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An Expert System on Site Selection of Sanitary Landfill

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Abstract

It is desirable to encapsulate the heuristic and empirical knowledge including hydrological and bio-geochemical considerations into the selection process of a potential landfill site. This paper delineates a prototype expert system, which has been developed using a commercially available microcomputer-based expert system shell VISUAL RULE STUDIO, for the selection of a landfill site. VISUAL RULE STUDIO acts as an ActiveX Designer under the Microsoft Visual Basic programming environment, with hybrid knowledge representation approach under object-oriented design environment. The blackboard architecture, which is able to group all the knowledge together into an integrated system effectively, is adopted. The evaluation is based on the hazardous waste site ranking system recommended by the U.S. Environmental Protection Agency, adapted to Hong Kong conditions. Increase in efficiency, improvement, consistency of results and automated record keeping are among the advantages of such a system.

Keywords: Sanitary landfill; Expert system; Blackboard architecture; Hazardous waste site ranking system; Site selection

Biographical notes

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Introduction

A sanitary landfill is one of the most popular refuse disposal means in an urban environment. In order to alleviate the nuisances to public health or safety, extensive studies must be carried out to select the most feasible location. This site selection process involves the study of a proliferation of factors including hydrological as well as bio-geochemical considerations such as composition of contained wastes, possible migration paths of the wastes, planned use of the landfill, population and land use, etc. In the evaluation process, it involves many decisions to be made by the designer based on empirical rules of thumb, heuristics, expertise, judgment, code of practice and previous experience. It is difficult for various teams composed of engineers and scientists to possess the broad expertise and knowledge in performing such site selections in a consistent manner. Specifically, a novice designer may face many difficulties in the design process. It is desirable to encapsulate this heuristic and empirical knowledge into the decision making process.

Previously, some algorithmic models were built to deal with the problem. In many instances, it is often difficult for anyone other than the model developer to use the model successfully. Moreover, expert knowledge is not necessarily algorithms or effective procedures of computer sciences. In fact, empirical rules are often not complete, or unique, or in specific frameworks. With the advent of artificial intelligence (AI), an expert system furnishes a solution to this decision making process through the incorporation of symbolic knowledge processing on the basis of the pertinent empirical, heuristic and expert rules.

During the past decade, the potential of AI techniques for providing assistance in the solution of engineering problems has been recognized. Expert systems are considered suitable for solving problems that demand considerable expertise, judgment or rules of thumb. Areas of early applications of expert system technology include medical diagnosis, mineral exploration and chemical spectroscopy. Expert systems have widespread applications in different fields and are able to accomplish a level of performance comparable to that of a human expert (Adeli & Kao 1996, Chau 1992, Chau & Albermani 2001, Chau & Anson, 2002, Chau & Chen 2001, Chau & Ng 1996, Chau & Yang 1993, Chau & Zhang 1995, Lin & Albermani 2001, Ranga Rao & Sundaravadivelu 1999, Shwe & Adeli 1991).

This paper delineates a prototype expert system for the selection of a landfill site, LANDFILL, which has been developed by using a commercially available microcomputer-based expert system shell VISUAL RULE STUDIO. The blackboard architecture with hybrid knowledge representation techniques including production rule system and object-oriented approach is adopted. The expert system developed is based on the uncontrolled hazardous waste site ranking system recommended by the US Environmental Protection Agency (1984), adapted to Hong Kong situations. Through custom-built interactive graphical user interfaces, the user is directed throughout the rating process. Solution strategies and development techniques of the system are addressed and discussed.

Expert systems

Expert systems are interactive computer programs that mimic and automate the decision making and reasoning processes of human experts in solving a specific domain problem, through delivering expert advice, answering questions, and justifying their conclusions.

A typical expert system is constituted by three core components, namely, knowledge base, inference mechanism and context. The knowledge base is a collection of general facts, rules of thumb and causal models of the behavior specific to the problem domain. The inference mechanism guides the decision making process by using the knowledge base to manipulate the context. The context contains facts that reflect the current state of the problem, constructed dynamically by the inference mechanism from the information provided by the user and the knowledge base. Besides, there are three auxiliary components, which are a knowledge acquisition module, a user interface and an explanation facility. The knowledge acquisition module serves as an interface between the experts and the expert system and provides a means for entering domain specific knowledge into the knowledge base. The user interface is responsible for translating the interactive input as specified by the user to the form used by the expert system. The explanation module provides explanations of the inferences used by the expert system, namely, why a certain fact is requested and how a conclusion was reached.

The order of execution of a conventional program is predetermined and any updates may require enormous effort. The programming algorithm is designed to ensure completeness and uniqueness of the solution. The model user often considers the program as a blackbox and does not have thorough understanding of the algorithm. On the other hand, an expert system separates the knowledge base from the control strategy, which allows for incremental addition of knowledge without manipulation of the overall program structure and hence the programmer need not guarantee completeness. By ranking several alternatives with inexact inference methods, several solutions with different confidence factors can be provided for a particular input condition. The user can also question the results through the explanation module.

The domain knowledge can be represented in several approaches, namely, production rules, frames and object-oriented programming. A production rules system, comprising a collection of rules, is good at depicting heuristic knowledge. A frame system is suitable for a complex and rich representation of knowledge. Object-oriented programming concept is used when it comprises a number of independent objects that process jobs by exchanging information via messages. A hybrid approach can be adopted to take advantages of both representation methods.

Several tools are available for developing an expert system, i.e. traditional programming languages, high-level tools or expert system shells. The programming language designed for AI (LISP or PROLOG) entails tremendous programming effort. High-level tools, such as KEE (Intellicorp 1986), can provide an integrated knowledge engineering environment combining features of the AI languages appropriately and efficiently. An expert system shell provides the skeleton of an expert system incorporating inference engine, user interface and knowledge storage medium, thus requiring the developer only to fill in the domain knowledge.

Domain knowledge

In general, landfills offer an economic and viable solution to the waste disposal problem. During the landfill operation process, engineering principles are applied to confine the refuse to the smallest practicable size, and to cover it with layers of earth at the end of daily operation or at a higher frequency as appropriate. This operation requires systematically depositing, compacting, and covering the wastes in compliance with specifications such as placing 150 to 300 mm of earth over every 600 mm of compacted fill. Besides, the top earth cover should have a minimum designated depth and be grassed to prevent erosion. A common projected land use of a landfill is a park with recreational facilities that are not affected by gradual ground subsidence.

Thorough investigation must be undertaken to select the most appropriate location for a landfill site. In the site selection process, four main factors are considered, namely, potential migration routes of the wastes, waste characteristics, planned features of the landfill and potential targets at risks. For potential migration routes, the study of contaminant movement away from the disposal site through air, surface water and ground water is focussed. The movement of wastes depends not only on physical, geographic and climatic characteristics of the site, but also on the waste characteristics. This feature can be quantified by its toxicity, persistence, corrosiveness, reactivity, ignitability, radioactivity, solubility and volatility. The planned features of the facility will affect the degree of contamination. Potential targets subsume population centers, critical habitats and sensitive ecological systems in its vicinity. All the knowledge can be represented so as to minimize or prevent a contaminant from entering into a potential migration route and arriving at a potential target at risk.

The site selection process comprises three basic components, namely, (i) data on physical, geographic, climatic, soil, water quality and socioeconomic conditions; (ii) political considerations, guidelines, standards and regulations established by the pertinent authorities; and (iii) expert judgments and heuristics. In this process, the expert plays a key role since an enormous expert effort is entailed in the synthesis and analysis of these components. The following tasks are also required, namely, designing the general scheme and a uniform ranking procedure, identifying constraining regulations, analyzing data, and selecting a specific landfill site together with size. The expert evolves one’s judgments and expertise, which is the result of an iterative and explorative learning process, into a set of explicit rules. Consequently, these rules can be denoted as empirical knowledge, which comprises expert inferences, heuristics and rules of thumb.

The prototype system

LANDFILL is an expert system designed to provide surrogate consultation during preliminary/detailed hazardous waste site investigations. It provides a versatile framework for the interpretation, classification and diagnosis of environmental conditions at waste disposal sites. In this study we have considered a site selection procedure for a landfill facility with potential ground water migration routes. This system is intended to be used as a consultation tool to assist waste disposal managers in the preliminary phases of site selection. The objective of such a consultation is to obtain a site rating using the expert rules and the decision logic described in the system’s knowledge base. The various options of LANDFILL are designed to assist a user in such an evaluation. Increase in efficiency, improvement and consistency of selection strategies, and automated record keeping are among the expected benefits of such an expert advisory system. The ranking criteria are based on: relative risk or danger, taking into account the population at risk; the hazardous potential of the substances at a facility; the potential for contamination of drinking water supplies, for direct human contact, and for destruction of sensitive ecosystems; and other appropriate factors.

The system can be compiled and encrypted to create a run-only system. This run-only system can be installed on a microcomputer for office use. The user can always overrule any design options and recommendations provided by the system. In other words, it plays the role of a knowledgeable assistant only.

In order to facilitate development of the expert system on landfill site selection, an expert system shell containing specific representation methods and inference mechanisms is employed. The knowledge base and explanation facility of the system have been implemented with the aid of a microcomputer shell program called VISUAL RULE STUDIO, which is a hybrid application development tool that integrates object-oriented techniques and the expert system technology (Rule Machines Corporation 1998). VISUAL RULE STUDIO acts as an ActiveX Designer under the Microsoft Visual Basic 6.0 programming environment. Production rules as well as procedural methods are used to represent heuristic and standard engineering design knowledge. By isolating rules as component objects, separate from objects and application logic, it produces objects that can interact with virtually any modern development product and thus rule development becomes a natural part of the component architecture development process. Besides, it can activate outside algorithmic programs, and has mathematical computation capabilities.

The blackboard architecture has been successfully used in solving a wide range of tasks, such as speech recognition, signal processing, and planning (Engelmore & Morgan 1988). A blackboard system consists of a number of knowledge sources that communicate through a blackboard and are controlled by an inference mechanism. The blackboard architecture is intended to support the development of systems in domains characterized by interaction between diverse sources of knowledge. The blackboard serves as a global data structure, which facilitates this interaction.

Objects are used to encapsulate knowledge structure, procedures, and values. An object's structure is defined by its class and attribute declarations within a RuleSet. Object behavior is tightly bound to attributes in the form of facets, methods, rules, and demons. Figure 1 shows the structure of VISUAL RULE STUDIO components. Each attribute of a class has a specific attribute type. The attribute types are compound, multicompound, instance reference, numeric, simple, string, interval, and time. Facets provide control over how the inference engines process and use attributes. Methods establish developer-defined procedures associated with each attribute. The set of backward-chaining rules that conclude the same attribute is called the attribute's rule group. The set of forward-chaining demons that reference the same attribute in their antecedents is called the attribute's demon group.

LANDFILL combines expert system technologies, object-oriented programming, relational database models and hypertext/graphics in Microsoft Windows environment. By defining various types of windows as different classes, such as Check Box, Option Button, List Box, Command Button, Text Box, etc., they can inherit common characteristics and possess their own special properties.

Besides the usual components in a typical expert system, namely, knowledge base, inference mechanism, session context, user interface, knowledge acquisition and explanation modules, it also incorporates a database. The database chosen is Microsoft Access, which was selected for several reasons including its popularity as a user-friendly relational database within industry, reasonable cost, and Visual Basic support by means of Visual Basic for Applications. The schematic view of this prototype system is shown in Figure 2.

Knowledge plays an important role in an expert system. In order to acquire knowledge, it is better to work with the expert in the context of solving particular actual problems, instead of directly posing questions about rules. The knowledge used has been acquired mostly from written documents such as code of practice, textbooks and design manuals and complemented by experts. The domain knowledge is translated into procedures and methods using object-oriented representation.

In this prototype system, knowledge is represented in the IF/THEN/ELSE production rules with confidence factors that can be assigned either automatically, or in response to the user's request. These rules are a formal way of specifying how an expert reviews a condition, considers various possibilities, and recommends an action. The explicit expertise under the production rule format in the knowledge base are employed to rank the potential landfill locations to identify the more feasible sites for further detailed studies. All landfill site selection parameters are categorized into four main factors, namely, groundwater route characteristics, targets at risk, facility characteristics and waste characteristics.

The groundwater route characteristics comprise a number of parameters including the depth of the groundwater at the aquifer, net seasonal precipitation, soil permeability, the physical state of the waste at the time of disposal, aquifer soil type and the depth to bedrock. The following is a typical example of the production rules.

```
Rule to find HazardGroundwaterDepth: 1 of 8
IF GroundwaterRoute.DepthOfGroundwater >= 6 AND
      GroundwaterRoute.DepthOfGroundwater < 25
THEN HazardScore.HazardGroundwaterDepth:= risky CF 70
```

The system transforms these production rules into user-friendly interactive menus, for instance as shown in Figure 3. Depending on the responses made by the user, appropriate rules will be executed. The sum of executed assigned hazard values will constitute the groundwater route characteristics hazard score (S_{gr}).

The corresponding rules at the second stage characterize the level of risk to potential targets. They include rules about the potential use of the aquifer of concern, the vicinity of nearest production wells, and nearby population served by the ground water. They include three groups of rules. The sum of the three executed assigned values will then yield the target score (S_t).

In order to determine the waste characteristics hazard score (S_{wc}), the system considers the toxicity, persistence, corrosiveness, reactivity, ignitability, radioactivity, solubility and volatility of each potential waste substance, along with its projected disposed quantity. The substance with the highest sum of the assigned values among all projected waste substances is selected as the representative waste material, with the values taken as the waste characteristics hazard score.

The remaining stage includes the expert rules about the planned containment characteristics of the proposed landfill facility. The executed assigned value is defined as the facility characteristics score (S_{fc}).

The system, comprising 200 rules or so, accounts for the facts that describe the domain knowledge on preliminary landfill site selection. The production rule also incorporates the fuzzy description: The user has to choose appropriate answers to all these questions in order to assign a hazard rating score to each parameter. The expert system then matches the selected answers with each rule, executes the appropriate ones, and computes the four partial scores. It ultimately derives the overall hazard rating score of the site, as follows:

$$S = \frac{100}{57330} * S_{gr} * S_{wc} * S_{fc} * S_t \quad (1)$$

The overall site hazard rating score is normalized between 0 and 100, which is utilized as a measure for the relative ranking of the specific site. Figure 4 shows a screen displaying the overall landfill site hazard rating score of a site at Tseng Kwan O. The scores can be employed as a yardstick for the relative safety of different sites. In a preliminary study, locations with high scores might be eliminated as potential landfills, whereas sites with low scores can remain for further comprehensive investigation.

The inference engines control the strategies that determine how, from where, and in what order a knowledge base draws its conclusions. These inference strategies model the reasoning processes an expert uses when solving a problem. The Process Control Knowledge module involves meta-level knowledge which establishes the problem solving strategy and controls the execution of the Design Knowledge modules. It evaluates the Design Status and decides what action should be performed mainly in data-driven forward chaining mechanism. The knowledge representations of the Design Knowledge modules, however, need both forward and backward chaining inference mechanism to arrive at the solution.

The system offers a friendly user interface. A combination of mouse and keyboard can be used to navigate the application. The use of a mouse or other pointing device renders the data entry a simple task even for novice computer users. As such, users simply point and click their way through the process to appreciate the dynamic behavior of the system. Whilst input data entries are kept at minimum, they are provided by the user mostly through selection of appropriate values of parameters from the menus and answers to the queries made by the system. The input data provided by the user will be rejected if it is not within the specified range. The system provides in multi-window graphics text display where graphic images are combined with valuable textual information. This kind of intelligent graphics is extremely valuable to novice designers because it enhances their confidence in the design provided by the expert system.

The HELP command buttons provide definitions of a variety of parameters involved in order that the user can select the appropriate options. Their primary functions are to aid the user to comprehend the expert's approach to the problem of landfill site selection, and to gain synthetic experience. In fact, the explanation facility is one of the distinct differences between a conventional computer program and an expert system, which is designed to explain its line of reasoning for acquiring an answer.

Conclusions

A microcomputer expert system, which assists in making decisions on selection of an appropriate landfill site, was developed and implemented. The prototype system illustrates that an expert system can act as storage for empirical knowledge so that advice on landfill site selection can be furnished in the preliminary design stage. It is shown that the hybrid knowledge representation approach combining production rule system and object-oriented programming technique is possible with the implementation of blackboard system architecture under a Windows platform. The knowledge base is transparent and can easily be updated, which render the expert system an ideal tool for incremental programming. Besides, its explanation facilities are capable of offering valuable information to the user, which can lead to a more efficient planning procedure. The educational spin-off of an expert system in training novice engineers or in transferring knowledge cannot be overemphasized.

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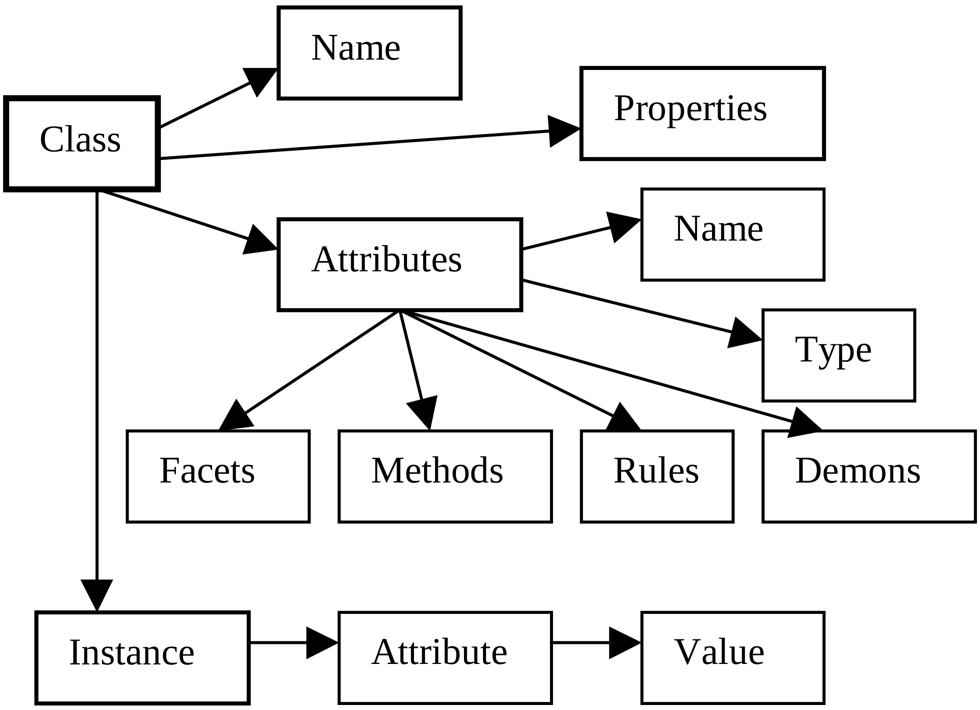

Figure 1. Structure of VISUAL RULE STUDIO components.

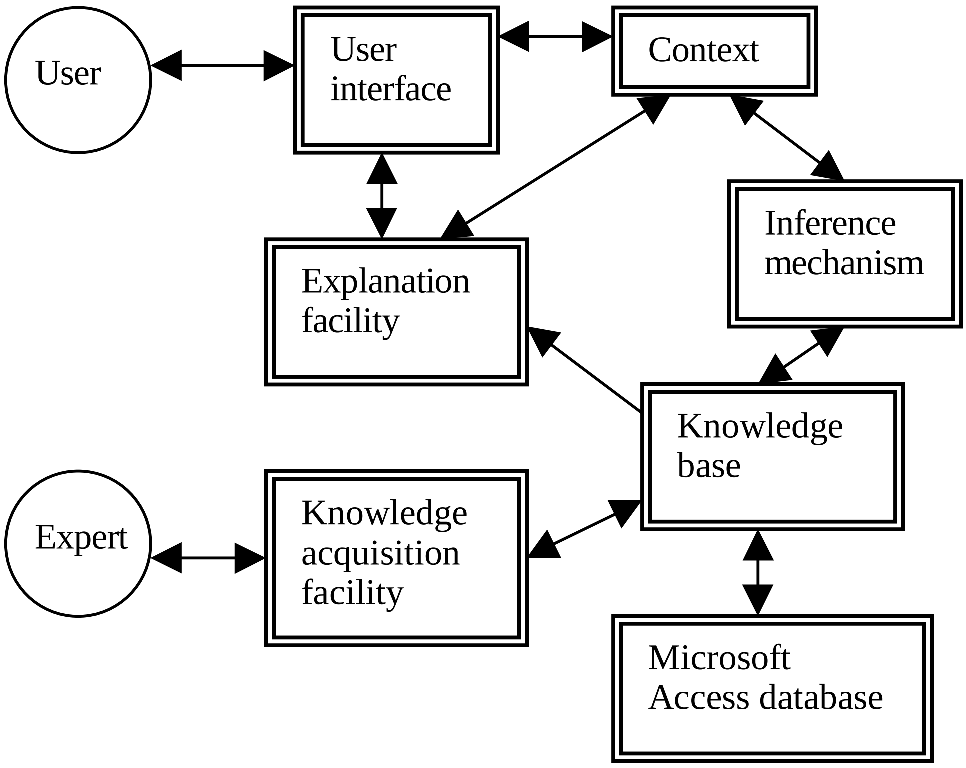

Figure 2. Schematic view of the expert system.

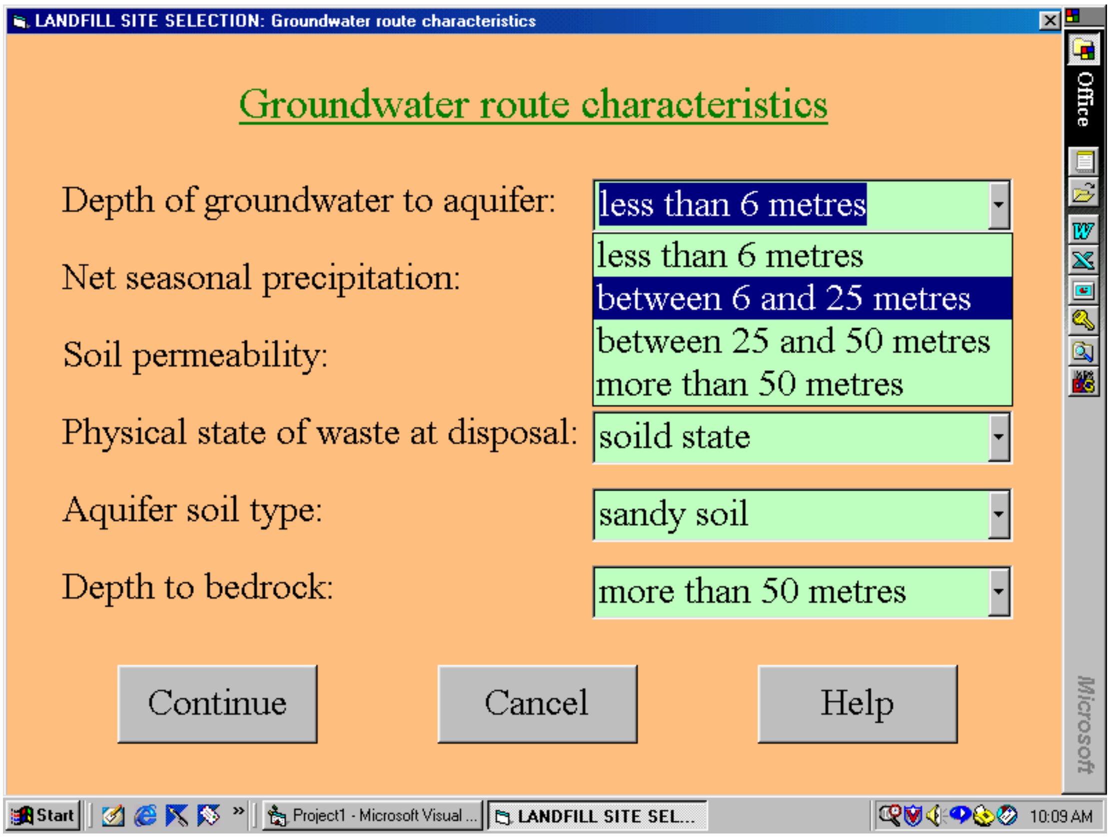

Figure 3. Screen displaying user-friendly data input of groundwater route characteristics.

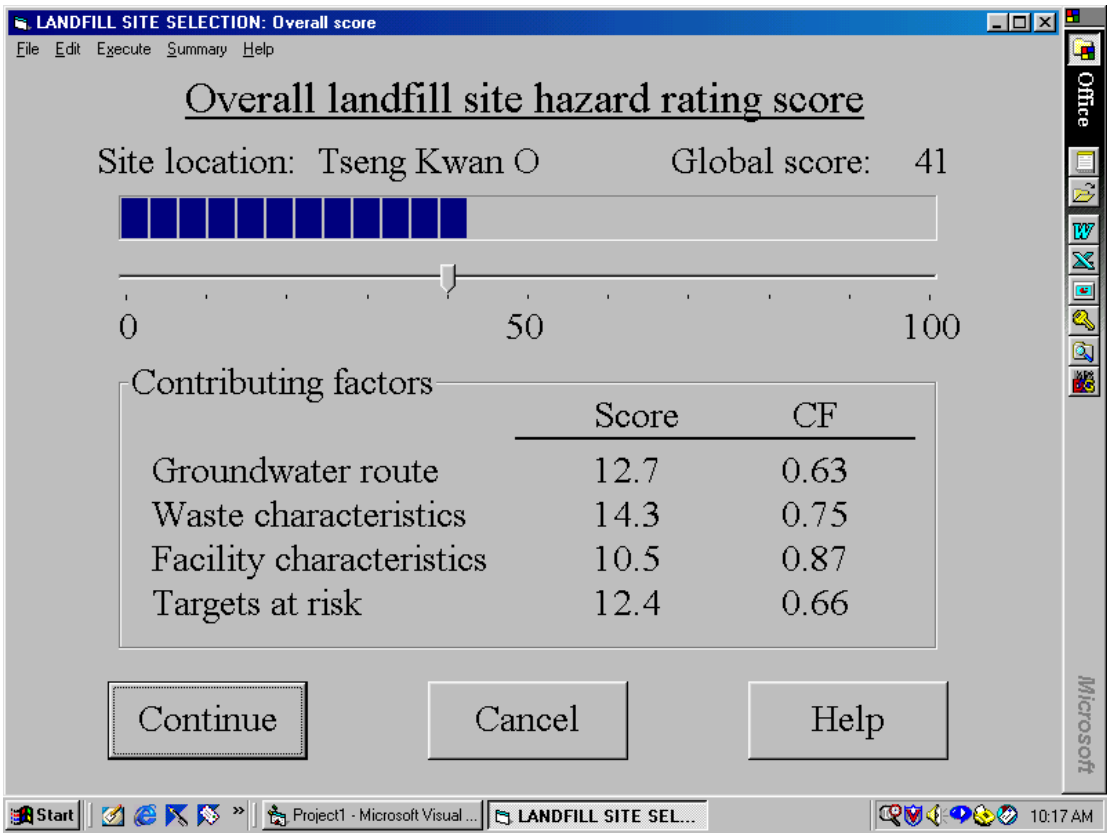

Figure 4. Screen displaying overall landfill site hazard rating score.