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A COM-based Spatial Decision Support System for Industrial Site Selection

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ABSTRACT Industrial site selection is a complex process for owners and analysts. The process involves not only technical requirements, but also economical, social, environmental and political demands that may result in conflicting objectives. Because of the compound nature of the process, it requires simultaneous use of several decision support tools such as expert systems (ES), geographic information systems (GIS), and multi-criteria decision making (MCDM) methods. This poses the challenge of integrating these decision support tools. Although current integration techniques such as loose and tight coupling have achieved considerable success, they have many limitations. To alleviate these limitations, this study used Component Object Model (COM) technology in designing a decision support system for industrial site selection. The use of the presented system was illustrated using real regional data that is maintained by a state agency.

KEYWORDS: Industrial Site Selection, GIS, ES, AHP, SDSS, and COM

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1. Introduction

Capital improvement facilities are major, long-term investments for owners and investors. Selection of an appropriate site is a critical decision that could significantly affect the profit and loss of the project under investigation. Often, site selection also significantly influences the life style of the surrounding communities. Therefore, developing expertise in industrial site selection is a big business when measured in terms of budgets committed, stature of decision-makers involved, size of communities affected, or prosperity of the community influenced.

In a site selection exercise, the analyst strives to determine the optimum location that would satisfy the proponents' selection criteria. The selection process attempts to optimize a number of objectives desired for a specific facility. Such optimization often involves numerous decision factors, which are frequently contradicting, and the process often involves a number of possible sites each has advantages and limitations.

A number of tools have been used to select proper sites for capital improvement facilities. These tools include Expert Systems (ES), geographic information systems (GIS), and Multicriteria decision-making (MCDM) methods. Although these tools have played an important role in solving site selection problems, each tool has its own limitations and could not be used alone to reach an optimum selection. This poses the challenge of integrating these decision support tools. Such integration was achieved through loose and tight coupling techniques. However, these techniques suffer many drawbacks and limitations. Thorough discussion of these techniques and their limitations can be found elsewhere (Carver 1991, Goodchild et al. 1992, Jankowski et al 1994, Jankowski 1995, Fedra 1996, Karimi and Houston 1996, Jun 1997, Kates 1997, WU 1998, Malczewski, 1999, Sui and Maggio 1999, Pullar and Springer 2000, Huang and Jiang 2002).

This paper presents a decision support system in which ES, GIS, and a MCDM method (analytic hierarchy process -- AHP) were successfully integrated by using the component object model (COM) technology to achieve software interoperability among the systems components. Interoperability is the ability of two or more software components to directly cooperate/communicate despite of their differences in programming language, interface, and execution platform (Finkelstein 1998). COM is a standard that enhances software interoperability by allowing different software components, possibly written in different programming languages, to communicate directly (Lewis 1999). COM specifies an object model and programming requirements that enable COM objects to interact with other COM objects. These objects can coexist in a single procedure/process, in independent procedures/processes, or even on remote machines. COM allows these objects to be reused at a binary level and thus third-party developers do not require access to source code, header files, or object libraries in order to extend the system (Zeiler 2001). The presented system benefits decision makers by providing an advisory expert system that recommends the proper values for the desired selection criteria (e.g., physical, environmental, geographical data, non-spatial criteria, etc.) It utilizes a GIS component to perform spatial data analysis and to identify alternative sites. The AHP component considers the analyst's prioritization of the non-spatial attributes to select the most suitable site among the identified alternatives.

2. Site Selection Process

The process of industrial site selection begins with the recognition of an existing or projected need. This recognition triggers a series of actions that starts with the identification of geographic areas of interest.

In the past, site selection was based almost purely on economical and technical criteria. Today, a higher degree of sophistication is expected. Selection criteria must also satisfy a number of social and environmental requirements, which are enforced by legislations and government regulations (SIOR and NAIOP 1990, Williams and Massa 1983, Keeney 1980, Moriarty 1980, Stafford 1979, Barbaro 1975).

Some of the issues that add to the complexity of the site selection process include existence of: a) a large number of possible sites, b) requirements that could result in contradicting objectives, c) intangible objectives that are difficult to quantify, d) diversity of stakeholders and their priorities, and f) uncertainties regarding future issues that could impact of the validity of today's decisions (Keeney 1980).

3. Site Selection Tools

For the last three decades, expert systems (ES), geographic information systems (GIS), and Multi-criteria decision-making (MCDM) techniques have been used in solving site selection problems. A brief description of the strength and weakness of each tool with regard to sitting problems is provided below.

3.1 Expert Systems

An Expert system is an intelligent computer program that uses stored knowledge and inference procedures to solve problems that require significant human expertise for their solutions (Eldrandaly 1996). Many expert systems have attempted to solve various site selection problems that are heavily dependent on human judgment and experience. Examples of such attempts are reported elsewhere (Arentz at el., 2000, Witlox and Timmermans 2000, Arentz et al 1996, Han and Kim 1990, Rouhani and Kangari 1990, Findikak 1986, Suh et al 1988). Expert systems, however, are incapable of generating solutions using spatial data. ES use symbolic knowledge to represent the human understanding of the problem on hand, which is not suited for processing spatial data. Furthermore, they lack essential capabilities such as the ability to represent buffering (i.e., defining a zone of a specified distance around features) and overlay (i.e., integration of different data layers), which are crucial to spatial data analysis (Jia 2000, Zhu and Healy 1992).

3.2 Geographic Information Systems

Geographic Information Systems (GIS) is a computer-based technology and methodology for collecting, managing, analyzing, modeling, and presenting geographic data for a wide range of applications. GIS appeared in the literature in early 1960s (Lo and Yeung 2002) and their use in sitting analysis started in late 1970s (Jones and Barron 2001, Quiambao 2001, Wright et al 1998, Murata 1996). The success of GIS in sitting problems is attributed to its ability to perform deterministic overlay and buffer operations (Carver 1991).

Although GIS possess ideal capabilities for performing spatial searches based on mappable data, they are incapable of processing multiple criteria and conflicting objectives (Carver 1991). They are also limited in integrating geographical information with subjective values/priorities imposed by the decision maker (Malczewski 1999).

3.3 Multi-Criteria Decision-Making Methods

These methods were developed to evaluate alternatives based on the decision maker's subjective values and priorities (Mollaghasemi and Pet-Edwards 1997, Jankowski 1995). They have been used to solve various site selection problems (Badri 1999, Korpela and Tuominen 1996). However, they assume homogeneity within the study area, which is unrealistic for site selection problems (Malczewski 1999).

4. Proposed Spatial Decision Making Approach

The procedural steps of the proposed approach entails two-phases as explained below and depicted in Figure 1.

Screening Phase - In this phase an ES is used to provide recommended values for the different suitability criteria and a GIS is used to determine the alternative sites that best satisfy these values. This phase consists of three steps:

(i) In the first step, the analyst declares the type of facility and defines the regions of interest.

(ii) Based on the facility type, the expert system recommends the suitability criteria (physical, environmental, geographical, engineering criteria, etc.) for site screening. The output of the ES is a set of recommended values for the suitability attributes. The decision maker has the option of either accepting or modifying these recommended values.

(iii) Using the values recommended by the ES, the GIS screens all candidate sites located in the defined region of interest. The output of this module is a list of candidate sites for further assessment.

Evaluation Phase – In this phase, AHP is utilized to identify the most appropriate site by comparing alternative sites on the basis of the non-spatial attributes. This phase consists of two steps:

(i) The values suggested by the expert system for the non-spatial evaluation factors (e.g., labor availability, costs, living conditions, tax breaks, etc) and their relative importance/weights are examined. The user has the option of accepting or modifying the ES recommendations.

(ii) The AHP component is used to further evaluate the candidate sites. The output of this module is a list of sites ordered by their level of suitability.

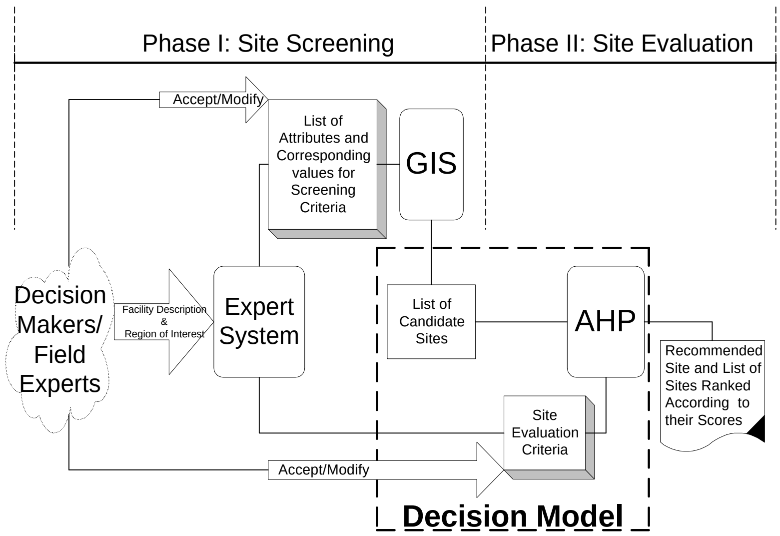

Figure 1. Framework of the proposed approach

5. Proposed Spatial Decision Support System

To implement the proposed decision-making approach, a prototype was developed using three COM-compliant commercially available software packages: Visual Rule Studio®, ArcGIS® 8.2, and Microsoft® Excel 2002. Visual Rule Studio® was used to develop the expert system component. ArcGIS® provided the GIS platform to manage the spatial data and conduct the required spatial analysis operations. Microsoft® Excel provided the tools to implement the AHP component. In addition, Microsoft® Visual Basic® 6.0 was used to provide the shell for the COM integration and to develop the system's user interface.

The proposed system was developed as a three-tire architecture. The first tier provided the ability to receive and control user's input and data presentation (Figure 2). The second tier contains the software packages (i.e., GIS, ES, and AHP). The third tier maintains the geodatabase and stores the geographical data. The following sections provide more details on the system's components.

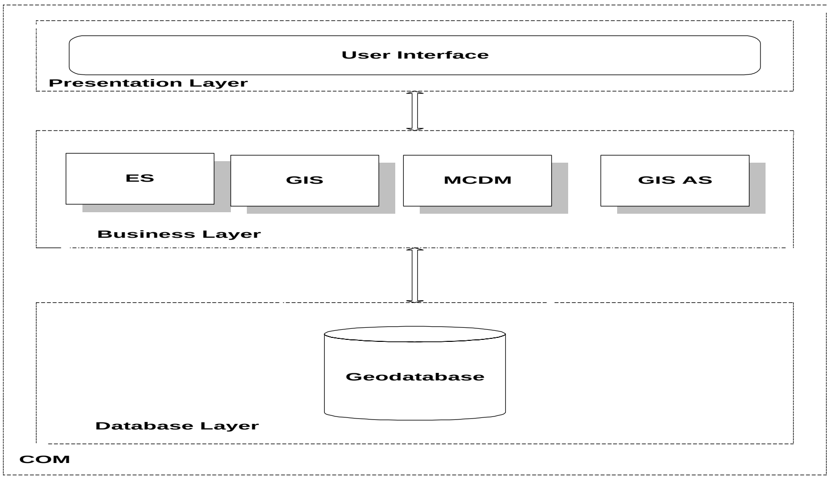

Figure 2. Three-tire architecture of the proposed system

5.1 User Interface

The user interface was developed using Visual Basic 6.0. The interface controls and integrates the software components of the system. As shown in Figure 3, this interface contains five buttons to indicate the user selection/intention (i.e., run ES, run GIS, run MCDM, activate the GIS help/advisory system, or quit the application).

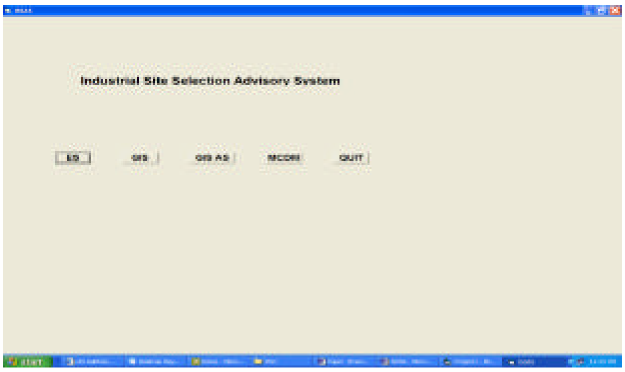

Figure 3. User Interface Screen

5.2 Expert System Module (ES)

A prototype expert system (Site Selection Criteria Advisory System- SSCAS) was developed to assist the decision maker in defining the different site selection criteria (site suitability and site evaluation criteria) that should be considered when choosing the most suitable sites for a specific industrial facility. The output of SSCAS is a set of recommended values for the suitability attributes (site screening phase) and a set of recommended values for the evaluation criteria to be used in building the AHP decision model (Evaluation phase). The decision maker has the option of accepting, rejecting or modifying these recommended values. Visual Rule Studio® (an object-oriented COM-compliant expert system development environment for windows) was used to develop the prototype expert system. Visual Rule Studio solves the problem of software interoperability by allowing the developers to package rules into component reusable objects called RuleSets. By fully utilizing OLE and COM technologies, RuleSets act as COM Automation Servers, exposing RuleSet objects in a natural COM fashion to any COM compatible client. Visual Rule Studio installs as an integral part of MS Visual Basic 6.0, Professional or Enterprise Editions, and appears within the visual Basic as an ActiveX Designer. This allows the developers to add rule objects to their existing or new Visual Basic application in much the same manner they would extend their application with a new form or ActiveX control (Figure 4). RuleSets can be complied within Visual Basic. EXE, .OCX, or .DLL executables and used in any of the ways the developers normally use such executables (RuleMachines 2002). The proposed expert system's RuleSet is deployed as an ActiveX DLL component as shown in Figure 5.

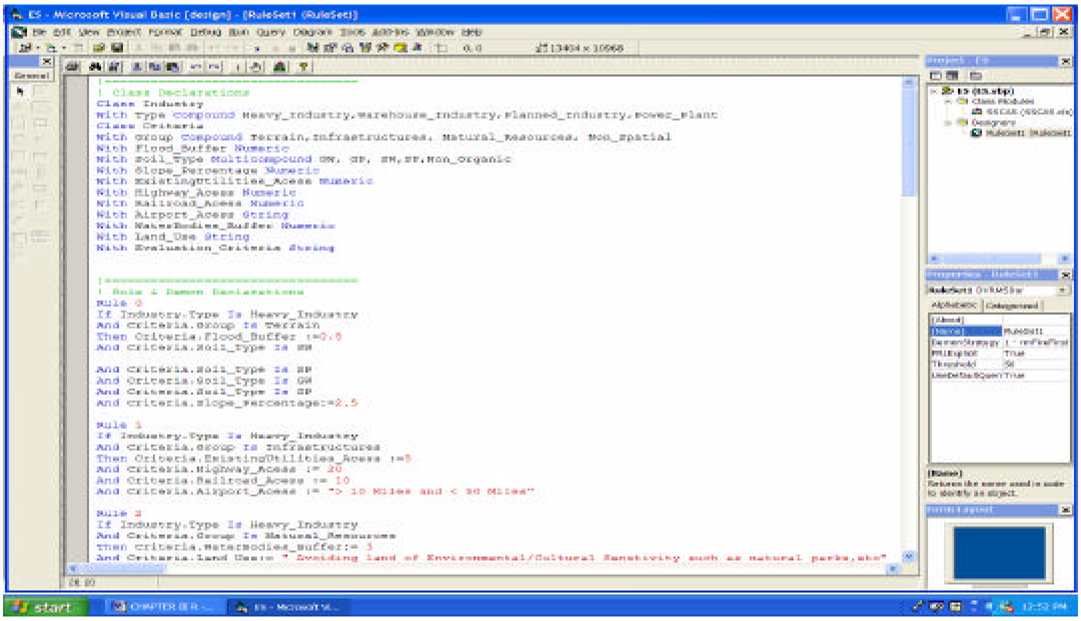

Figure 4. A fragment of the RuleSet of the proposed expert system

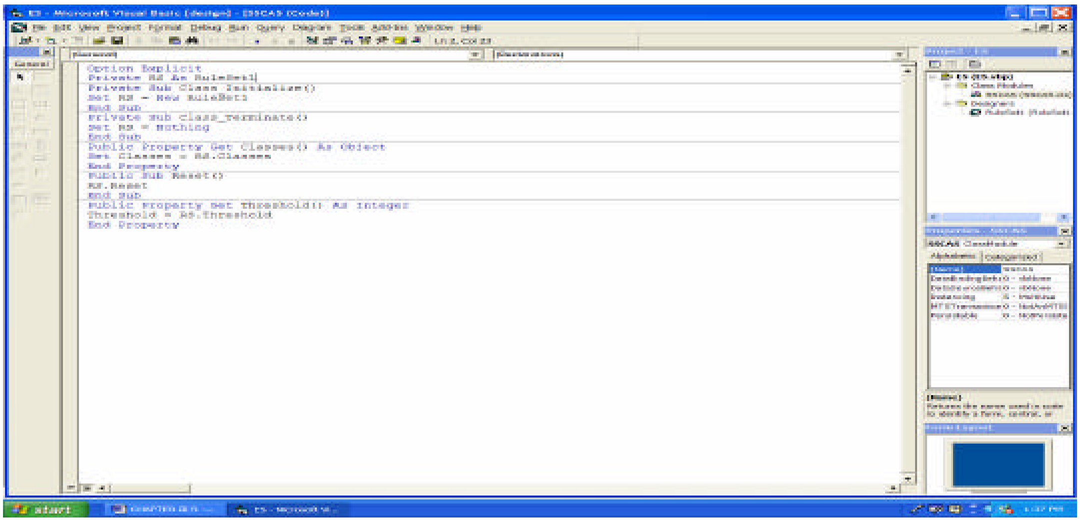

Figure 5. ActiveX DLL VB project of the proposed ES component

The Visual Rule Studio's object-oriented rules technology is a new adaptation of rule-based expert system technology. It is based on the Production Rule Language (PRL) and Inference Engines of LEVEL5 Object®. Rules in a production system consist of a collection of If Condition-Then Action statements. Each rule has a left-hand-side, or IF part, and a right-hand-side, or THEN part. The IF part of a rule comprises the conditions or antecedents of the rule. The THEN part is the action part of a rule and is often called the rule’s consequent or conclusion. The rule language of Visual Rule Studio is a high-level grammar for business problem representation and abstraction designed specifically for the specification and processing of business rules. A RuleSet may contain class declarations and methods, forward-chaining rules, backward-chaining demons, and an agenda. The grammar of the PRL uses an object-referencing notation that is the same as that of all popular language environments, such as, C++, Java, and Visual Basic. Visual Rule Studio objects are used to encapsulate knowledge structure, procedures, and values. An object’s structure is defined by its class and attributes declarations within a RuleSet. Object behavior is tightly bound to attributes in the form of facets, methods, rules, and demons. Figure 6 shows the breakdown of a Visual Rule Studio object’s structure.

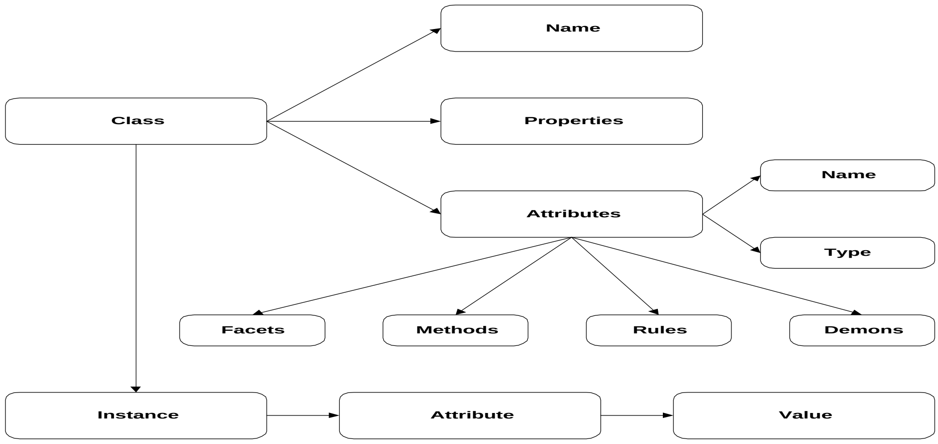

Figure 6. Structure of a Visual Rule Studio Object (adapted from RuleMachines 2002).

The inference engine of Visual Rule Studio's production system acts as the "*unseen hand*" or executor which causes processing to take place. Processing here is defined as the combining of supplied data with rules to create inferred data. It is the inferred data that is the desired end result of the production system processing. The Visual Rule Studio inference engine provides two primary problem-solving engines relevant to production systems: the forward chaining engine and the backward chaining engine. In the proposed expert system forward chaining engine is used. Starting from an initial or current set of data, the forward chaining inference engine makes a chain of inferences until a goal is reached. In forward chaining the data values of the context are matched against the IF parts, or left-hand-sides, of rules. If a rule's IF side matches the context, then the inference engine executes the Then part, or right-hand-side of the rule. If the execution of the Then part of a rule changes the data values of the context, then the inference engine repeats the entire match-execute cycle again using the new state of the context data values as a new initial set of data (Figure 7).

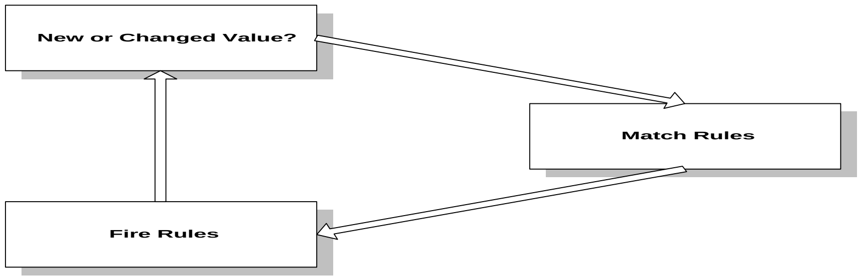

Figure 7. Forward chaining inference processing (adapted from RuleMachines 2002).

ES button is used to load the expert system user interface (Figure 8) and hence activate the proposed prototype expert system (SSCAS) using Automation technology. Microsoft-Automation is a COM-based technology that allows an application to programmatically manipulate another through a set of well-defined interfaces. A COM component that makes Automation objects available to other applications is known as an Automation server. An Automation object is just an application's object that is exposed for access by other applications. The application or programming tool (such as Visual Basic) that accesses the Automation objects provided by the Automation server is known as the Automation controller (Lewis 1999). To call the proposed expert system Automation server, the first thing that should be done is to set a reference to the ES (SSCAS.dll) type library (Type libraries are files that describe an object in a standardized format so that COM clients can find which properties and methods of an object are supported). Then using the *CreateObject* function to create an instance of the ES server. Figure 9 shows a fragment of the VB code that uses the ActiveX DLL expert system component (SSCAD.dll).

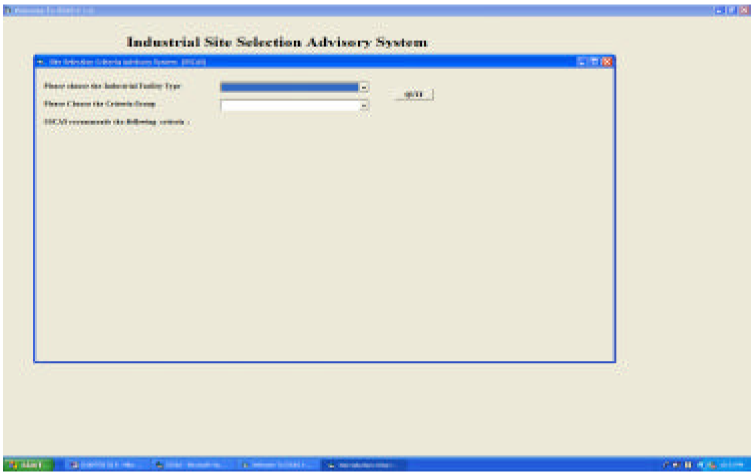

Figure 8. Proposed expert system user interface

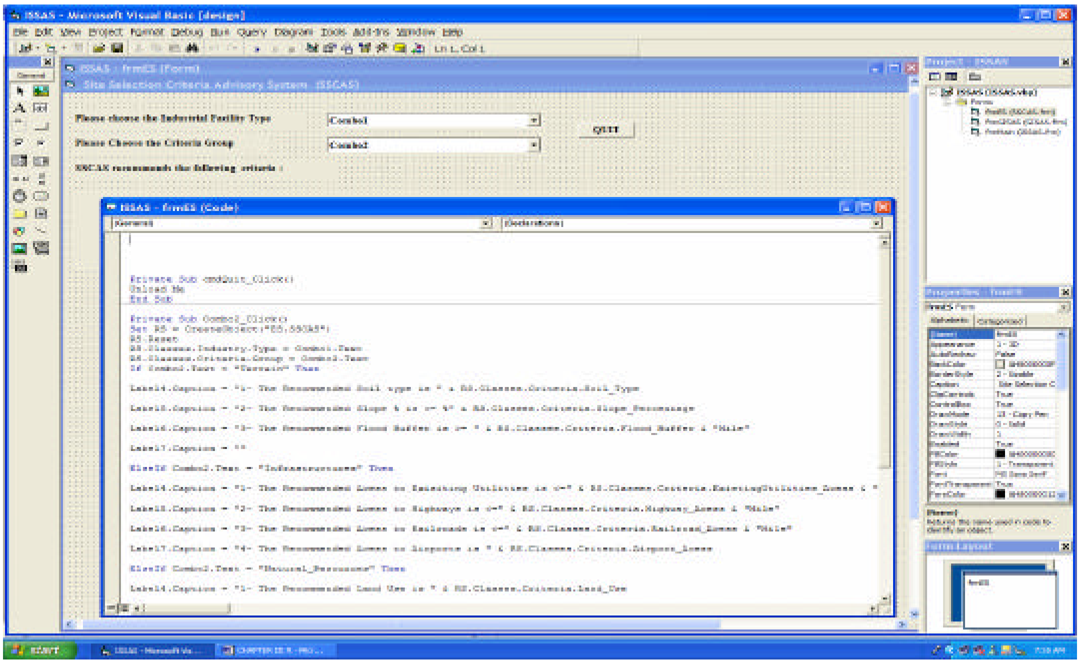

Figure 9. A fragment of the VBA Code that uses SSCAS.dll

5.3 GIS Module

ESRI ArcGIS Desktop software was used as the GIS module in the proposed system to conduct the required spatial analysis operations. It provides a scalable set of software for geographic data creation, management, integration, analysis, and presentation (ESRI 2001).

The GIS button is used to activate ArcGIS 8.2 (ArcMap Application) using Microsoft Automation Technology. Unlike other Automation servers, creating a running instance of ArcMap requires creating a Document object first, which in turns creates the application. Further information on the above can be found elsewhere (Zeiler 2001).

The following code was developed to call the ArcMap from the proposed user interface.

```
Private m_pDoc As IDocument
Private m_pApp As IApplication
Private Sub cmdStartArcMap_Click()
If m_pDoc Is Nothing Then
  ' Start ArcMap
  Set m_pDoc = New MxDocument
  ' Get a reference to the application
  Set m_pApp = m_pDoc.Parent
  ' Show ArcMap
```

```
        m_pApp.Visible = True
      End If
    End Sub
```

5.4 GIS Advisor System Module (GIS AS)

The GIS Advisory System is a help program that was written in visual basic 6. This program was developed to help the user in performing the different spatial analysis operations using ArcGIS. Whenever the user specifies a required operation, the program provides a step-by-step procedure to perform the required operation using ArcGIS. Figure 10 shows a sample of the VB code of this program.

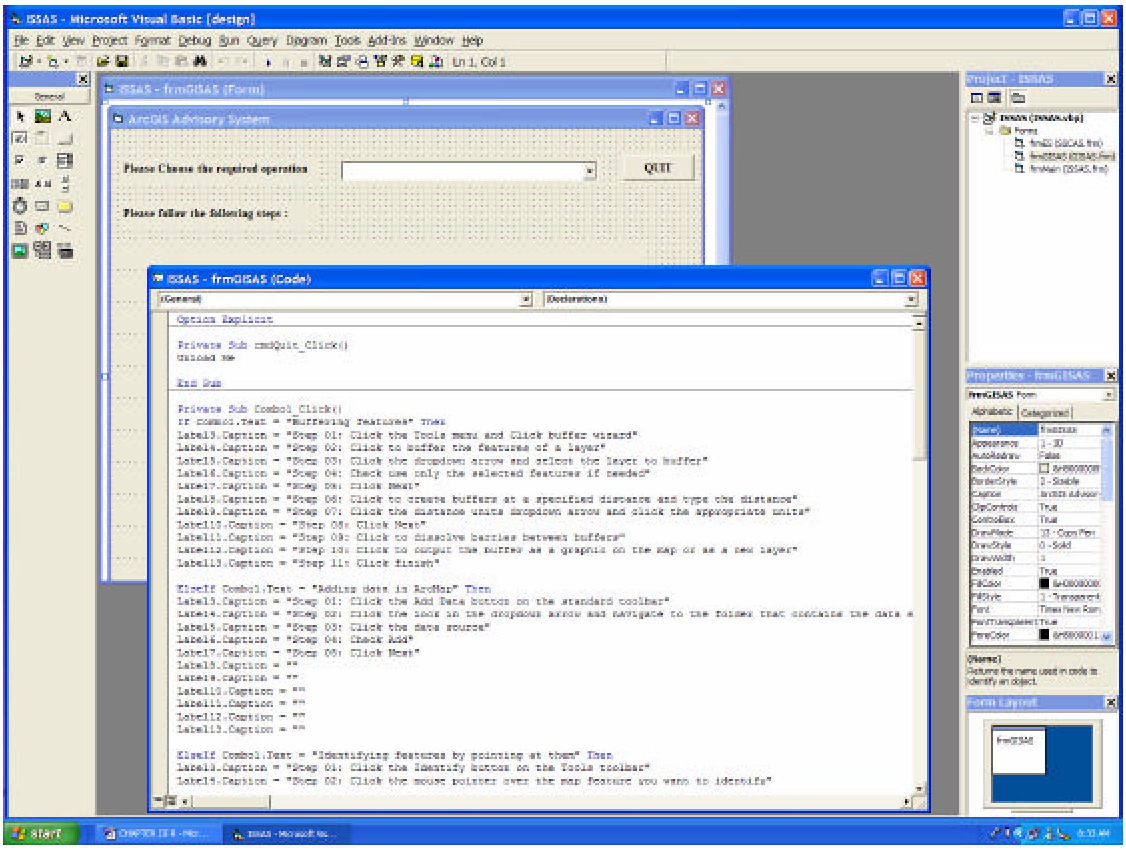

Figure 10. VB code for GIS AS

5.5 MCDM Module

After identifying the alternative sites, selection of the most appropriate site can be made by consideration of the non-spatial multicriteria imposed by the user. Analytic Hierarchy Process (AHP), a MCDM technique, is used to solve this multicriteria problem. AHP is a multicriteria decision-making technique that allows the consideration of both objective and subjective factors in selecting the best alternative. AHP is based on three principles: decomposition, comparative judgment, and synthesis of priorities. The decomposition principle requires that the decision problem be decomposed into a hierarchy that captures the essential elements of the problem. The principle of comparative judgment requires assessment of pairwise comparisons of the elements within a given level of the hierarchical structure, with respect to their parent in the next-higher level. The synthesis principle takes each of the derived ratio-scale local priorities in the various levels of the hierarchy and constructs a composite (global) set of priorities for the elements at the lowest level of the hierarchy (i.e., alternatives). Additional description on AHP can be found elsewhere (Mollaghasemi and Pet-Edwards 1997, Malczewski 1999, Winston and Albright 2001, Forman and Selly 2001).

Microsoft-Excel® and Visual Basic for Application (VBA) were used to develop an Excel application to implement the AHP technique. This Excel application involves four user forms and one code module as shown in Figure 11. Microsoft ActiveX Data Object (ADO) is used within the AHP Excel application to read the required information from the geodatabase as shown in Figure 12.

The ADO is used to read the evaluation criteria and the results of the screening phase (candidate sites) from the personal geodatabase. Figure 13 shows a sample of the VBA code written to access the different evaluation criteria from the criteria table in the geodatabase using ADO and to write them in the list of the combo box of the Site Criteria Selection user form.

MCDM Button is used to activate the AHP Excel application using Microsoft-Automation. The following VB code is written to call the Excel automation server and to use the AHP Excel application.

```
'VB code to open the MS Excel and to use the AHP Excel application
Private Sub AHP_Click()
Dim appExcel As Excel.Application
Set appExcel = New Excel.Application
Workbooks.Open FileName:=" c:\Khalid PhD\MCDM\AHP.xls "
appExcel.Visible = True
End Sub
```

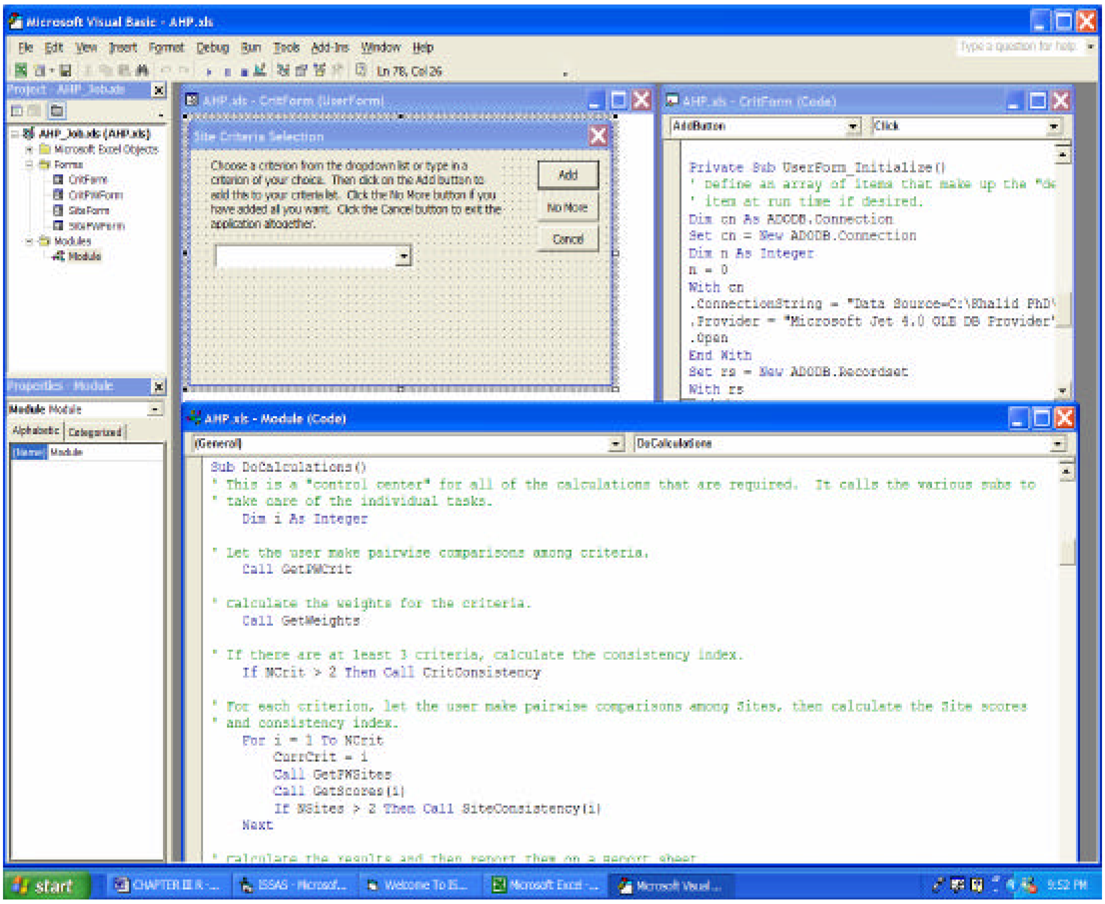

Figure 11. AHP Excel Application

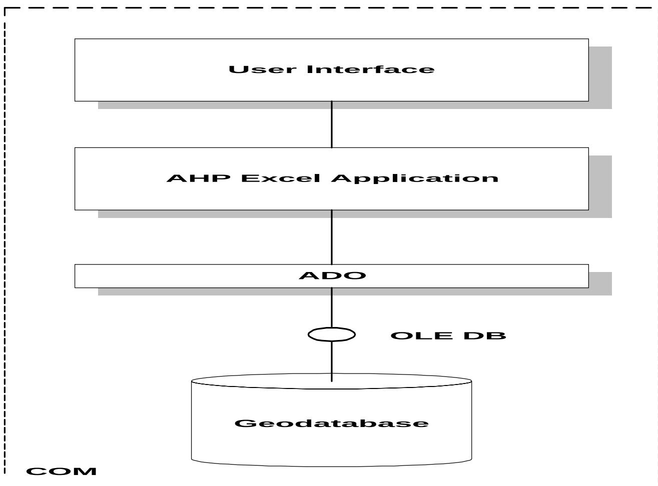

Figure 12. Using ADO to access the data from the geodatabase

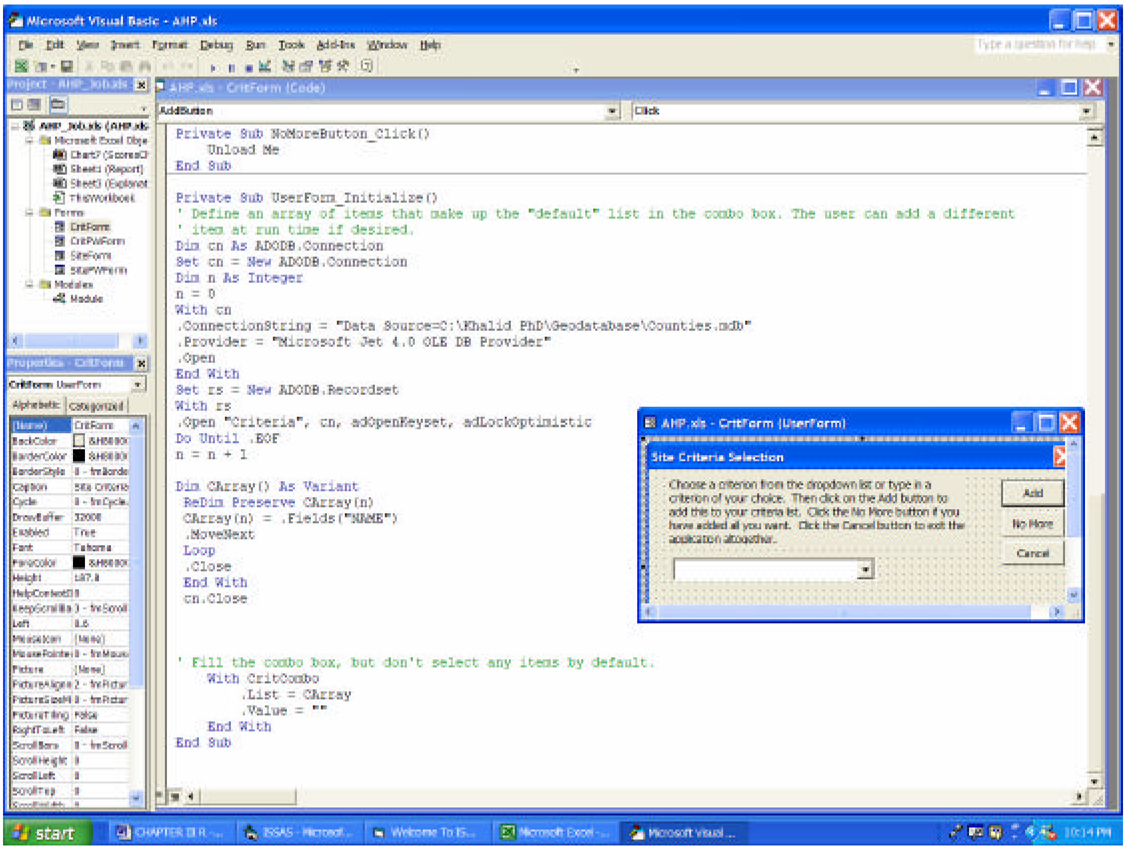

Figure 13. VBA code to deploy ADO

6. Case Study

An illustrative example is provided here through the exercise of identifying the optimum site for a power plant facility that could serve a potential metropolitan area in either Brazos or Burleson Counties. The data for this exercise were obtained from Texas Natural Resources Information System. Table 1 summarizes the physical suitability criteria recommended by the ES that had to be satisfied in the site-screening phase. ArcGIS® 8.2 was used to perform the spatial analysis required in the screening phase of candidate sites. Fourteen layers were created in ArcGIS® to address the physical suitability requirements. Upon the completion of the analysis, four candidate sites were identified as shown in Figure 14. Then AHP module was used to evaluate the four candidate sites based on the non-spatial criteria recommended by the ES (*that is, Labor Availability, Labor Cost, Utilities Costs, Taxes, Public Education, and Housing*). The results of the AHP analysis are shown in Figures 15 and 16.

Table 1. Physical suitability criteria recommended by the ES

Criteria Groups	**Items**	**Constraints**	**Values**
Terrain	Soils	Stability, Strength, Drainage	GW, GP, GM, GC, SW, SP
	Slopes	Erosion, Drainage, Constructability	<5%
	Floods	Buffer Zone to Avoid Catastrophes	>0.5 Mile
Infrastructure	Existing Utilities	Communications, Power, Water Connections	<5 Mile
	Roads	Distance to State and Interstate Roadways	20 Miles
	Railroads	Distance to Railroad Sidings	<10 Miles
	Airports	Distance to Commercial Airports	> 10 Miles and <100 Miles
Natural Resources	Land Use	Avoid land of Environ/Cultural Sensitivity	-
	Water Bodies	Buffer Zone to avoid Environmental Pollution	1 Mile

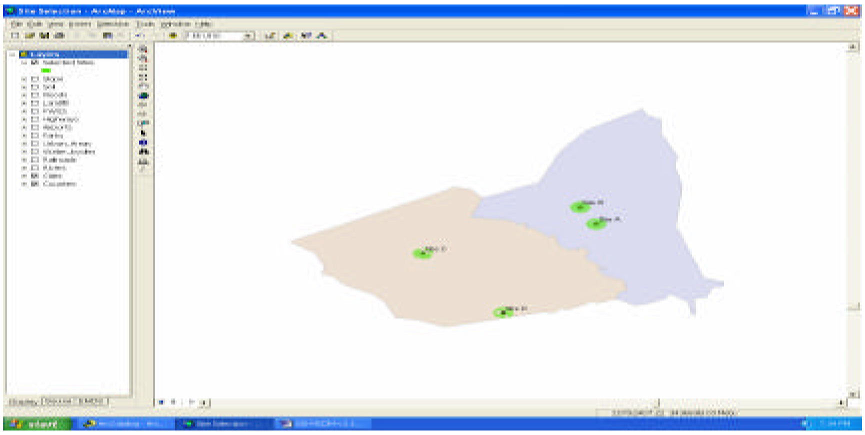

Figure 14. Results of the screening phase

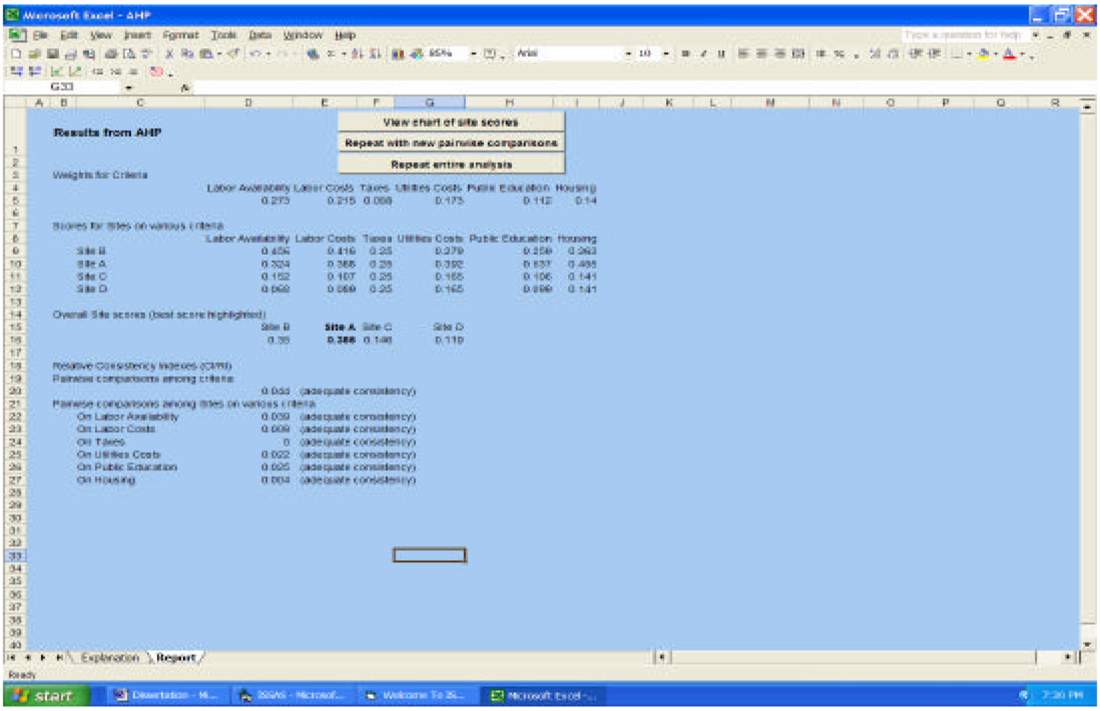

Figure 15. Results of the AHP evaluation

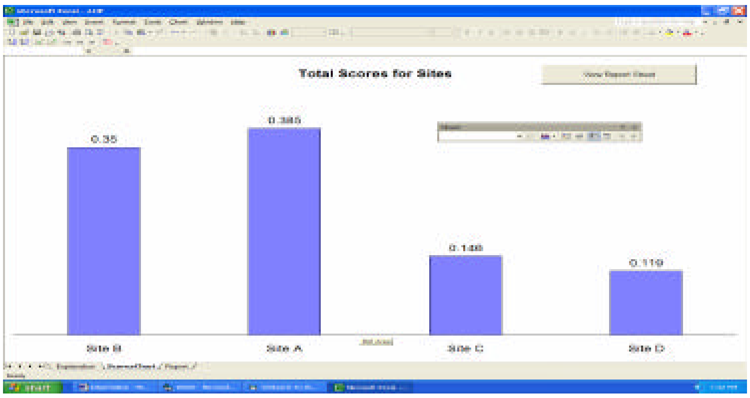

Figure 16. AHP Score Chart

7. Conclusions

Selecting the location for an industrial site is a complex process that involves physical, economical, social, environmental and political requirements that may have conflicting objectives. Such complexity necessitated the simultaneous use of several decision support tools such as ES, GIS, and AHP. Using the COM technology eliminated traditional problems encountered in the process of integrating several software packages. In this research GIS, ES, and AHP were successfully integrated using COM Technology. The integrated system could benefit developers, consultants, and planners. The system presented provided a comprehensive procedure in which three commercially available software packages were successfully integrated using COM technology. The presented system is considered a prototype because the knowledge base supporting the expert system contains only a limited range of industrial facilities and their sitting criteria and by no means a complete treatment of the problem. The prototype developed could be minimally modified to suite similar applications in other industries. This study is regarded as the first step in the long term research agenda of the authors to improve the quality of spatial decision making by designing efficient intelligent spatial decision support systems. Therefore, suggestions for improvement and issues for future research may include the following research topics: Expanding the expert system component of the proposed system (SSCAS) to include more industrial facilities and to consider more decision factors that affect the selection process; Developing an intelligent user interface to mask the complexities of GIS; Developing multi-user capabilities for group decision making; and Enabling access through the internet.

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