NETWORK EXPERT GEOGRAPHIC INFORMATION SYSTEM FOR LANDFILL SITING

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ABSTRACT: A prototypical network expert geographic information system (GIS) is developed to facilitate municipal solid waste landfill siting. A forward chaining knowledge base consisting of related siting rules extracted from various literature is used to establish an expert system. Siting analysis is performed by a GIS and evaluated by rules triggered from the expert system. The expert system and GIS are integrated into an expert GIS to combine the advantages of both systems. Also, a multimedia network interface is designed for local or remote access to the system from anywhere on the Internet. With the interface, a general user does not require previous knowledge of the expert system and GIS to use the system. This networking capability not only significantly reduces the cost of distributing tools to each user, but also avoids the difficulty that each user may encounter in installing and managing tools on the computer. Finally, a case study is provided to demonstrate the effectiveness of the developed system in facilitating landfill-siting analysis. The system can be directly accessed via Internet from the home page http://ev004.ev.nctu.edu.tw/ENGLISH/wsite/index.html.

INTRODUCTION

Landfilling remains an important waste management approach even though reduction, recycling, and incinerating programs are widely used to divert waste streams from landfills. Increasing overpopulation, urbanization, and limited land resources have not only decreased the lifetime of landfills, but also aggravated the difficulty in finding new landfills. Landfill capacity crisis has therefore become a critical environmental issue arousing widespread local public concern (Lowrance 1989).

Landfill siting is a relatively difficult, complex, tedious and protracted process (Allanach 1992). Many siting factors and criteria must be carefully analyzed. An initially chosen candidate site may be later abandoned because opposition arises on the basis of previously neglected but important factors; costs are subsequently increased and the final decision of a landfill site postponed. A landfill is generally prohibited from an environmentally sensitive area such as a water-resources conservation district (*Regulation* 1993), floodplain, or wetland (Repa 1992), or restrained at a certain buffer distance from a surface water body (British 1993). On the other hand, landfills should be located near public roads to reduce related costs of construction and operation (Lindquist 1991). Issues involving impact on nature and society, the lifetime of a landfill, land concession, and water-resource protection should also be evaluated. Zyma (1990) suggested that an appropriate landfill should have minimum impact on environment, society, and economy, comply with regulations, and receive general public acceptance. In considering these difficulties, Ham (1993) noted that the number of landfills is decreasing and the size of landfills has increased with time. Overall, landfill siting has become more difficult owing to the general public's attitude of "not in my backyard."

Such a complex landfill siting analysis is generally multidisciplinary and requires extensive effort to assess numerous factors and environmental, social, economic, and engineering constraints before an appropriate decision can be reached. Spatial data should be collected, in addition to the overall condition, for environmental, social, economic, and engineering factors to assess microscale impacts, e.g., the exposure risk for adjacent areas. Implementing such a complicated procedure in a conventional information processing approach would be expensive and tedious. Moreover, such a process may have to be repeated several times as new factors are introduced or as siting constraints alter. In many cases, a landfill is inappropriate because critical factors are not fully analyzed because of limited funds, coupled with tedious procedures required to process related siting information, for enforcement verification of related constraints. Such a circumstance is partially true for many local governments.

In this work, a computerized tool capable of facilitating the siting procedure is proposed. An appropriate tool for assisting in the landfill siting procedure should include the features of (1) providing guidance in addition to human expertise; (2) ease of data processing and information presentation; and (3) relatively low cost. Our previous work developed a network-based system to assist the siting analysis using a geographical information system (GIS), *GRASS* (1993), and a multimedia network interface (Kao et al. 1994). This early version of the system, however, required extensive manual judgment to review siting rules for evaluation of candidate sites. Therefore, in this work, a rule-based expert system is developed as a significant system improvement, capable of performing automated enforcement checking of siting criteria and rules. Also, the expert system is integrated into the system with the GIS and the multimedia network interface. The entire system is intended for use by officers of local environmental agencies, engineers of local consulting companies who implement any related landfill-siting projects, students in related courses, and other interested people on the Internet.

A rule-base expert system is a computer program which represents expertise in symbolic or numerical forms of modularized conditional rules that are easily modified and expanded. The expert systems are no longer merely a research technique. They have been useful in solving many real-world problems. A summary of expert system applications to environmental engineering problems was provided by Ortolano and Steineman (1987) and Hushon (1990). Numerous other applications in various areas of civil and environmental engineering can be found in the earlier issues of this journal. The

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Note. Discussion open until March 1, 1997. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on October 25, 1995. This paper is part of the ***Journal of Computing in Civil Engineering***, Vol. 10, No. 4, October, 1996. ©ASCE, ISSN 0887-3801/96/0004-0307–0317/$4.00 + $.50 per page. Paper No. 11885.

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knowledge base established for the expert system attempts to function as a computerized expert, at least to some extent.

Landfill siting generally requires processing of a variety of spatial data for environmental, social, economic, and engineering factors. Implementing such data processing via the conventional approach of using drawing and calculation tools is usually time-consuming. GIS converts georeferenced data into computerized maps; map analysis tools provided by the GIS make manipulation of the maps by computer a relatively easy and efficient process. Lindquist (1991) demonstrated GIS applications and its advantage for landfill siting. Michaels (1988) stated that a GIS can be used to (1) combine various demographic, geological, land-use, and census-tract maps; (2) apply landfill criteria; and (3) identify suitable areas for locating a landfill. In this study, both the expert system and GIS are combined to assist in a landfill siting.

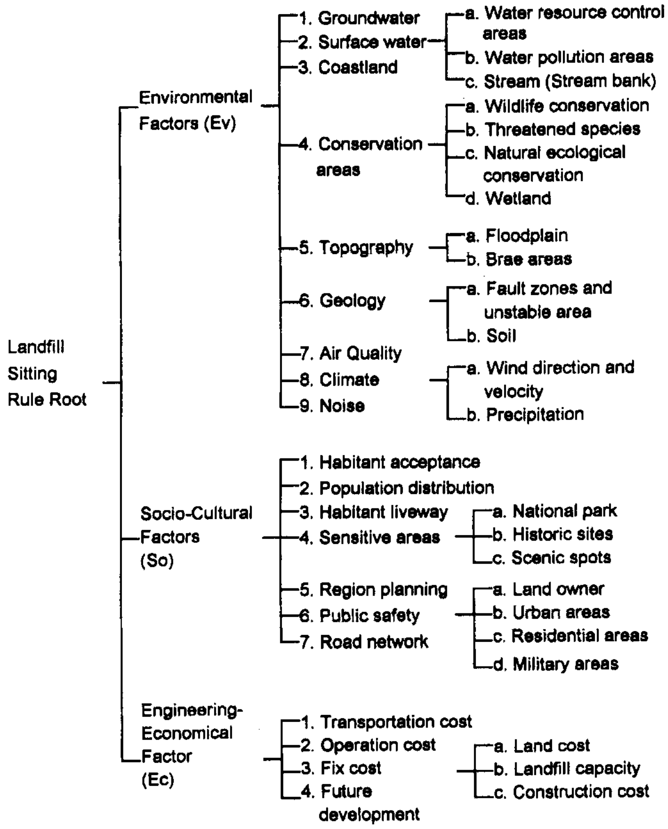

FIG. 1. Hierarchical Structure of Assessment Factors as part of Rule-Base Organization

Although use of an expert GIS for a landfill siting has not been discussed in previous literature, use of expert GISs for other applications has been documented. For instance, Hammad et al. (1993) used ARC/INFO and KEE to construct an expert GIS for bridge planning. Evans et al. (1993) developed an expert GIS shell using ARC/INFO and NEXPERT. Those expert GISs, although useful, were developed using costly commercial tools with restrictive limitations when connected to an external program. A local government cannot afford the distribution of the expensive tools to many end users. Moreover, training appropriate computer experts for learning and maintaining the tools is difficult for a local government owing to limited budget and manpower.

The expert GIS developed in this work is based on a publicly accessible GIS, GRASS, and an inexpensive expert system shell, CLIPS (Giarratano and Riley 1991). Furthermore, instead of distributing the developed tools to the computer of each end user, the tools are made available on the network for 24-hour remote accesses. A friendly multimedia network interface based on publicly accessible World Wide Web (WWW) interface (Berners-Lee 1993a) was provided to link the expert system and GIS. With the interface, the user is not required to have previous knowledge of GRASS or CLIPS for using the system. The user can select any desired criteria, and a map of acceptable sites is presented via network. This networking capability not only markedly reduces the cost of distributing tools to each end user, but also avoids any difficulty that may be encountered when installing tools on each user's computer.

This paper is organized as follows. The development and

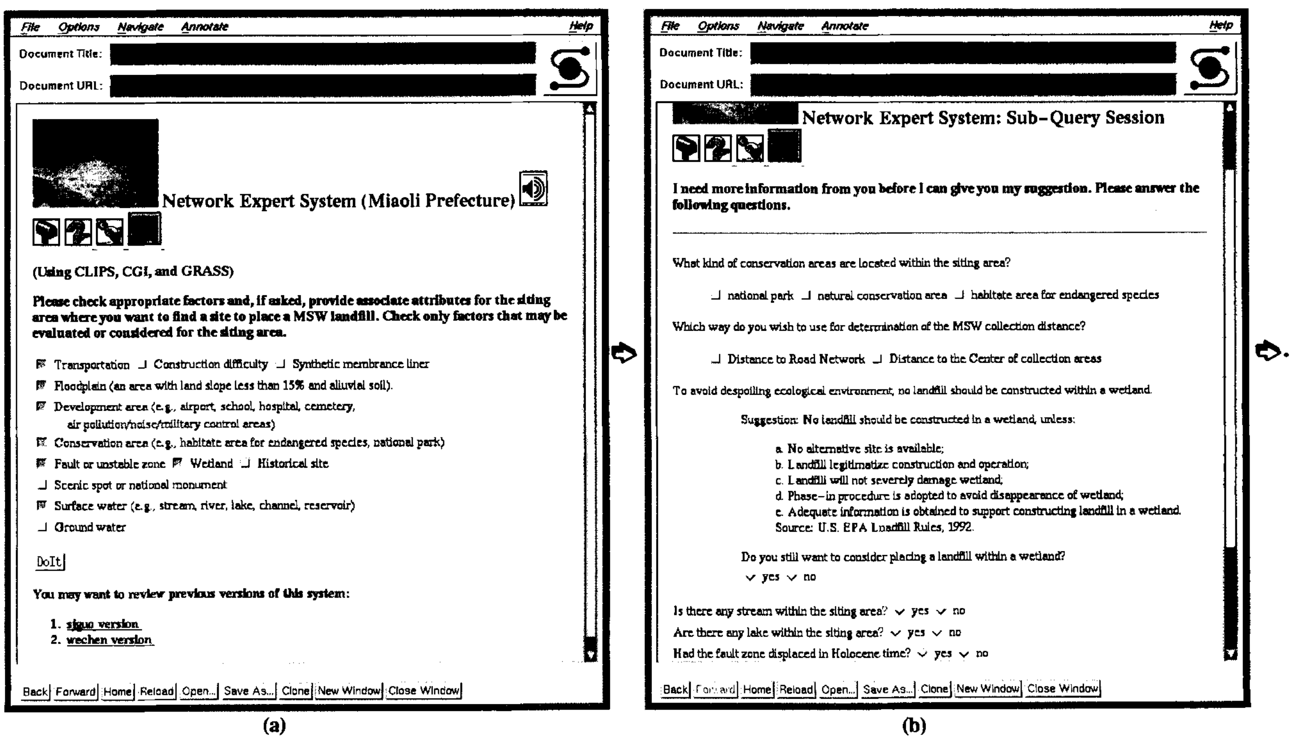

FIG. 2. Sample Network Expert Subsystem Interface: (a) Initial Screen of Subsystem; (b) Sample Query Session of Subsystem

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implementation of the proposed expert system, to facilitate a landfill siting, is first described, followed by a description of a GIS-assisted landfill siting system. Integration of both the expert system and GIS is then explained. Next, a description is provided for the user-friendly network multimedia interface designed for using the integrated system. Finally, a case study for Miaoli Prefecture in central Taiwan demonstrates the effectiveness of the developed system.

LANDFILL SITING USING AN EXPERT SYSTEM

Rule-Base Organization

All expertise or design standards were expressed by a set of modularized rules. The main sources of the domain knowledge of the developed rule-base expert system include local and foreign regulations [e.g., Repa (1992)] case studies [e.g., *Siting* (1991)], reports [e.g., U.S. EPA (1990)], and other literature [e.g., Noble (1992)] that provides siting guidance or related expertise. The rules were first indexed by a three-part coding system based on the enforcement level, assessment factor type, and source of each rule. The coding system is similar to the object-attribute-value format proposed by Knowles et al. (1989) for ease of information retrieval and future update convenience. The first part consists of four different codes: E—essential rules, S—secondary rules, R—recommended rules, and P—particular rules. Essential rules are mostly regulations that a landfill must comply with. Secondary rules are basically regulations as well, but are not directly proposed for landfill siting or not clearly defined. Recommended rules are the conditional or heuristic rules suggested by some researchers or engineers, but not yet included in a formal regulation. Particular rules are those rules applied for a specific site or extracted from previous case-study experiences and cannot be ascribed to the foregoing three categories. The second part expresses the type of assessment factor that a rule is related to. Factors are classified into three groups: environmental (Ev), sociocultural (So), and engineering and economic (Ec). Fig. 1 shows parts of the hierarchical structure of factors. The last part of the code indicates the sources of the rules: Lr—local regulations, Lm—local reports or previous literature, Fr—foreign regulation, and Fm—foreign reports or literature. With the coding system, each rule can be quickly recognized for its associated knowledge type and source from its assigned index. It also allows for quick retrieval of related rules for a specified code. For instance, a rule indexed by "E.Ev.4.d.1.Lr" indicates that the rule is essential, environmental, for ecological conservation area, for a wetland, and from a local regulation,

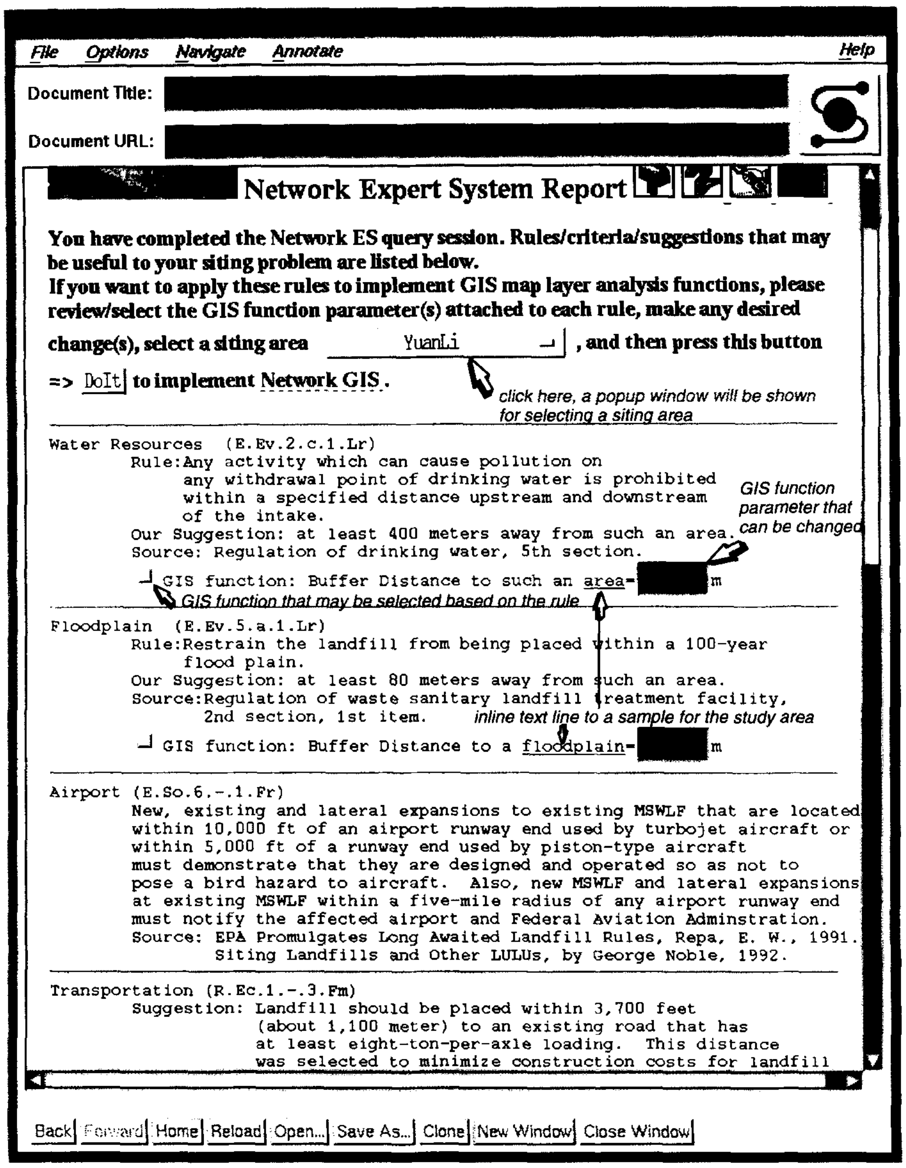

FIG. 3. Sample Result from the Network Expert Subsystem (ES → GIS)

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and the "*.Ev.4.*.*.Lr" expresses all rules extracted from local regulations for ecological conservation areas.

Expert System Development

The knowledge base of the expert system was constructed into a set of condition-action rules. The forward-chaining inferencing engine was adopted here for applying rules and deriving facts. Rules were built in the "IF-THEN" structure. Two sample rules for checking adjacent surface water and floodplain are shown in the following and their associated codes in CLIPS syntax are shown in Appendix I:

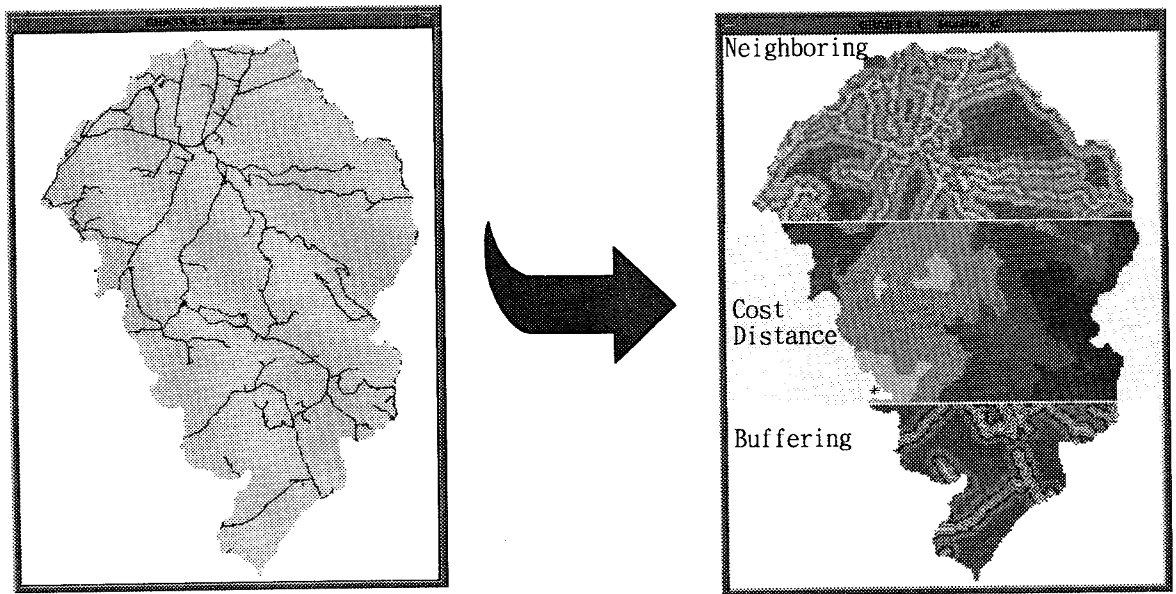
IF	(water body exists within the area)
and	(water body is stream)
and	(stream is a source for drinking water)
THEN	(landfill should not be placed 200 m from the stream)

IF	(land slope < 15%)
and	(alluvial soil)
THEN	(floodplain exists within the area)
and	(landfill should not be placed in floodplain)

Facts are input by the user from a WWW query session, as shown in Fig. 2. The expert system was also developed in line mode for execution on a ASCII terminal, although it is not described here. The expert system was built using CLIPS, a forward-chaining expert shell (Giarratano and Riley 1991). The current version is available on both Unix or personal computer platform with a window-based interface. The developers have opened the entire C source code to all users, thereby making it easy to integrate CLIPS into an existing software system with great portability.

Implementation

The current expert system built on CLIPS can be implemented as a standalone tool for the purposes of preliminary siting guidance, site evaluation, and information retrieval, other than as the supporting tool for the network expert GIS (as described later in this paper).



(a) (b)

FIG. 4. Sample Map Layer Created with GIS Analysis Functions

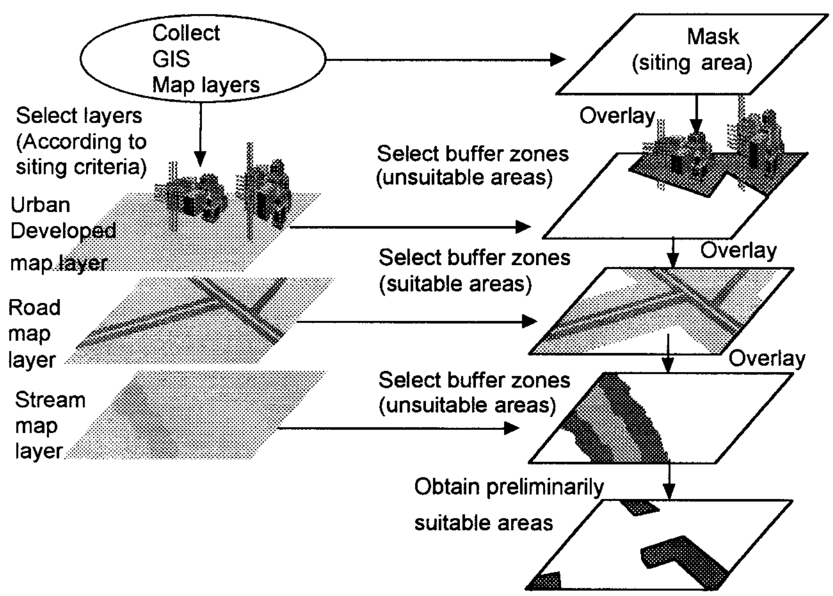


FIG. 5. Typical Procedure for Applying GIS Analysis Functions to Assist Landfill Siting

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Preliminary Siting Guidance

At the beginning of a siting process, the expert system can be used by a project manager or analyst to screen criteria and related information to establish a case-dependent siting guideline. The user is prompted by a series of possible considered factors and questions, as the WWW interface shown in Fig. 2., through all environmental, social and cultural, and engineering and economic factors for assigning suitable siting rules. If a selected rule requires any further condition, e.g., buffer zone, the user is prompted further for input of a desired value. At the end of the query session, as shown in Fig. 3, a list of selected criteria triggered from the system is provided. The list is intended for use as guidance for implementing the siting process and as the criteria used with the GIS system to find suitable areas from computerized map analyses described in the following section.

Site Evaluation

When one or several candidate sites are available after a preliminary siting process, the analyst can apply the expert system to evaluate the sites for various factors. Site suitability is checked against rules and expertise included in the expert system. According to the site characteristics, the user can select appropriate factors and answer appropriate questions in the query session. The facts provided are checked for matched rules. Matched rules are triggered for additional facts, if applicable, and more rules are triggered until no more rules match the facts. Finally, a list of assessment results and related suggestions is provided.

Information Retrieval

The analyst frequently requests detailed information for a specific siting factor when a candidate site includes some vague attributes that require further justification. For instance, the analyst may want to know the entire set of related rules for a site close within some distance of a stream. The expert system with the rule-base coding system can easily fulfill such a request.

The expert system can also be applied, in addition to the three aforementioned functions, with the GIS and the multimedia network interface described in the following sections. The system is intended to substitute experts, at least to some extent, and reduce the cost of implementing a siting process by a local government or related sectors.

Landfill Siting Using GIS

GIS is an information management system capable of providing spatial analysis tools for sorting, retrieving, and manipulating georeferenced computerized maps. GIS is widely used in various research fields including landfill siting. Lindquist (1991) stated four advantages of applying a GIS to assist landfill siting: (1) an objective zone exclusion process solely according to a set of provided screening criteria; (2) capability of handling a large amount of complex geographic data; (3) flexibility for implementing "what-if" data analysis; and (4) visualization of results and graphical presentation. GRASS (1993), a GIS developed by the U.S. Army Construction Engineering Research Laboratory, was used in this study for establishing the supporting landfill siting GIS. GRASS is pri-

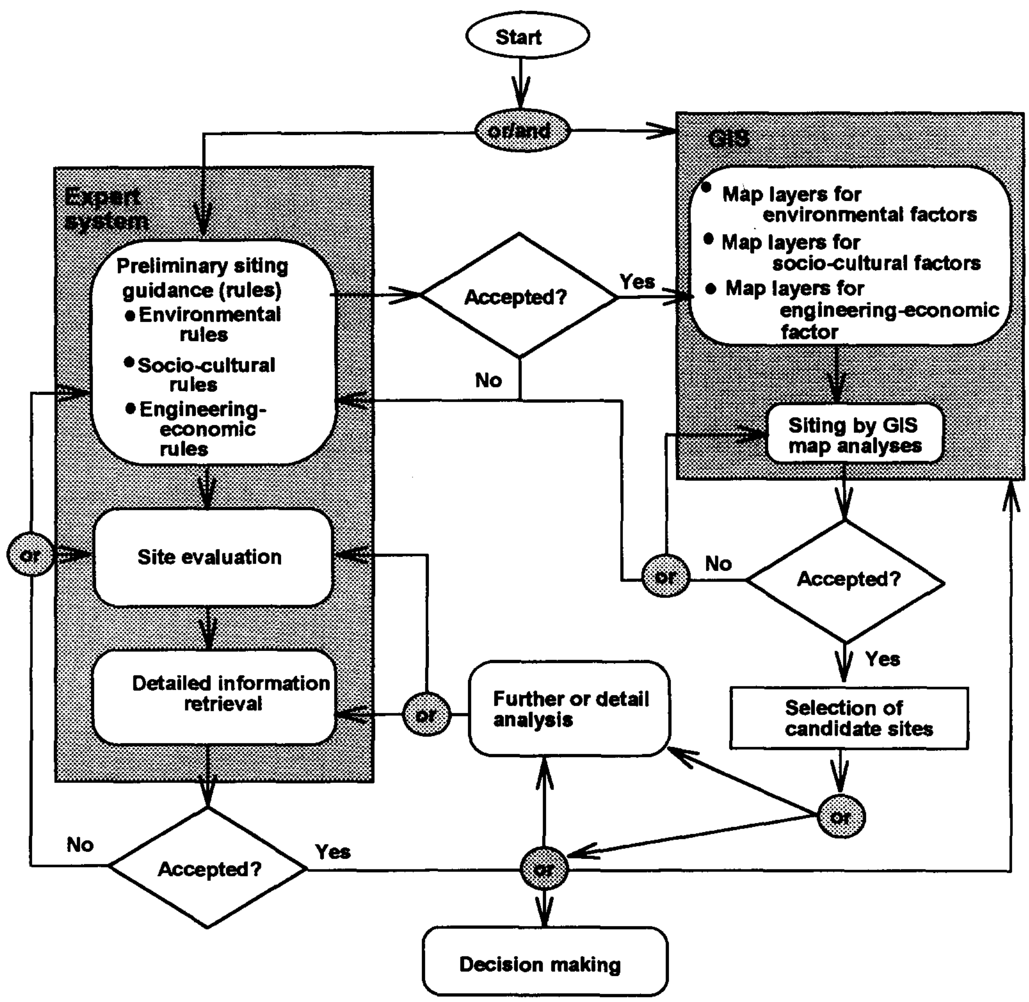

FIG. 6. Typical Procedure for Applying Developed Expert GIS to Facilitate Landfill Siting

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marily a raster-based GIS operated on a Unix Platform, although limited vector-type analyses are also available. In the raster mode, spatial data are divided into cellular georeferenced objects. Attributes that describe the features of a geographical object are expressed by numbers and are linked to the GIS cell that represents the object. A collection of connected GIS cells is called a map layer; each map layer stores a feature of an area. Various raw map layers are collected in this research for the studied area described later. The map layers include the following:

- Environmental factors: ground-water level, water-resources conservation district, stream network, natural ecology conservation area, wetland, floodplain, fault zones, soil, national park, etc.
- Sociocultural factors: airport location, urban development areas, historic and important cultural sites, population density, etc.
- Engineering and economic factors: road network, land slope, digital elevation, land cost, etc.

Other than the foregoing map layers, intermediate or analysis map layers are created by GIS map analysis functions. Major GRASS GIS map analysis functions frequently used for this siting study are described as follows for buffer zoning, neighboring computation, cost distance, and overlay by map calculation.

Buffer Zoning

A landfill is generally prohibited from being placed within a distance from some environmental sensitive areas. For instance, a landfill should be kept more than 200 m from a stream bank; or for a site > 200 m but close, within a distance of a special treatment facility, e.g., a good liner, which should be made available. The GIS buffer zoning function is suitable for applying such rules to exclude sensitive buffer areas. The bottom portion of the map layer in Fig. 4 shows a sample result obtained from this function. This function can also be applied for other factors. For example, exposure risk to a populated city is generally a function of the distance between the landfill and the city. With a similar process, buffer strips for different risk levels can be created by this function.

Cost Distance

For this function, the value of a cell in the raw map layer is regarded as the cost of moving across the cell, and the cumulative cost between two cells is determined by the least-cost path. This function produces a map layer for the cumulative cost between one or more prespecified cells, as the "*"

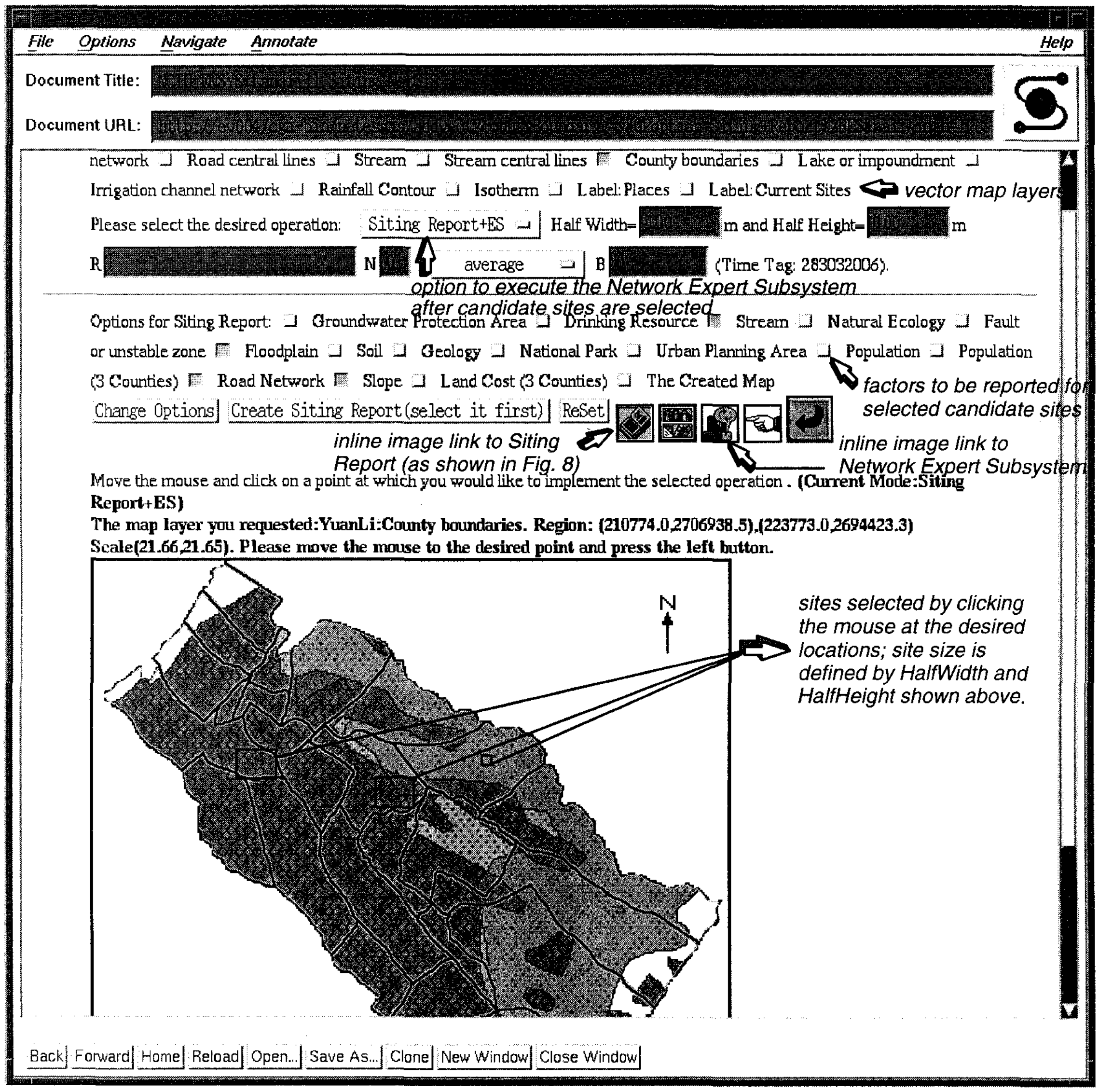

FIG. 7. Sample Network GIS Interface with Clickable Map Layer

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shown in Fig. 4(b), and all other cells from a provided map layer. This function is particularly useful for determining impacts of a site to all other cells or the efficiency of a site evaluated based on a factor. The middle portion of Fig. 4 shows an example of the map layer resulting from application of this function for a specified point to a road network. In this figure, the lighter areas indicate low transportation cost and the darker areas represent high transportation cost due to inaccessibility to a road or long distance to the point.

Neighboring Computation

Neighboring computation reassigns the value of a GIS cell by a user-specified (e.g., average, median, mode, minimum, and maximum) function based on values of the current and adjacent GIS cells. The upper portion of Fig. 4 displays the results obtained from using this function for a road network map layer. Such an analysis map layer can be used for estimating transportation cost, human activity, or land cost.

Overlay by Map Calculation

Overlay by the map calculator provided by GRASS is the most frequently used GIS function in this study. Values of features of cells are expressed by numbers in various GIS map layers. With logical or arithmetical operations, this overlay function performs arithmetic expressions on existing map layers to create a new map layer. Of the expression, each map layer is treated as a single variable and the new value of a cell is computed based on the expression from the cell values at the same georeferenced location of existing map layers.

Fig. 5 shows a typical procedure of applying the GIS with these functions. The user may first select a desired area for siting a landfill by reviewing available map layers and defining siting criteria by the user or rules triggered from the expert system. Appropriate GIS map analyses are then performed according to these criteria to create intermediate or analysis map layers. Further analysis is undertaken by other GIS map analysis functions, such as the aforementioned, to produce specific map layers for various factors and criteria. Finally, with the map calculator, the map layer for possible candidate sites is created by overlaying these intermediate and analysis map layers.

EXPERT GIS

The expert system and the GIS described are both useful in facilitating landfill siting analyses. Computerized expertise can be provided by the expert system based on user-provided facts; spatial information can be effectively processed by the GIS.

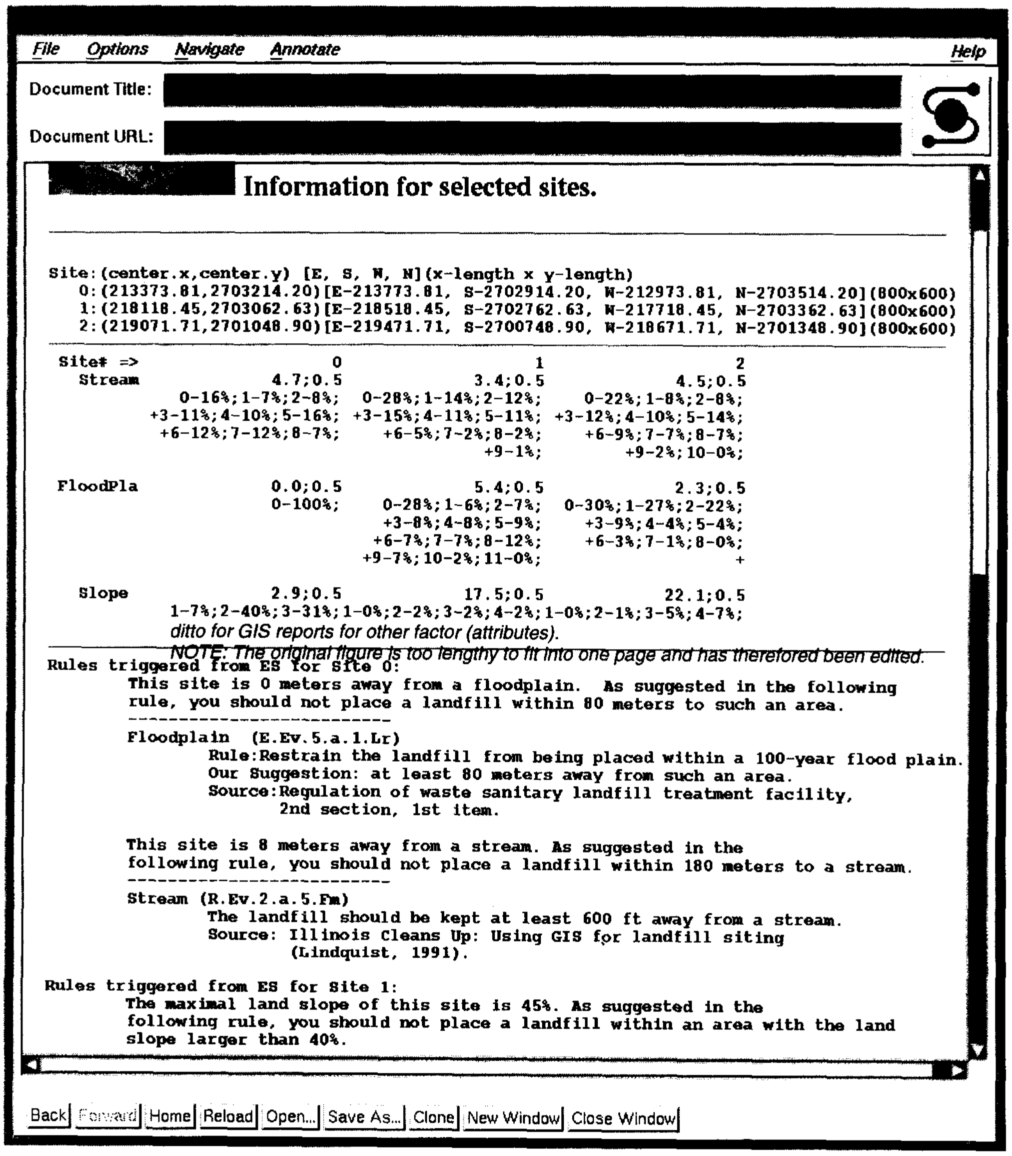

FIG. 8. Sample Report for Candidate Sites Selected by User

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To take advantage of the feature of both systems, an expert GIS is developed here by adding interface programs to integrate both systems.

Clearly defined rules triggered by the expert system are expressed by a formatted text file that is processed by developed interface programs to produce GRASS commands for implementing desired GIS map analyses. Qualitative rules are, however, not implemented with the GIS; a fuzzy expert system is currently being developed based on the fuzzy set theory (Chen and Hwang 1992) for processing such rules with the GIS. On the other hand, candidate sites preliminarily selected from GIS map analyses with facts extracted from various map layers can feed back the expert system to obtain further guidance. Again, a fuzzy GIS applying a fuzzy set method and linguistic terms to express qualitative rules is being developed, along with the fuzzy expert system to process qualitative criteria based on some fuzzy membership functions. The interface programs were coded by UNIX shell scripts and Perl (Wall and Schwartz 1991).

The expert system, GIS, and the integration of both can be applied by following the procedure shown in Fig. 6. After a siting demand is initiated, the analyst is free to use either the expert system or the GIS or both, partially or fully integrated, to explore appropriate sites for placing a landfill. Unsuitable areas are excluded using the map layer analysis functions provided by the GIS on the basis of selected siting rules triggered from the expert system.

Candidate sites can be selected by the analyst after reviewing the provided map analysis results. Those sites are assessed and compared based on considered factors. Further suggestions are provided by the expert system according to facts created from GIS map analyses, with the WWW interface provided by the system, as shown in Fig. 7. For instance, sample facts for a candidate site may be reported by map analyses as follows:

The site has 30% alluivion soil
The site is 340 m away from a stream
The maximal land slope of the site is 32%

Next, by applying these facts to the expert system, matched rules are triggered and an evaluation report is provided to the user, such as the sample shown in Fig. 8. If selected candidate sites do not satisfy siting goals or information is insufficient to justify the sites to make the final selection, the process can be repeated by triggering other sets of rules and implementing other GIS map analyses.

MULTIMEDIA NETWORK INTERFACE AND EXPERT GIS SYSTEM

Multimedia interface combines different media of text, images, graphics, audio, and video to provide a friendly environment for accessing multiple complex computer systems. Maher and Balachandran (1994) applied such a multimedia approach to facilitate the case-based structural design and concluded that multimedia technology provided tremendous flexibility for representing design information. The prototype expert GIS, although powerful, may not be widely accepted by a general user because difficulty arises when manipulating the system without previous experience in using GRASS and CLIPS. A multimedia WWW interface was therefore designed with HyperText Markup Language [(HTML); Berners-Lee (1993b)] and common gateway interface protocol [(CGI); McCool (1995)] to provide a friendly siting-analysis environment. With the interface, a general user does not require previous knowledge of GRASS or CLIPS when using the system. The prototype can be remotely accessed via network without having to install the GRASS or CLIPS on the local computer. The WWW interface can transfer not only textural, but also audio

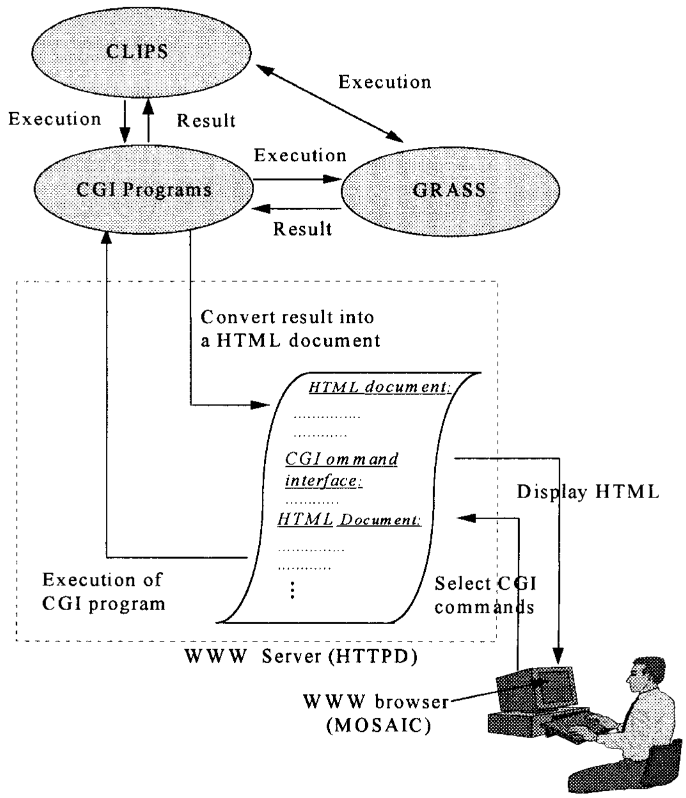

FIG. 9. Multimedia Network Interface Implementation

and graphical data. Video data are currently unavailable, although the interface also has the capability to transfer such data.

Many CGI UNIX shell scripts and Perls programs were developed to link subsystems and to allow for the evaluation of various criteria of landfill siting (locally or remotely) from a computer attached to the Internet. CGI is a standard protocol for external programs to exchange information with a WWW information server. Information is transferred by multimedia documents in HTML format. The multimedia network interface is implemented in the process shown in Fig. 9. The user utilizes a WWW browser [e.g., Mosaic, Andreessen (1993)] to access the multimedia interface and to select command options from the interface in an attempt to trigger rules in the expert system and/or to determine how to implement map analysis by the GIS. User-provided commands are fed into a CGI program that executes the expert GIS based on the commands; results of associated texts and graphical map layers are converted into HTML format and sent back to the user via network. Candidate sites can be evaluated simply by clicking a computer mouse on the desired sites shown on the graphical map displayed within the multimedia interface, as shown in Fig. 7. The prototype system is made available for remote public access, even from an international user, to reduce the cost of distribution and analysis.

DEMONSTRATION WITH A CASE STUDY

GIS map layers, analysis results, rules, and related information for a case study for Miaoli Prefecture in central Taiwan were provided with the system to demonstrate the use of the developed system. Varied map layers were collected for the area. The address of the WWW multimedia home page http://ev004.ev.nctu.edu.tw/ENGLISH/wsite/index.html is shown in Fig. 10. The prototypical system can be accessed from anywhere on the Internet. The entire system is exemplified with illustrative examples for Miaoli Prefecture. The system is divided into six major subsystems and two derived systems. The

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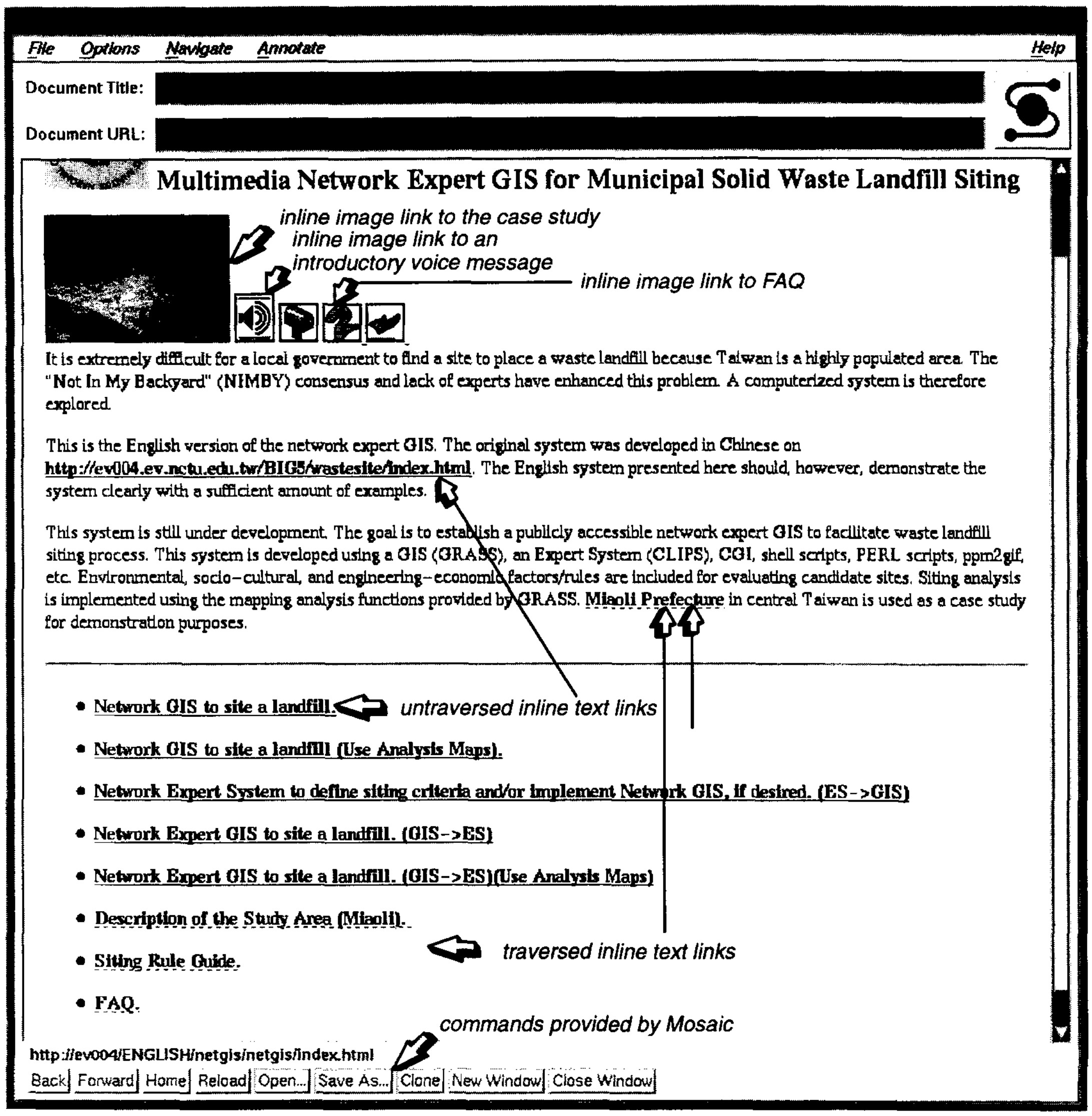

FIG. 10. WWW Home Page of Developed Prototypical System

major subsystems include network GIS, network expert system with/without GIS, network expert GIS, description of the study area with related information, siting rule guide, and frequently asked questions and answers. Two derived systems are network GIS and network expert GIS with precreated analysis map layers. Analysis map layers were created with the aforementioned GIS analysis functions from raw map layers collected for related siting factors. Most analysis map layers were created to screen out obviously unsuitable areas for placing a landfill to save the analyst's time in implementing further analysis. However, those map layers can be created with different GIS analysis functions provided in the network GIS subsystem, as shown in Fig. 11.

A description of how these map layers were created is provided with the Miaoli study area description subsystem. All subsystems are constructed into several multimedia hypertext documents—such as those shown in Figs. 2, 3, 7, 8, 10, and 11—and interconnected with numerous in-line images or text links. The following demonstration of the developed system is focused primarily on the two major subsystems of the network expert system and network expert GIS, following the procedure shown in Fig. 6.

Expert System → Rule Report or GIS

As illustrated in Fig. 6, the network expert GIS can be applied in two ways. One is to first select or define appropriate rules and criteria to screen out unsuitable areas of a siting area. The other, demonstrated in the following subsection, starts with applying GIS map layer analysis functions to obtain suitable sites; then, if desired, the expert system can be initiated to review the sites based on existing rules.

For the former application, the analyst may first select and define appropriated rules and answer the questions prompted by the expert system, with the network query interface illustrated in Fig. 2. At the end of the query session, a report of rules and suggestions triggered from the expert system is presented to the analyst, as shown in Fig. 3. In this final expert system report, options are provided to the analyst to determine whether to implement GIS analysis functions based on the selected rules for obtaining preliminary suitable areas. If this option is selected, the resulting map layer is presented to the analyst for selecting candidate sites, as shown in Fig. 7.

GIS → Expert System

Another approach of applying the developed network expert GIS is to start with the network GIS subsystem. Fig. 11 shows a sample interface of this subsystem. Appropriate GIS analysis functions are provided for each of the map layers. After providing the analyst's name and selecting a desired siting area, map layers for considered factors should be selected with desired GIS analysis functions. Other than the entire Miaoli Prefecture, several counties within the prefecture can be selected

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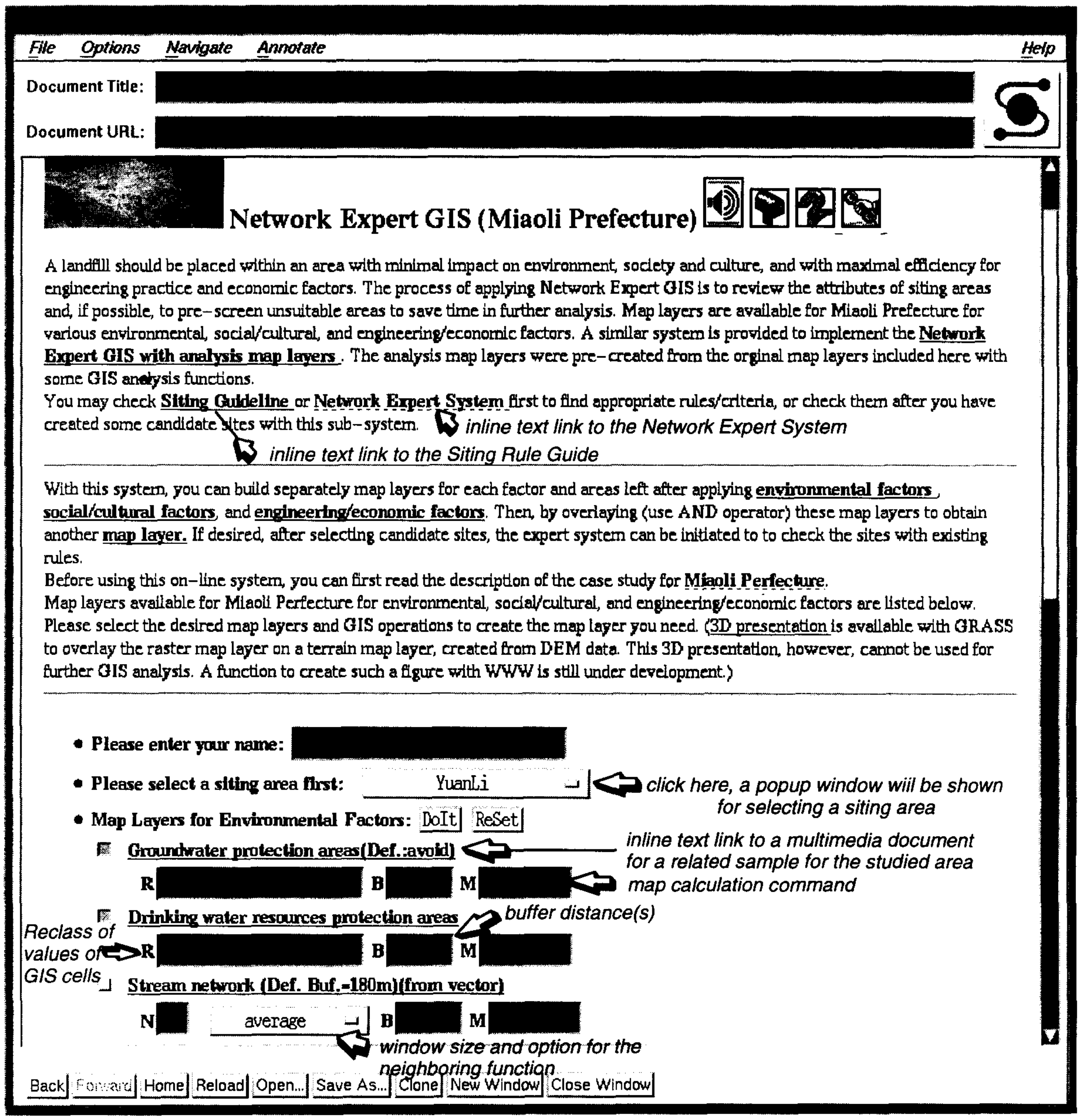

FIG. 11. Initial Interface of Network Expert GIS Subsystem (GIS → ES)

as the siting area. GIS analysis functions are executed by GRASS with CGI scripts; however, the analyst does not need to know how to use the GRASS and CGI for utilizing the system. If no GIS analysis function is provided, a simple overlay function is used. A subsequent map layer is created after the user selects desired options and functions and clicks the mouse on "DoIt" button shown in the interface. The resulting map layer is converted into a clickable image, such as the one shown in Fig. 7. On the clickable image, the analyst can review the map to select candidate sites with a computer mouse. Candidate sites can be selected by simply clicking the mouse on the desired place of the resulting map layer. Only a rectangular site can be selected; a function for selecting an irregular shape is currently being developed. The map layer shown in Fig. 7 can be magnified if it is too small to select a site or review adjacent areas. Several map layers in vector format can be displayed with the resulting map layer to assist the analyst in identifying the location of or adjacent information on a site. Related information for each of the selected candidate sites is reported to the analyst, as shown in the top portion of Fig. 8.

An option for connecting the expert system is provided with the interface. If the analyst selects the option, data extracted from GIS map analysis results for the candidate sites are converted into facts, in CLIPS format, for executing the expert system. Related rules triggered by the expert system are reported, as shown in the bottom portion of Fig. 8. If this option is not selected, only the top portion of Fig. 8 is presented.

CONCLUSION

In this work, a prototypical network expert GIS was developed to facilitate landfill-siting analyses. A publicly accessible GIS (GRASS), a low-cost expert system shell (CLIPS), and public domain network multimedia tools (HTML; CGI) were used to establish the system. This inexpensive system can be remotely accessed anytime from the Internet without having the GRASS or CLIPS installed on the local computer of each end user. All information, siting analysis results, and feedback from experts are transferred via network. This networking capability avoids the distribution cost of the system to each end user and the difficulties that might be encountered in installing and managing the system on the computer of each end user. The prototype provides an analyst not only with appropriate functions to site a landfill, but also with a good environment

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for analyzing a siting problem. Although the prototype is designed primarily for siting a landfill, many other site-selection problems for transfer stations, incinerators, recycling facilities, etc. can be implemented with a similar system.

Several other enhancements for improving the prototype are in progress at National Chiao Tung University (NCTU) for adding a fuzzy weighting system to the expert system and GIS, a mix-integer linear compactness optimization based subsystem, and a directional risk analysis tool using a ground-water and an air-pollution model. All programs developed in this study are available for noncommercial public accesses. The WWW home page address is http://ev004.ev.nctu.edu.tw/ENGLISH/wsite/index.html Information to obtain programs can be requested by sending an e-mail message to environ @ev004.ev.nctu.edu.tw

ACKNOWLEDGMENTS

The writers would like to thank a number of friends on the Internet network who helped with the use of *GRASS* in this work, and the Construction Engineering Research Laboratory, Army Corps of Engineers, Champaign, Illinois for providing the publicly accessible *GRASS*. Much appreciation to James Darrel McCauley of Purdue University for his assistance in establishing the interface programs for data exchange among *GRASS* and developed tools.

APPENDIX I. SAMPLE RULES IN CLIPS SYNTAX

```
Rule: stream rule
    (defrule water body
     (stream-dri ?dis)
     (water body exist)
     (water body is stream)
     (source for drinking water)
     =>
     [assert (distance is ?dis)]
     (printout t "select landfill placed" ?dis "m from the
        stream." crlf)

    (defrule dis
     (distance is ?dis)
     [test (< ?dis 400)]
     =>
     [assert (disallow to build)]
     [printout t "landfill should not be place" ?dis "m
        from the stream." crlf)
     (printout t "suggestion: For drinking water source,
        landfill cannot be placed within 400 m from the
        stream" crlf)
     (printout t "source: Taiwan, Chung-Chin Consultant
        Association" crlf)

Rule: floodplain rule
    (defrule floodplain)
     (slope ?slope)
     (alluvial soil)
     [test (< ?slope 15)]
     =>
     [assert (disallow to build)]
     (printout t "suggestion: landfill can't be placed in
        floodplain)
     (printout t "Taiwan EPA landfill Rules" crlf)
```

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