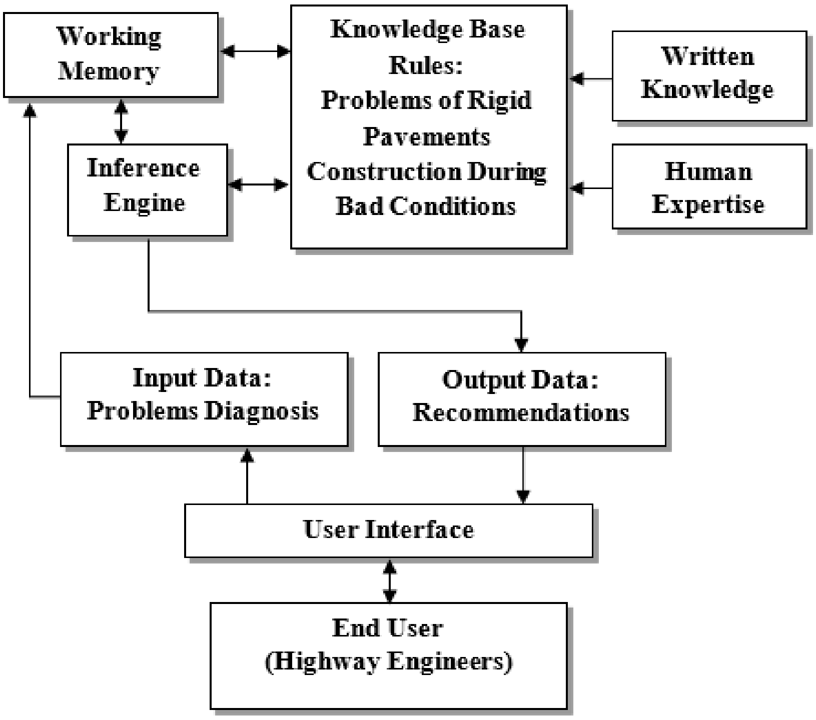

Figure 1. System architecture

2.1. Raining during concreting

This problem may occur at any stage of the construction operation. Rainwater has very harmful effects on plastic concrete because it resolves a concrete structure and eliminates its strength. The effects of rainwater on concrete pavement differ significantly depending on rain intensity, length of duration, and actions for protection adopted by contractors. Covers and side forms may protect concrete against the effects of rain. The following actions must be adopted to control this problem.

- The construction should be stopped.
- The concrete plant needs to be informed to stop concrete feeding.
- Construction joint for the last constructed part should be performed.
- Any unused concrete affected by rainwater needs to be removed.
- Performed parts can be protected from rainwater by covering them with suitable covers. Concrete surface distortion brought about by water or covers should be avoided.
- Construction can resume after rain stops or if protective measures (such as temporary shades) are implemented to protect the concrete from rainwater.
- The defective parts should then be rectified as follows:

➢ Case I

If rainwater has reached the newly coated pavement and damaged only the curing membrane before it has dried sufficiently, which makes it unable to resist damage, one or two coats of a curing compound should be applied on the defective parts. The prescribed amount of the curing compound should be used.

➢ Case II

If rainwater has reached the plastic concrete and resulted in minimal damage to the surface, and the problem was diagnosed before concrete setting, the surface should be floated and trowelled again, ensuring that excess water is not overworked in the surface. Texturing may solve this problem.

➢ Case III

If rain has reached the plastic concrete, the problem was diagnosed before concrete setting and the water caused moderate (3 mm to 20 mm in depth) or severe blemishes (deeper than 20 mm), the following conditions should be checked before selecting a solution:

- If rain stopped before final setting of concrete.
- Rainwater affected the surface only.
- Weather conditions are suitable for concrete placing (no rain is expected, and air temperature is 4 °C and above).
- Staff is ready to resume concrete placing operation.
- Plastic concrete is available for placing.
- Fixed-form paving is performed.

If all these conditions are met, the defective concrete (surface part) should be removed manually and replaced with new concrete. Afterwards, the surface should be finished carefully.

If conditions 1, 2, 3, 4, and 5 are met, forms should be installed firmly on both sides of the defective area. The defective concrete should then be removed manually and replaced with new concrete. Afterwards, the surface should be finished carefully.

If one or more of conditions 1, 2, 3, 4, or 5 are not met, the following conditions should be checked after concrete hardening:

- If moderate or severe blemishes are present, surface scaling or any other blemish less than 20 mm should be rectified after concrete hardening by diamond grinding to remove surface blemishes and provide texture.
- If blemishes are severe, defective panels should be removed and reconstructed correctly.

➢ Case IV

If rainwater has caused defects that cannot be visually evaluated in the site, the decision should be delayed until concrete hardening. After concrete hardening, representative cores from suspected lots should be sent to a professional laboratory that can perform a hardened concrete petrographic examination ASTM C856. This examination can verify if rainwater distorted the surface hardness or entrained the air-void system.

If the laboratory found that the concrete is acceptable, the suspected lots can be accepted. Otherwise, the lots should be rejected and replaced.

If the information obtained from the petrographic examination report is insufficient, surface scaling tests on core top surfaces should be adopted in accordance with ASTM C672. This should be based on the reported results:

- If the evaluation is No Scaling, the problem should be ignored.
- If the evaluation is Slight Scaling, the parts should undergo diamond grinding.
- If the evaluation is Severe Scaling, the parts should be removed and reconstructed.

➢ Case V

Rain occurs prior to a cold front, especially if the general weather is warm/hot and/or humid. This condition then results in a temperature decrease of more than 11 °C. In this situation, the risk of uncontrolled cracking increases. Concrete becomes warmer as it dries, and low air humidity may occur on top of the warm concrete, which may result from the cold front. This condition usually occurs because of decreased dew point, which makes the concrete more susceptible to plastic shrinkage cracking.

If air temperature is expected to decrease, measures should be implemented to protect the plastic concrete from freezing and uncontrolled cracking.

➢ Case VI

If rainwater infiltrates the joints after concrete hardening, all rainwater-contaminated joints should be sandblasted and airblasted after drying and before sealing.

➢ Case VII

If rainwater causes surface dusting, rectify dusting based on severity level.

➢ Case VIII

If rainwater causes improper surface texture, the surface should undergo diamond grinding.

➢ Case IX

If the concrete froze before it attained sufficient strength, defective lots should be removed and reconstructed.

2.2. Concreting during cold weather

This problem occurs in cold regions or during the cold season when the temperature is 5 °C and below. Low temperatures can cause a concrete structure to freeze, which poses the risk of damage. Cold weather occurs if the following conditions take place for more than three consecutive days:

- The mean of the maximum and minimum recorded temperatures from midnight to midnight is an average daily temperature of 4 °C or below.
- The recorded weather temperature is 10 °C or below for any 12-hour interval or more.

Special considerations should be kept in mind during cold weather paving and addressed before any forecasts of near or below freezing point temperature. When concrete is protected against freezing, its hydration process can continue, which provides it with more heat to resist freezing and to become stronger. Greater concrete strength eliminates uncontrolled pavement cracking and enables jointing. The following actions must be adopted to control this problem.

If concreting can be delayed, the concreting operation should be conducted during warmer weather to avoid problems associated with cold weather concreting. Otherwise, the following cases are considered:

➢ Case I

Concrete production should be performed under the following conditions:

- If the slab thickness is less than 300 mm and the ambient temperature is higher than -1 °C, concrete should be produced with a temperature of 16 °C or more.
- If the slab thickness is less than 300 mm and the ambient temperature is between -1 °C and -18 °C, concrete should be produced with a temperature of 18 °C or more.
- If the slab thickness is less than 300 mm and the ambient temperature is lower than -18 °C, concrete should be produced with a temperature of 21 °C or more.
- If the slab thickness is more than 300 mm and the ambient temperature is higher than -1 ∘C, concrete should be produced with a temperature of 13 °C or more.
- If the slab thickness is more than 300 mm and the ambient temperature is between -1 °C and -18 °C, concrete should be produced with a temperature of 16 °C or more.
- If the slab thickness is more than 300 mm and the air temperature is lower than -18 °C, produce concrete with temperature of 18 °C or more.

➢ Case II

Concrete placement should occur under the following conditions:

- If the slab thickness is less than 300 mm, the concrete placement temperature must be within 13 °C to 24 °C.
- If the slab thickness equal or more than 300 mm, the concrete placement temperature must be within 10 °C to 21 °C.
- A concrete load should not be placed if its temperature is outside the specifications.

➢ Case III

Any concrete exposed to freezing before attaining sufficient strength should be rectified appropriately based on the following conditions:

- If the concrete is exposed to even one freezing cycle before attaining strength of 3.5 MPa, the concrete should be removed and reconstructed.
- If the concrete is exposed to two freezing cycles or more before attaining strength of 24 MPa, a petrographic examination should be performed.
- If the concrete is exposed to one freezing cycle before attaining strength of 24 MPa, concrete protection measures can continue.
- If the concrete is exposed to any number of freezing cycles after attaining strength of 24 MPa, the problem can be neglected.

2.3. Concreting during hot weather

Hot regions or seasons can pose problems, which makes relevant preparations for hot weather paving necessary. Hot weather occurs if one of the following conditions exists for three or more consecutive days:

➢ For more than half of any of the 24-hour period, the average air temperature does not drop below 30 °C.
➢ The average air temperature exceeds 25 °C on a daily basis.

The following actions must be adopted to control this problem.

➢ If hot weather is expected during the planning stage, the preventive actions should be implemented.
➢ Hot weather precautions should be applied during construction in the following cases:
  - If air temperature during construction is more than 30 °C.
  - If the evaporation rate from concrete is more than 1 kg (m2/hr). Evaporation rate can be estimated from Equation 1 [23].

$$E = 5([T_c + 18]^{2.5} - r[T_a + 18]^{2.5})(V + 4) \times 10^{-6} \quad (1)$$

Where, E: Evaporation rate, kg/m^2); T_c: Concrete temperature, °C; T_a: Air temperature, °C; r : Relative humidity in percent/100; and V : Wind velocity, km/h

2.4. Concreting during dusty weather

A dust storm can be defined as an ensemble of sand and dust particles which are lifted to great heights by a strong and turbulent wind. Concreting during dusty weather may result in contamination of concrete with dust, which may reduce the strength and durability of concrete. The following actions must be adopted to control this problem.

➢ If dust started after spreading the curing membrane, the problem can be neglected because the membrane can protect the concrete from contamination.
➢ If dust suddenly started, the following actions should also be performed:

  - The construction operation should be stopped.
  - The concrete plant should stop concrete feeding.
  - Construction joint should be performed for the last part.
  - The performed parts should be covered, ensuring that the pavement surface will not be distorted.
  - Construction can resume when the dust stops.

➢ If plastic concrete was slightly contaminated with dust, the problem can be neglected.
➢ If the plastic concrete was severely contaminated with dust, the contaminated parts should be removed and reconstructed.
➢ If the contamination cannot be visually evaluated in the site, samples should be sent to the laboratory for petrographic examination.

2.5. Machine failure during concreting

Failure of any construction train machine can interrupt the construction process and lead to other problems. The term "paving train" refers to the combination of individual machines that place and finish concrete pavement. For highway applications, a typical paving train includes spreader with belt placer, slip-form paver, texturing machine, curing cart (usually together with the texturing unit). The following actions must be adopted to control this problem.

- If the curing compound spreader fails, the compound should be sprayed manually while ensuring that it fully covers the pavement surface.
- If the texturing machine fails, another machine should be used as soon as possible. Otherwise, texturing can be performed by diamond grinding after concrete hardening.
- If the longitudinal floating tool fails, floating can be performed manually and construction shift can continue.
- If the concrete placer or paver fails, the following actions can be applied:
    - The construction operation should be stopped.
    - The concrete plant should stop concrete feeding.
    - Construction joint should be performed for the last performed part.
    - Construction can resume if the machine is operational again and deemed efficient, or when new machine is provided.
- If the paver fails during fixed-form paving, the construction can continue manually to the nearest planned expansion or construction joint when the staff is ready, tools (such as hand-operated and self-propelled vibratory screeds, single-tube finishers, and revolving triple tubes) are available, and under suitable conditions (such as narrow pavement and small paving task).

2.6. Non-Coordination of concrete feeding during construction

Irregular, interrupted, or discontinuous concrete delivery to the site can interrupt the construction and lead to other problems. Less or more concrete may be delivered than placed concrete. The following actions must be adopted to control this problem.

- If delivered concrete quantities are more than the placed concrete, the plant operator should be contacted and informed that delivered loads should be reduced. Any defective load should be rejected.
- If concreting has been interrupted for 30 minutes or more, the following actions can be implemented:

- Transverse construction joint should be performed considering the following:
    - A transverse joint should not be constructed within 3 m of other joints.
    - Any panel less than 3 m in length should not be constructed, and excess concrete should be removed.
- Communication with plant operators should take place to solve the problem.
- Construction can resume when uniform concrete feeding is provided.

2.7. Raw material changes

Raw material changes (cement, supplementary cementitious materials, aggregates, or chemical admixtures) may be changed by the supplier during construction. Change of raw materials can affect concrete properties. The engineer must be informed of any change in raw materials. The engineer can diagnose a problem in the concrete plant or in site by testing. Changes in the properties of plastic concrete may indicate changes in raw materials. The following actions must be adopted to control this problem.

- If an ingredient source has been replaced or if the required amount changes by more than 5% (excluding admixtures used within recommended dosages), trial batches are needed. Thus, a backup plan, as described in preventive actions, should be implemented.
- If a problem has occurred and no backup plan exists, an alternative mix design should be prepared, and the gathered data should be strengthened.
- If concrete was produced and placed in the site by using new materials before approval of the new mix design (based on the initial mix design), workability, setting time, air entrainment properties, and early-age strength (maturity and/or three-day strength) should be compared with the initial mix design. This process should be performed carefully. Testing frequency during the initial days of the project should be increased.
- Any load with defective concrete should be rejected.

3. Computer Based System Development

The represented knowledge previously described in section 2 was coded within computer based form to simplify the interaction between the system and the end-user and to facilitate and accelerate the reasoning process. The developed computerized system mainly consists of three components: user-interface, working memory, and inference engine. The following subsections abstracts the three components.

3.1. User-Interface

User interface is the interface between user and the system. The user communicates with the system via this interface. Generally, user interfaces obtain information needed to solve a particular problem by asking the user to answer questions or prompting the user to provide relevant information in a preformatted manner. User interface was designed in such a way that effectively collect information and structurally present the whole system without restricting the overall performance. A good graphic user interface was designed to reduces the required learning time and the number of mistakes made by first-time users. Regardless of how well the knowledge base is organized or how effective the system's performance is; the quality of user interface design alone may determine the fate of the expert system. The interface was designed to be clear, user-friendly, and interactive. The interface window includes a number of components or controls (each represents a tool) such as frames, labels, text boxes, images, option buttons (radio buttons), checkboxes, command buttons, windows media player, adobe acrobat reader, combo boxes, and message boxes. Each control was designed to perform a specific function in the form, as described in the following subsections. Each interface window includes the title bar and the minimize, maximize, and close buttons. Forms and controls are called objects. Figure 2 presents an example of user-interface.

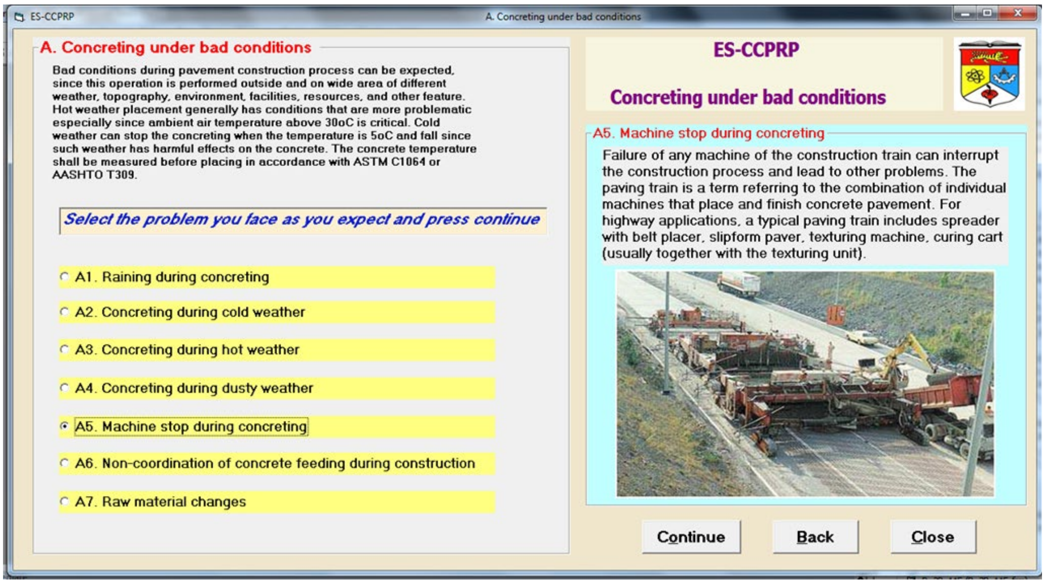

Figure 2. An example of user-interface

3.2. Working memory

The working memory resembles a database of conventional programs. The contents of the working memory, sometimes called data structure, change with each problem situation, which makes it the most dynamic component of the system, assuming that it is updated. It monitors program status and contains a large amount of data for the given problem. In the present system, the working memory typically contains information on a particular instance of the problem addressed. An illustrative example is given below:

When a user selects the problem ("Non-coordination of concrete feeding during construction") the system needs to identify a number of related conditions in the construction site (input data). Initially, these conditions are given the following values in the working memory of the system. These are the following:

- Delivered quantities are less than the required - Option value = False
- Delivered quantities are more than the required - Option value = False
- Construction delay for more than 30 minutes (YES) - Option value = False
- Construction delay for more than 30 minutes (NO) - Option value = False
- Loads waiting for a long time (YES) - Option value = False
- Loads waiting for a long time (NO) - Option value = False
- Time elapsed from when water was added to the mix – Numeric value = 0
- Maximum allowable time from when water was added to the mix – Numeric value = 30
- High-early strength cement or admixture is used in the mix - Option value = False
- Retarder is used in the mix - Option value = False
- No admixture is used in the mix - Option value = False
- Maximum allowable concrete temperature – Numeric value = 35 (Default)
- Concrete temperature – Numeric value = 0
- Air temperature – Numeric value = 0
- Concrete is hauled by non-agitating truck - Option value = False
- Concrete is hauled by agitating truck - Option value = False
- Agitator is on static mode – Check box value = 0
- Number of revolutions – Numeric value = 0
- Maximum number of revolutions – Numeric value = 300 (Default)

When a user starts selecting the conditions through the graphical interface (selecting an option button, ticking a checkbox, and typing numbers in text boxes) the working memory assigns new values to the related conditions, such as the following:

- Delivered quantities are less than the required - Option value = False
- Delivered quantities are more than the required - Option value = True
- Construction delay for more than 30 minutes (YES) - Option value = False
- Construction delay for more than 30 minutes (NO) - Option value = False
- Loads waiting for a long time (YES) - Option value = True
- Loads waiting for a long time (NO) - Option value = False
- Time elapsed from when water was added to the mix – Numeric value = 71
- Maximum allowable time from when water was added to the mix – Numeric value = 60
- High-early strength cement or admixture is used in the mix - Option value = False
- Retarded is used in the mix - Option value = False
- No admixture is used in the mix - Option value = True
- Maximum allowable concrete temperature – Numeric value = 35 (Default)

- Concrete temperature – Numeric value = 24
- Air temperature – Numeric value = 37
- Concrete is hauled by non-agitating truck - Option value = False
- Concrete is hauled by agitating truck - Option value = True
- Agitator is on static mode – Check box value = 0
- Number of revolutions – Numeric value = 267
- Maximum number of revolutions – Numeric value = 300 (Default)

The inference engine uses this information in conjunction with the knowledge base rules to derive additional information regarding the problem to be solved.

3.3. Inference engine

Inference engine is the control mechanism that organizes the problem data and searches the knowledge base for applicable rules. The inference engine reaches a conclusion by matching appropriate rules under a set of specific facts. Basically, the inference engine operates as follow: IF the premise of a rule is true, THEN the conclusion is true. A simple example related to concreting problems during rainy weather is chosen to explain how the inference engine works. The example is described in Figure 3. The inference engine obtains facts from working memory, which in turn obtains information from user's input data. The user uses the graphical interface to easily feed the system with inputs by selecting options or typing values. For instance, in the example of concreting problems during rainy weather, the user can tick the suitable checkboxes to select the existing site conditions. The inference engine translates these selections into values. The inference engine assigns a value of 1 for every ticked checkbox and a value of 0 for every unticked checkbox. The inference engine then considers these values with the other inputs and searches the knowledge base for a matching conclusion. When some data are missing, the inference engine cannot respond. Explanation mechanism provides explanations regarding conclusions reached by inference mechanism. The explanations are usually straightforward, tracing back the inference steps, and justifying how a conclusion was reached; Figure 4 is an example.

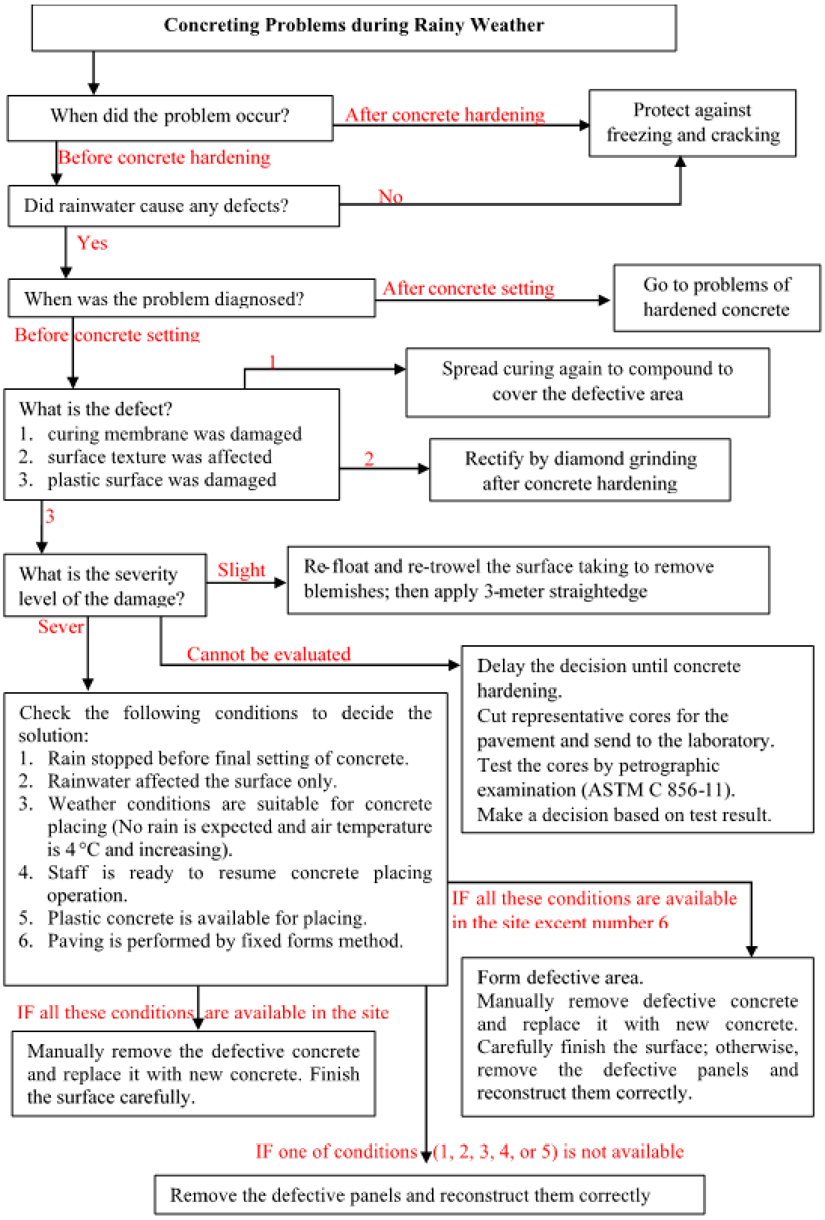

Figure 3. Example of inference engine work

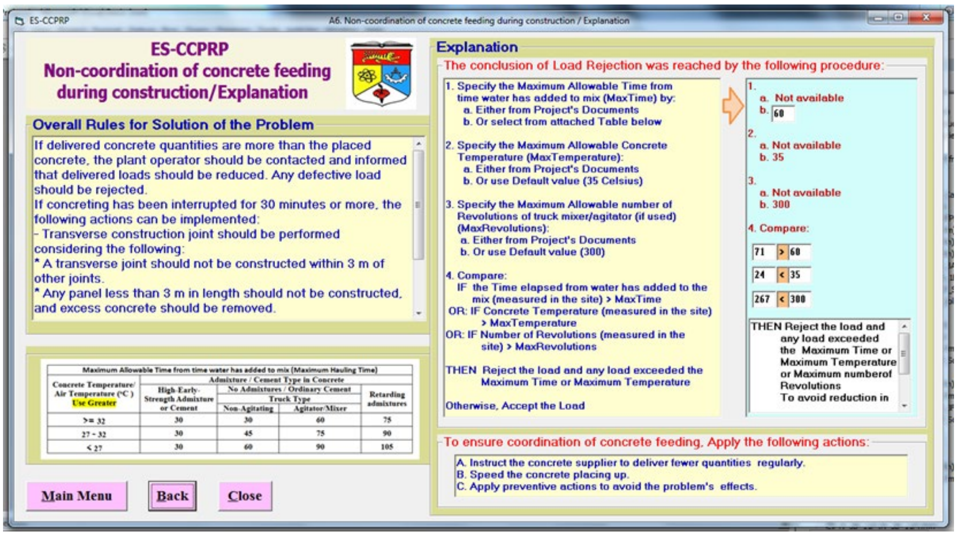

Figure 4. Explanations presented in the user interface

4. System Testing and validation

A questionnaire survey was designed to test the satisfaction of 4 experts in rigid pavement. Rigid pavement experts evaluated the system by using the questionnaire described in Table 2. The evaluation reflects their satisfaction through their high ratings (more than 3 out of 5). The satisfaction of experts indicates that they positively evaluated the user interface; this result also verifies the system. Table 2 summarizes the testing and evaluation of the system by the domain experts.

Table 2. Evaluation results of the system by 4 domain experts

	Questions	Scores 1	2	3	4	5	Average
1	The system is easy to use				✓✓✓✓		4.00
2	The system runs quickly					✓✓✓✓	5.00
3	The user interface is user-friendly			✓	✓✓	✓	4.00
4	The questions are helpful				✓✓	✓✓	4.50
5	The questions are clear				✓✓	✓✓	4.50
6	The terms are clear				✓✓	✓✓	4.50
7	Presentation of results is clear				✓✓✓	✓	4.25
8	Presentation of results is complete				✓✓	✓✓	4.50
9	Obtaining explanations from system is easy				✓✓✓	✓	4.25
10	The system is helpful to provide solutions				✓✓✓✓		4.00
11	The system is helpful to specify the causes of problems				✓	✓✓✓	4.75
12	The system is helpful to adopt preventive actions				✓	✓✓✓	4.75
13	The system is helpful to specify effects of problems				✓	✓✓✓	4.75
14	The explanations are useful			✓	✓	✓✓	4.25
15	Generally, I am satisfied with the system			✓	✓✓	✓	4.00

5. Conclusions

This study covered the development of a new knowledge-based system to be used as a helpful tool for highway engineers in overcoming the problems of bad conditions during construction of rigid pavements. Domain problems were identified and classified based on literatures and domain experts' opinions. The procedures to diagnose the problems including their description tests measurements and related conditions were identified in detail. The recommendation to overcome the problems were acquired and explained. The acquired knowledge was represented in rules and computerized as a software. The software has a simple graphical user interface designed to simplify the user's task. The user selects an option, ticks the checkboxes, and enters values in the text boxes to identify the characteristics of the encountered problems and the site conditions easily. The graphical controls of the user interface are very familiar to Microsoft Windows users. The system provides the user with description text, pictures, and videos to help the latter in diagnosing encountered problems. The inference engine handles the inputs quickly, searches the knowledge base for matched rules, and provides suitable recommendations via graphical interface in the form of texts, pictures, and videos. In addition, the system provides the user with the procedure used to reach a conclusion. The developed system can help the domain engineers to overcome the domain problems with low time, efforts, and cost. It can be also used as an educational system. In addition, it can be used as a media to archive and transfer the domain knowledge. The researchers can use the present system as a base to develop similar systems in different transportation engineering branches. The developed system was validated by extensive evaluation of domain experts. It was acceptable in terms of its knowledge, correctness, running time, and its user-friendly interface. The overall satisfaction was 4 out of 5 which represents 80%.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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