Pol. J. Environ. Stud. Vol. 21, No. 2 (2012), 435-445

Original Research

TSST: an Expert System for Temporary Soil Stabilization on Commercial and Residential Building Sites in Malaysia

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Received: 28 January 2011
Accepted: 11 July 2011

Abstract

Urban development has been particularly rapid in Malaysia. An adverse environmental effect of urban growth in Malaysia has been the frequent occurrence of excessive soil losses from construction sites. According to Malaysian regulations, construction activities require an erosion and sediment control plan duly approved by the Department of Drainage and Irrigation before starting activities. An erosion and sediment control plan is for the local authority to effectively manage construction projects with particular emphasis on minimizing soil erosion during construction activities. The selection of temporary soil stabilization technique is an important, but complex and time-consuming, task that has to deal with a huge amount of data, domain regulations, and expert knowledge in terms of environmental protection, water pollution prevention, and soil erosion mitigation. An expert system has been successfully applied in various domains including environmental science. In this paper, an expert system – TSST – developed by using Microsoft Visual Basic was introduced. TSST to be used for selection of temporary soil stabilization technique at housing and new township development projects was designed based on the legal process in Malaysia. TSST primarily aims to provide an educational and support system for engineers and decision-makers during construction activities in terms of having the least negative impact around the area. It displays an erosion and sediment control plan in report form. When the use of TSST in such a plan becomes widespread, it is highly possible that it will benefit in terms of having more accurate and objective decisions on construction projects that are mainly focused on erosion and sediment control measures.

Keywords: expert system, temporary soil stabilization, commercial and residential building sites, geographic information system

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Introduction

Rapid urbanization is one of the emerging problems of our time. In the past half-century, the pace of urbanization in developing countries has accelerated greatly. Associated with this growth is change of land cover types and deterioration in urban environmental quality [1]. Environmental problems due to the construction sector in developing countries are at different levels. There often is weak management at construction sites [2]. Construction activities can disturb soil and travels down from a building site that eventually ends up in rivers. There are three significant steps involved in minimizing soil erosion during construction activities:

- Information about site characteristics
- Consideration of all factors likely to be affected in selection of soil stabilization technique
- Evaluation of the collected data in an accurate way

This evaluation is completed before decisions related to project implementation are taken, and it is a challenging process requiring intense knowledge and data.

An expert system is a computer program capable of performing at a human-expert level in a narrow problem domain area. It is usually used to model the human decision-making process [3]. Diagnosis problems and an advisory system have always been attractive candidates for expert system technology. Since then, diagnostic and advisory expert systems have found numerous applications, particularly in engineering and manufacturing [4].

Expert systems have been applied successfully in such domains as environmental science, agriculture, geosciences, biology, engineering, computer science, medical science, and operation research/management sciences [5, 6]. Ahmad Basri demonstrated the use of an expert system for design of composting facilities [7]. Shams presented an integrated Geographic Information System (GIS) with an expert system to site municipal solid waste landfill in developing countries [8]. Abd Manaf designed and developed an expert system to help with solid waste management [9]. Jin presented a GIS-based expert system for onsite stormwater management [10]. Say proposed an expert system for an environmental impact assessment (EIA) application energy power station [11]. Lee proposed an application of knowledge-based system (KBS) with GIS in river land use assessment [6]. Oprea also contributed an expert system (ES) to analyze soil, water, and air pollution [12].

The present paper concerns the design considerations and the development of a rule-based expert system, Temporary Soil Stabilization Technique (TSST). This paper aims to inform the project owner and decision-makers at the stage of soil stabilization technique selection in the newest, the most accurate, and fastest way. TSST has been developed based on Visual Basic software 6, which satisfies certain requirements. The motivations for the project were the following:

- There are many housing and new township development projects in Malaysia; therefore the identification of the soil protection techniques is of major practical interest for Malaysia.
- No similar work on construction activities has been undertaken in Malaysia by the use of expert systems.
- Developed tools related to soil and water pollution prevention, water quality management, and stormwater management do not fulfill certain requirements of the Malaysia environmental condition.

The new system has been applied to study construction sites located in Malaysia (Fig. 1).

Soil Erosion and Sedimentation at Construction Site

In recent years have seen increasing concern in Malaysia over soil erosion, siltation, and the deterioration of water quality in many river systems [13]. Urban development has been particularly rapid in Malaysia [14]. Apart from urban expansion, development also has occurred in inland hilly areas as well as near coastlines and on islands for resort purposes. Hillside development has been rapid in the last two decades and has resulted in acute environmental problem in many locations. Planning and achieving sustainable development in such an environment is particularly important in regard to drainage, flash flood, erosion and sediment and slope stability management [15]. An adverse environmental effect of urban growth in Malaysia has been a frequent occurrence of excessive soil losses from construction sites and from sites cleared of vegetation but awaiting development [14, 15]. Under Malaysian conditions, erosion by water is the most significant due to high mean annual rainfall, storm frequency, and density. Higher rates of erosion will occur when the vegetation cover is disturbed or removed. Once the vegetation is cleared, interception of rainfall will be greatly reduced. This will result in a drastic increase in surface runoff volume and velocity. Increase runoff certainly causes substantial soil erosion [13]. There has also been deterioration in a number of water

Fig. 1. The study area: Malaysia.

courses and quality of receiving water [14]. Malaysia is subject to intense and more frequent rainstorms than most developed countries and thus requires more stringent control measures (non-structural or structural) to deal with the problem [15].

The importance of the EIA and environmental study of large development projects are increasing [16]. Thorough construction planning and efficient site utilization are of importance in construction site management [17]. The Department of Drainage and Irrigation Malaysia (DID) has proposed erosion and sediment control plans (ESCP) for local authorities to effectively manage construction projects with particular emphasis on minimizing soil erosion during construction activities. One step in the ESCP guideline covers erosion control measures [18]. According to the law and the project location, design criteria are defined to regulate sites for erosion minimization. Finally, a follow-up plan is continuously monitored to meet related regulations. In these steps, assessment is the most important, although it is a labor-intensive task because it relates to a huge amount of data, domain regulations, and expert knowledge in terms of environmental protection, water pollution mitigation, and soil erosion control.

For these purposes computer systems are essential tools. It is a fact that construction activities cause environmental problems in Malaysia sectors. Mainly for this reason, the quality and reliability of the ESCP reports have great importance in the implementation of construction activity processes in terms of having the least negative impact around the area. The quality and reliability of ESCP reports can be increased by having this kind of software, which covers the information on the Malaysian legal ESCP process. TSST introduced in this study was developed as an expert system and easily updateable software for the objective erosion control measures in construction projects.

Table 1. Some examples of developed expert systems in environmental engineering.

System name	Year	Developer	Subject
CDC	1999	Ahmad Basri	Design of composting facilities
Tea	2001	Shams	Solid waste landfill sitting
UrusSisa	2004	Abd Manaf	Solid waste management
CEDINFO	2007	Say	EIA application energy power station
KBS-RWQ	2009	Abdul Ghani	Water quality management
SBC-SOIL	2009	Opera	Soil pollution analysis
SBC-WATER	2009	Opera	Water pollution analysis
SBC-AIR	2009	Opera	Air pollution analysis

Expert System

An expert system has been used in such areas related to the environment as environmental planning, environmental impact assessment, and environmental monitoring [11-19]. It is promising technology that manages data and information, diagnoses the problem, and provides the required advice and expertise to solve the problem. It thus seems well suited to many of the tasks associated with an environmental management plan. It provides a structured approach to environmental management and helps users cope with large volumes of environmental management study [11]. The summary of developed expert systems in environmental engineering is shown in Table 1.

The basic components of expert system are illustrated in Fig. 2. The knowledge base contains all relevant rules,

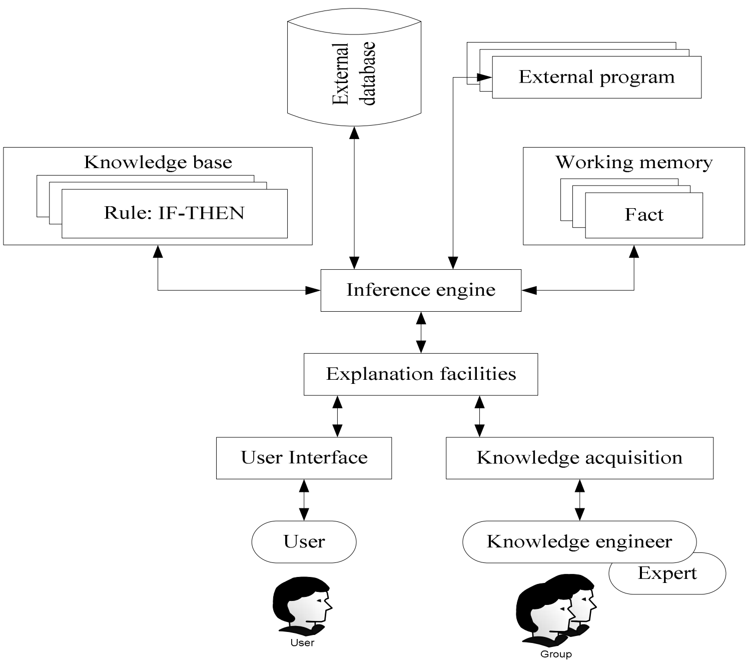

Fig. 2. Complete structure of ES [4].

facts, information data, and the relationships among them [20]. The working memory is a database of facts and information relevant to the domain area used by the rules [21]. The inference engine combines data that is input by the user with the data relationships stored in the knowledge base [20]. It makes inferences by deciding which rules are satisfied by facts, prioritizes the satisfied rules, and executes the rules with the highest priority. The user interface is responsible for translating the interactive input as specified by the user to the form used by the expert system [22]. It allows the user to monitor system performance, gives information, controls problem solving strategies, or requests explanations. The knowledge acquisition serves as an interface between the expert system and the experts that provide a means for entering domain-specific knowledge into the knowledge base [20]. An explanation facility allows the system, when requested or programmed, to explain its reasoning and the problem-solving process to the user [23]. It allows the user to understand how the expert system arrived at certain answers and results [24].

Lee et al. [6] have illustrated that expert system development is a time-consuming task that needs the cooperation of domain experts and knowledge engineers. Knowledge base in a successful expert system that is applied usually adopts the rule-based representation technique. The simplest way for executing the system is explicit knowledge directly from experts, rule by rule. Thus, in developing the TSST, there are several tasks to be completed: user interface, knowledge base, inference engine, and explanation facilities. The user interface is designed to be friendly to help users to enter data as query inputs, and to visualize results in the form of reports and maps in GIS form. The knowledge base is designed and developed by acquiring and analyzing domain knowledge, law, and regulations from textbooks, manuals, research publication, and domain experts, and stored in a rule-based format. The inference engine is built by forward chaining mechanism. The explanation facility explains how system recommendations are derived. The characteristics of the TSST are listed in Table 2, which specifies domain, knowledge resources, knowledge acquisition technique used, knowledge representation technique used, user interface, inference engine, explanation facility, update facility, development method, development tools, and objectives of the TSST. Details are described in the following sections.

Table 2. Characteristics of TSST.

Items	Characteristics
Domain	Soil stabilization during construction activity
Knowledge resource	Expertise, law, and regulations from textbooks, manuals, research publication, and experts about soil stabilization during construction activity
Knowledge acquisition technique used	Interview with domain experts
Knowledge representation technique used	Rules
User interface	Microsoft Windows image
Inference engine	Forward chaining
Explanation facility	Rules and relationships between regulations
Update facility	Rule editing for knowledge base update
Development method	Prototype method
Development tools	Visual Basic
Objective	To help project owner and decision-makers in selecting soil stabilization technique during construction activity

User Interface

Graphical interface and pop-up menus that are features of flexibility assure that standard compatible interface such as Microsoft Office is developed for the purpose of friendliness and user satisfaction. It promotes a friendly environment, help menus, and easy reporting for the users [25]. A standard Microsoft Windows image is employed in the development of TSST interface so that the users who are already familiar with it would not have much difficulty in adapting to the interface. This system is defined as a mechanism for interface optimization through utilization of natural language and graphical interface. Visual Basic (VB) provides a session window where the system developer creates images that allow the user to interact with the knowledge base. The application is then able to interact with the user via dialog windows. The main screen consists of several cascading menu bars and options that contain commands for the user to select. A variety of option menus, multiple forms, multiple selection list boxes, and message boxes are available. These windows pop up in the middle of the screen for attention of the user. The user interface presents help and essential information facilities. According to Azadeh et al. [25], help menus should contain detailed information about all features and sub-features of the expert system.

Knowledge Base Development

There are three stages to build the knowledge base for TSST, including knowledge acquisition, knowledge assessment, and development of a knowledge base in a rule-based form. Knowledge is acquired from various sources of expertise and codified into an expert system.

Knowledge acquisition: In this study the knowledge was extracted from multiple sources of expertise in the field of soil stabilization techniques during construction activities. It is advantageous to use multiple sources in order to arrive at an acceptable agreement on ideas and procedures. The knowledge from domain experts was obtained through communication with them. This interaction consisted of a series of systematic consultations extended over a period of a few months. To this end, three

Table 3. Type of sub-characteristics for site.

Characteristics	Sub-characteristics
Flow condition	
FC_1	Sheet, rill, gully
FC_2	Channelize
Slope inclination	
SI_1	< 1:4
SI_2	1:4-1:2
SI_3	> 1:2
Soil classification	
SC_1	Gravely
SC_2	Sandy
SC_3	Dry Silts and Clays
SC_4	Wet Silts and Clays
SC_5	Peat
Surface area	
SA_1	≤ 0.4 ha
SA_2	0.4-2 ha
SA_3	≥ 2 ha
Atmospheric conditions	
AC_1	Raining
AC_2	Moderate temperature and humidity
AC_3	Hot temperature and humidity
Accessibility of equipment	
AE_1	Accessible
AE_2	Not accessible
Duration of need	
DN_1	≤ 3 months
DN_2	3-12 months
DN_3	≥ 12 months

meetings were organized with five experts each with experience in theoretical (from university), practical (from industry) or a combination of both circumstances. Experts were specialists in the field of construction management, soil erosion and sediment control, environmental engineering, environmental impact assessment, and water engineering. After the third meeting, the experts were asked to propose:

- Site characteristics important for system development
- Erosion control measures that should be considered for soil protection
- Assessment criteria for selection of soil stabilization technique.

In response, the experts proposed their recommendations regarding site characteristics and soil stabilization technique. The experts suggested flow conditions, slope inclination, soil classification, surface area, atmospheric conditions, accessibility of equipment, and duration of need. According to site characteristics, each character has various sub-characteristics that are presented in Table 3. For the assessment items, according to their expertise the experts defined four criteria: cost, efficiency, durability, and availability of technical expertise. They suggested straw mulch (SS_1), wood mulch (SS_2), soil binder (SS_3), hydroseeding (SS_4), hydraulic mulch (SS_5), and rolled erosion control product (SS_6) as erosion control measures.

In this stage, the study developed assessment tables for each site characteristic, sub-characteristic, and related regulations. Expert assessment for sub-characteristics of each characteristic are listed in Table 4 based on guidance for temporary soil stabilization [26].

Knowledge base development: Decision tables are used to acquire rules for building the decision tree. The TSST knowledge base is designed by using a decision table. For example, considering the soil types, there are five subtypes

Table 4. Regulation for assessment of site sub-characteristics.

Characteristics	Sub-characteristics	Assessment
Flow condition	FC_1	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	FC_2	SS_6
Slope inclination	SI_1	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	SI_2	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	SI_3	SS_3, SS_6
Soil classification	SC_1	SS_6
	SC_2	SS_1, SS_3, SS_4, SS_5, SS_6
	SC_3	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	SC_4	SS_1, SS_2, SS_4, SS_5, SS_6
	SC_5	SS_1, SS_2, SS_4, SS_5, SS_6
Surface area	SA_1	SS_1, SS_2, SS_4, SS_5, SS_6
	SA_2	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	SA_3	SS_1, SS_3, SS_4, SS_5
Atmospheric conditions	AC_1	SS_6
	AC_2	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	AC_3	SS_3, SS_6
Accessibility of equipment	AE_1	SS_1, SS_2, SS_3, SS_4, SS_5, SS_6
	AE_2	SS_1, SS_6
Duration of need	DN_1	SS_3, SS_5
	DN_2	SS_1, SS_2, SS_5, SS_6
	DN_3	SS_3, SS_4, SS_5, SS_6

for which assessment grades are available. The value of each sub-type is regarded as the condition while suggesting the action. An example decision table is generated as shown in Table 5. When using this table, if sheet flow (FC_1), dry silts and clays soil (SC_3), slope < 1:4 (SI_1), ≤ 0.4 ha surface area (SA_1), moderate temperature and humidity (AC_2), accessible (AE_1), and ≤ 3 months need duration (ND_1) are true (rule 1), then the system recommendation is hydraulic mulch (SS_5). To confirm this rule, expert recommendations were achieved. However, some conditions may occur that have more than one solution. To deal with this case, questionnaires were designed to be filled in by experts as illustrated in the following section.

Knowledge assessment: As opposed to the previous stages (which were preparations for the objectives of the study), this stage aimed at acquiring expert knowledge. Based on the input of the previous stage, questionnaires were designed for the experts using a series of structured interviews. As the experts might have different experiences, it becomes important to integrate the opinions of multiple experts to obtain high quality recommendations.

To confirm system rules where some conditions have one solution, experts' recommendations were achieved by applying the certainty factor (CF), a number to measure the expert's belief or disbelief. The minimum value of the certainty factor is -1.0 (definitely false) and the maximum +1.0 (definitely true). The net certainty of hypothesis H for conjunctive and disjunctive rules is established as equations 1 and 2 [4]:

$$\text{IF}\langle\text{evidence } E_1\rangle \text{ AND } \langle\text{evidence } E_2\rangle\ldots \text{ AND}\langle\text{evidence } E_n\rangle \text{ THEN } \langle\text{hypothesis}\rangle\{cf\}. \quad (1)$$
$$cf(H, E_1\ E_2\ \ldots\ E_n) = \min[cf(E_1), cf(E_2), \ldots, cf(E_n)] \times cf.$$

$$\text{IF}\langle\text{evidence } E_1\rangle \text{ OR } \langle\text{evidence } E_2\rangle\ldots \text{ OR}\langle\text{evidence } E_n\rangle \text{ THEN } \langle\text{hypothesis}\rangle\{cf\}. \quad (2)$$
$$cf(H, E_1\ E_2\ \ldots\ E_n) = \max[cf(E_1), cf(E_2), \ldots, cf(E_n)] \times cf.$$

To cope with some conditions that have more than one solution, the recommendation of the system was achieved by application of Expert Choice 11 software. It was applied as a multi-criteria decision support tool where the research problems were classified into three levels of hierarchy: objective, criteria, and alternative by integrating the opinions of multiple experts. The ultimate goal of evaluating the ideal model can be achieved, followed by evaluation alternatives, and finally the criteria (Fig. 3).

For selection of the best recommendation, goals, alternatives, criteria, and number of experts were modeled using Expert Choice 11 (a sample screen of using Expert Choice is shown in Fig. 4).

To graphically demonstrate the rule of knowledge base, a decision tree is used to view the assessment results for the selection of soil stabilization technique. An example of a decision tree is illustrated in Fig. 5.

Table 5. An example decision table for selection of soil stabilization technique.

Rules	Conditions																				Actions
	FC_1	SI_1	SI_2	SI_3	SC_1	SC_2	SC_3	SC_4	SC_5	SA_1	SA_3	SA_2	AC_2	AC_1	AC_3	AE_1	AE_2	DN_1	DN_2	DN_3	Suggestions
1	T	T	-	-	-	-	T	-	-	T	-	-	T	-	-	T	-	T	-	-	SS_5
2	T	T	-	-	-	-	T	-	-	T	-	-	T	-	-	T	-	-	T	-	SS_1, SS_2, SS_5, SS_6
3	T	T	-	-	-	-	T	-	-	T	-	-	T	-	-	T	-	-	-	T	SS_4, SS_5, SS_6
4	T	T	-	-	-	-	T	-	-	-	T	-	T	-	-	T	-	T	-	-	SS_5
5	T	T	-	-	-	-	T	-	-	-	T	-	T	-	-	T	-	-	T	-	SS_1, SS_5
6	T	T	-	-	-	-	T	-	-	-	T	-	T	-	-	T	-	-	-	T	SS_3, SS_4, SS_5

Inference Engine

The inference mechanism designed in the TSST is forward chaining. It starts by finding the best input and selecting it for the final model [27]. The inference process follows:

(1) selecting one flow condition, slope inclination, soil type, surface area, atmospheric condition, accessibility of equipment and duration of need

(2) performing inference based on knowledge base

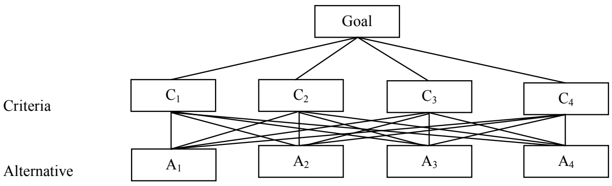

Fig. 3. Goal evaluation by criterion and alternative.

(3) suggesting assessment results. In the beginning, a user can select one flow condition, slope inclination, soil type, surface area, atmospheric condition, accessibility of equipment, and duration of need.

According to the selected information, the inference engine of TSST checks the conditions by using rules stored in a knowledge base and recommends the result.

Explanation

In TSST, the explanation facility presents the user with the recommended procedures and gives explanations that support the choices. An example is used to demonstrate how an explanation facility functions. By selecting information requested and rule matching, its related recommendation is shown. After user inquiry, some explanation texts based on knowledge base are provided. This is accomplished as presented in Fig. 6. By this, a user can realize their interrelationships with respect to the assessment

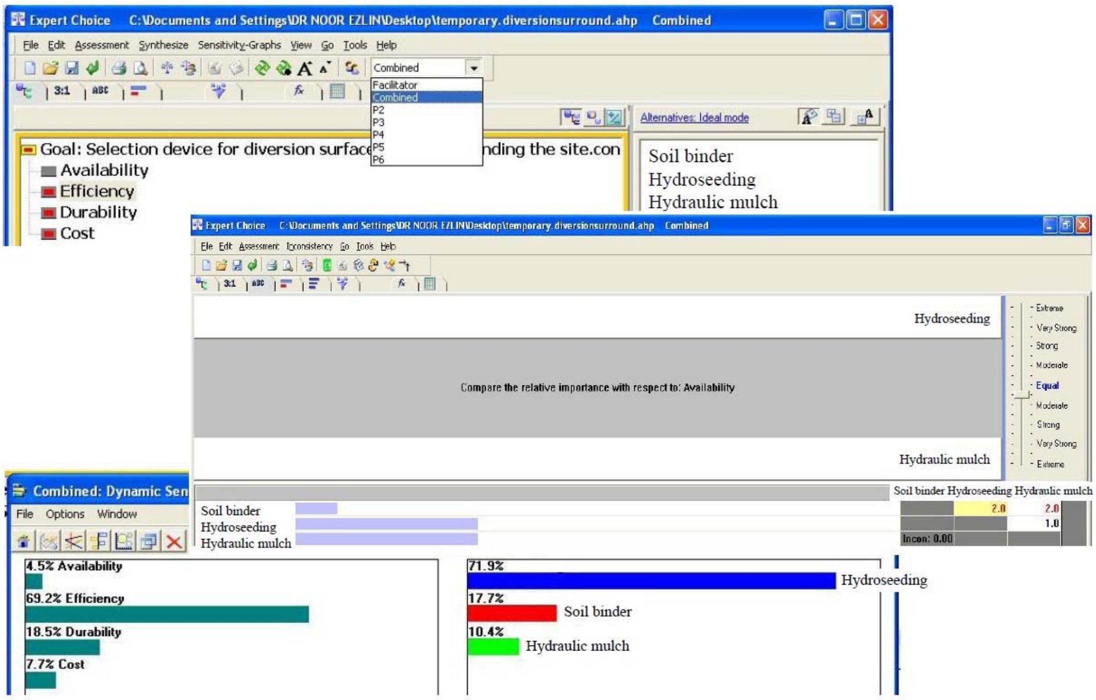

Fig. 4. A sample screen that shows using Expert Choice 11 software.

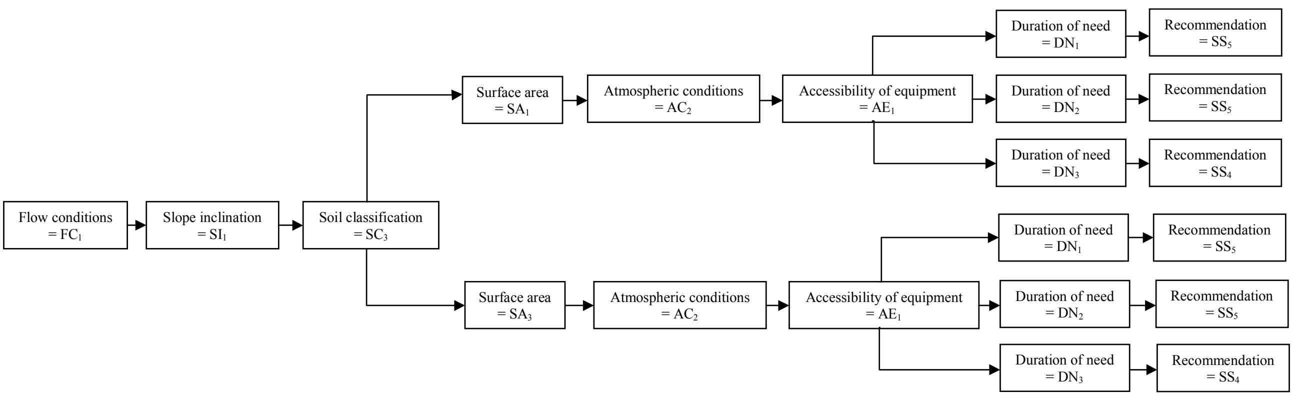

Fig. 5. Decision tree for knowledge base.

Table 6. Development Planning Guidelines in the Hills and Highlands based on surface level.

Surface level	Assessment	Recommendation
< 150 m	low land	Suitable for houses, business, industrial, institution, hotel, tourism and recreation.
150-300 m	Hill land – low-risk zone	Suitable for development with medium density
300-1000 m	Highland – sensitive, risky zone	Suitable for development with medium density. 90% of the development area should be donning landscaping.
> 1000 m	Mountain – very sensitive, risky zone	If the development is allowed, the protection ways to prevent the fallen ground should be done.

Table 7. Development Planning Guidelines in the Hills and Highlands based on slope range.

Slope range	Assessment	Recommendation
< 15º	Class I – Low-risk zone	Suitable for every land development such as houses, business, hotels, tourism, and recreation and also need follow the guideline.
15º-25º	Class II – Medium-risk zone	Suitable for every land development such as houses, business, hotels, tourism, and recreation and the control of slope condition should be implemented to avoid failing land.
25º-35º	Class III – High-risk zone	The development of the area can be considered after taking the result from the environmental impact assessment (EIA) and erosion and sediment control plan (ESCP).
>35º	Class IV – Very high-risk zone	Development should be avoided and discouraged.

Source [13-30]

results. Furthermore, TSST explains development planning guidelines in the hills and highlands based on Malaysian regulations as presented in Tables 6 and 7. Moreover, the interface of TSST utilizes GIS functions as a supportive component to display spatial maps. A sample screen of displaying recommended best management practices (BMPs) is shown in Figs. 7 and 8.

System Testing and Evaluation

The developed TSST was tested, and the outputs generated at each test stage were checked and validated. The tests were run to check all different components of the developed TSST. This was done periodically during all stages of system development to check that system performance is accurate.

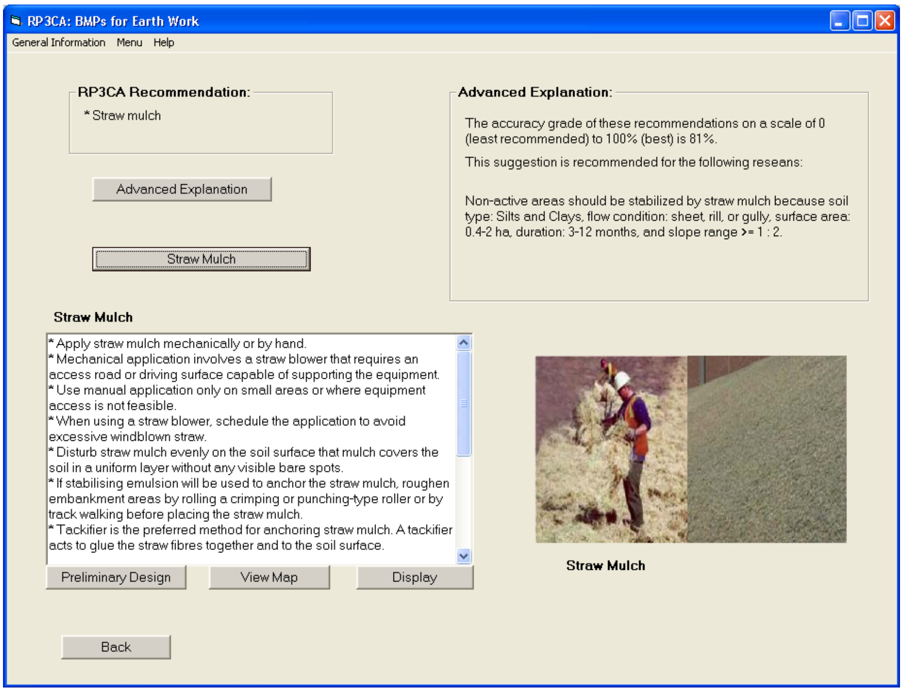

Fig. 6. An example of the explanation facility.

Table 8. Feedback from experts.

Review session	Reviewer feedback				
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Knowledge acquisition techniques	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable
Knowledge base contents	Acceptable	Adequate	Acceptable	Adequate	Acceptable
Explanation facilities	Adequate	Adequate	Acceptable	Adequate	Adequate
Speed of decision-making	Acceptable	Adequate	Acceptable	Adequate	Acceptable
User friendliness	Acceptable	Adequate	Acceptable	Adequate	Acceptable
Help facilities	Adequate	Acceptable	Adequate	Acceptable	Adequate
System recommendations	Acceptable	Acceptable	Adequate	Acceptable	Acceptable

For system evaluation, the TSST was demonstrated to four experts who are specialists in soil science and ESCP. They were asked to use TSST and provide comments by applying the system for three case studies. With regard to the system verification, the assessment result of these cases was consistent with that by experts.

For the system evaluation, the system was also demonstrated to three domain experts and two software development specialists who were asked to use the TSST and provide comments. A special questionnaire was designed to help acquire information with respect to the TSST [6, 28, 29]. It covered several sections and topics such as user friendliness, knowledge acquisition techniques, knowledge base contents, explanation facility, speed of decision-making, help facility, and confidence about recommendations. With regard to the system evaluation, the experts illustrated that system performance is acceptable. Feedback is summarized in Table 8. Moreover, they suggested that the TSST knowledge base should be maintained continuously because regulations may change over time.

Conclusion

This research has briefly described the selection of a temporary soil stabilization technique, and defined expert system with respect to its use in selecting a soil stabilization method; it also developed an expert system as a soil stabilization technique advisor for users to apply in housing and new township development projects. VB is used to develop

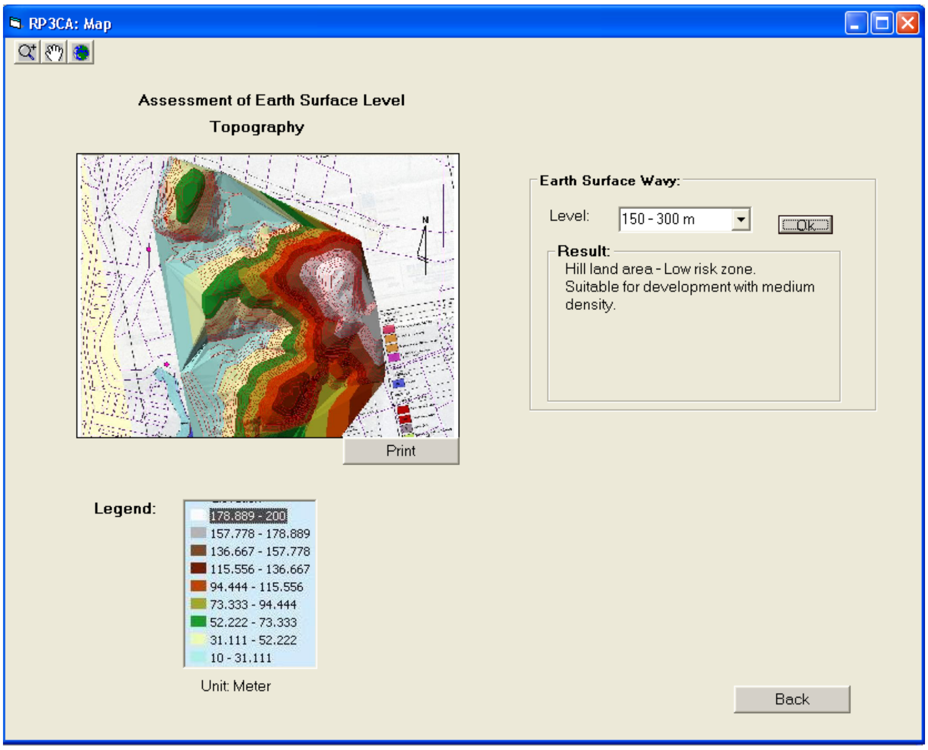

Fig. 7. Assessment of earth surface level topography in GIS form.

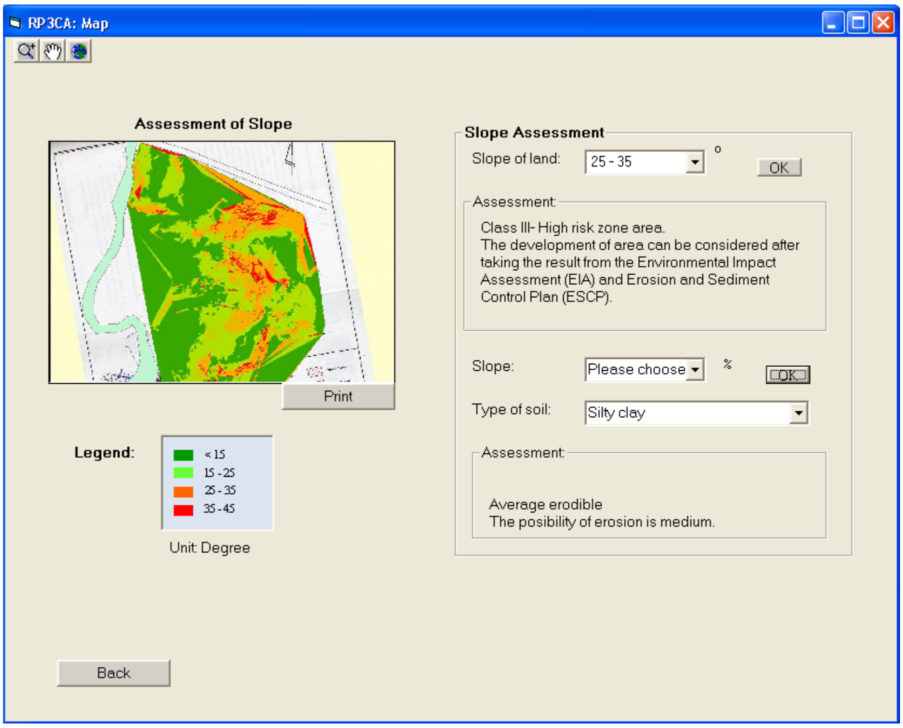

Fig. 8. Assessment of slope range in GIS form.

the user interface and knowledge base to provide system suggestions. The study employs questionnaire and decision tables to acquire expert knowledge, uses a certainty factor for measuring expert belief and disbelief of system rules, applies Expert Choice 11 software for integrating multiple expert opinions where various alternatives are available by considering cost, durability, efficiency, and the availability of technical expertise as criteria, transform expert experience into rules, store rules in a knowledge base, use a forward-chaining mechanism to build the inference engine, develop an explanation facility to retrieve advice details, and provide recommendations and results. To carry out the development of TSST, it is found that the knowledge acquisition and establishment of knowledge base are the most difficult and important tasks. Knowledge sources in this study include books, guidelines, research publications, and expertise about temporary soil stabilization techniques. The knowledge base in TSST that is generated by using questionnaires and decision tables depends on the knowledge gained from experts who were interviewed. This requires the development of an in-depth comprehension of knowledge modeling in particular, and of the applicable domain in general. The TSST utilizes GIS functions as a supportive component to display site location and system recommendation in maps. The TSST applied in the selection of temporary soil stabilization technique in housing and new township development projects in Malaysia. The knowledge base in an expert system is a continuously changing entity, which requires continuous improvement and expansion, hence the latest findings in literature or experiences should be incorporated. The system could be incorporated as part of integrated temporary soil stabilization techniques during construction activities for other types of construction activities. Other perspectives in terms of applications such as dams, tunnels, railways, airports, and industrial construction may need particular special knowledge bases. An additional module could be combined with the present system. They can include cost estimation, design, and permanent soil stabilization techniques. These modules were excluded in this research because of time and other resource limitations.

Acknowledgements

The authors would like to thank the Malaysian Ministry of Science and Technology Innovation, (01-01-02-SF0363).

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