

Integrating GIS and MCDM Using COM Technology

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Abstract: Problems involving the processing of spatial data such as industrial site selection and land use allocation are multi-faceted challenges. Not only they often involve numerous technical requirements, but may also contain economical, social, environmental and political dimensions that may have conflicting values. Solutions for these problems involve highly complex spatial data analysis processes and frequently require advanced means to address physical suitability conditions, while considering the multiple socio-economic variables. Geographic Information Systems (GIS) and Multi-Criteria Decision-Making techniques (MCDM) are two common tools employed to solve these problems. However, each suffers from serious shortcomings. GIS, which deals mainly with physical suitability analysis, has very limited capability of incorporating the decision maker's preferences into the problem solving process. MCDM, which deals mainly with analyzing decision problems and evaluating the alternatives based on a decision maker's values and preferences, lacks the capability of handling spatial data (e. g., buffering and overlay) that are crucial to spatial analysis. The need for combining the strengths of these two techniques has prompted researchers to seek integration of GIS and MCDM. Current integration strategies (loose coupling and tight coupling) have their own limitations. Such limitations were successfully eliminated by using Component Object Model (COM) technology to integrate GIS and MCDM. An illustrative example was included to validate the capabilities of the presented integration strategy.

Keywords: GIS, MCDM, AHP, integration strategies, software interoperability.

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1. Introduction

Exercises involving spatial decision-making such as industrial site selection, land use allocation, and alike are challenges that are multi-faceted by nature. They usually involve not only technical requirements, but also economical, social, environmental and political dimensions. It is not uncommon for the decision variables to have conflicting values. Solutions for such challenges frequently involve highly complex spatial decision-making processes that require simultaneous use of several decision support tools such as Geographic Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) techniques. Integration of the capabilities of these tools is crucial to the feasibility of reaching a final solution. Therefore, developing efficient integration strategies became a high priority to many researchers.

The purpose of this paper is to present a new integration strategy that employs Component Object Model (COM) technology to assure software interoperability.

2. Background

GIS and MCDM are currently the two most common decision support tools employed to solve spatial decision-making problems. GIS is a computer-based technology and methodology for collecting, managing, analyzing, modeling, and presenting geographic data for a wide range of applications [3]. MCDM techniques are decision support tools designed to analyze decision problems, generate useful alternative solutions, and evaluate alternatives based on the decision maker's values and preferences. The general objective of these methods is to assist the decision-maker in selecting the best alternative from the number of feasible alternatives under the presence of multiple choice criteria and diverse criteria priorities [8, 15]. A literature review suggests that a number of approaches have been used in formulating MCDM tools.

In this research, the authors used the Analytic Hierarchy Process (AHP), which is one of the most common used MCDM tools. AHP is a method that allows the consideration of both objective and subjective factors in ranking alternatives. Since its introduction in the mid 1970s, AHP has been applied in a wide variety of practical applications in various

fields including economics, planning, energy policy, health, conflict resolution, site selection, project selection, and budget allocation. It assists the decision making process by allowing decision-makers to organize the criteria and alternative solutions of a decision problem in a hierarchical decision model.

The AHP decision hierarchy involves a number of steps: Identification of the goal (e. g., to select the most suitable industrial site), use of a set of decision factors/ variables/ criteria (e. g., labor climate, economic costs, and living conditions), and determination of a set of alternatives/choices (e. g., site 1, site 2 and site 3). The levels of the hierarchy may be expanded as needed (e. g., cost could be considered in terms of labor, utilities, and taxes). At the lowest level on the hierarchy we find the alternative solutions. Comparisons of the available choices/ alternatives are made on a pair-wise basis. For example in considering taxes, AHP would determine whether site 1 is “better” (i. e., has higher tax discount) than site 2 and if so, by how much? Similar comparisons are performed at each level on the hierarchy. This measure of importance/weight is done using a nine-point scale, which is widely utilized in the AHP technique. The AHP process synthesizes the alternatives’ priorities into overall set of values that indicate the relative importance of each factor at the lowest level of the hierarchy. Detailed description of MCDM and AHP is reported elsewhere [13, 15].

Nonetheless, the GIS and MCDM tools suffer from some serious shortcomings when used in decision-making problems involving spatial data. While GIS possess ideal capabilities for performing spatial searches based on mappable criteria, they are of limited use when multiple criteria with conflicting objectives are considered in the analysis [2]. GIS also have limited capabilities for integrating geographical information with subjective values and preferences imposed by decision makers. Likewise, MCDM techniques possess ideal capabilities for analyzing decision problems, generating useful alternative solutions, and evaluating alternatives based on values and preferences imposed by decision makers. However, these techniques assume a spatial homogeneity within the study area, which is unrealistic for many spatial decision-making situations [13]. Malczewski [13] suggested that there is a serious need for an explicit representation of geographical dimension in the MCDM techniques. Integration of the capabilities of the GIS and MCDM would eliminate these shortcomings and could effectively improve our abilities to solve complex spatial decision-making problems.

3. Current Integration Strategies

Attempts to integrate GIS and MCDM have been reported by many researchers [2, 8, 9, 10, 13]. These attempts could be summarized under two basic

strategies: Loose coupling and tight coupling. A brief description of each is presented below.

- *Loose Coupling*: In this approach, integration of GIS and MCDM tools is achieved through sharing data files written in ASCII or other standard file format using standard file transfer utilities [6]. At this level of integration, each tool runs independently, the user interface is kept independent on each tool, and therefore the need for additional software to provide common/overall interface platform does not exist. The only requirement, however, is that the user must ensure an appropriate format for all data files to avoid incompatibility. Obviously, the manual manipulation of the exchange files tends to be cumbersome and error prone [4, 10]. Examples of loose coupling were reported elsewhere [8, 9, 10, 12].
- *Tight Coupling*: In this approach, one system provides a user interface for viewing and controlling the entire application that may be built of several programs [16]. In GIS applications, tight coupling is usually developed within the GIS tool [7]. This integration mode relies on the use of both the macro and script programming capabilities offered by the GIS tools and conventional programming languages. A macro language (e. g., ARC/ INFO-Arc Macro Language-- AML[®]) can be used to bundle a series of individual commands in a batch mode or develop a customized user interface for a specific application. However, such languages are seldom powerful enough to handle sophisticated models. A logical alternative, therefore, is to use conventional programming languages such as C++ or FORTRAN to write modeling libraries/routines and incorporate them into the GIS tool. Several software packages were developed to allow users to develop libraries/routines that could be called from the normal pull-down menus of a particular software package [17]. Examples of tight coupling applications were reported elsewhere [19].

Compared to loose coupling, tight coupling is considered to be more effective integration method, as problems could be modeled using generic tools in a single integrated database. However, tight coupling suffers from three limitations:

1. Computations would not be optimal.
2. Difficulty in writing the model in terms of standard GIS functions.
3. Several problems could develop due to the complexity of the communication between the GIS macro language and the user-developed libraries/routines [7, 11, 13, 17].

4. Component Object Model (COM)

Although the aforementioned techniques (loose and tight coupling strategies) have achieved considerable

success in integrating GIS with MCDM tools, each has drawbacks and limitations as mentioned previously. Employing the concept of software interoperability (e. g., Component Object Model (COM)) when integrating GIS and MCDM tools could eliminate these drawbacks [7, 13]. 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 [5]. Interoperable systems, therefore, are systems composed of autonomous, locally managed, heterogeneous components that cooperate to provide complex services.

The development and deployment of successful interoperability strategies require standardization that provides the communication channels and format needed for direct exchange and integration of information [18]. The GIS community has recently embraced well-known standards to develop specifications for GIS' data and functionality exchanges. Examples of these standards include Microsoft-COM[®] and Object Management Group-CORBA[®] (Common Object Request Broker Architecture) [1]. COM is a standard that enhances software interoperability by allowing different software components, possibly written in different programming languages, to communicate directly [14]. 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 [20].

5. New Integration Strategy

The coupling strategy presented here is based on employing the COM technology for performing MCDM within a GIS. In this work, two different COM-complaint software packages are used: ESRI-ArcGIS[®] 8.2 and Microsoft-Excel[®] 2002. Visual Basic for Application (VBA) was used to develop an Excel application that implements the AHP technique. Microsoft ActiveX Data Object (ADO) was used within the AHP Excel application to read required information from the geodatabase. ADO was implemented using a set of COM-based interfaces that provide applications with uniform access to data stored in diverse information sources. The following is an example of the code written to implement ADO to read the required information from the geodatabase:
"Define an array of items that make up the "default" list in the combo box. The user can add a different item at run time if desired"

```
Dim cn As ADODB.Connection
Set cn = New ADODB.Connection
Dim n As Integer
n = 0
With cn
    ConnectionString = "Data Source =
    C:\Counties.mdb"
    Provider = "Microsoft Jet 4.0 OLE DB Provider"
    Open
End With
Set rs = New ADODB.Recordset
With rs
    Open "Criteria", cn, adOpenKeyset,
    adLockOptimistic
    Do Until .EOF
        n = n + 1
        Dim CArray () As Variant
        ReDim Preserve CArray (n)
        CArray (n) = .Fields ("NAME")
        MoveNext
    Loop
Close
End With
cn.Close

"Fill the combo box, but don't select any items by
default"
With CritCombo
    List = CArray
    Value = ""
End With
End Sub
```

In the case of a problem requiring that the GIS further manipulate the results of the AHP program, this could be accomplished easily by using the ADO to write back the AHP results in the Geodatabase. We used *Microsoft-Automation* to manipulate the AHP-Excel application from within the ArcGIS[®]. *Microsoft-Automation* is a COM-based technology that allows an application to programmatically manipulate another through a set of well-defined interfaces. A VBA macro was written to call the Excel *automation server* and to use the AHP Excel application. An *automation server* is a COM component that makes *automation objects* available to other applications. An *automation object* is just an application's object (e. g., AHP-Excel application) that is exposed for access by other applications. The following ArcGIS[®] macro (VBA macro) was written for the system presented:

```
"VBA macro to open the MS Excel and to use the
AHP"
Excel application
Sub AHP ()
    Dim appExcel As Excel.Application
    Set appExcel = New Excel.Application
```

```
Workbooks.Open FileName:= "c:\AHP.xls"
appExcel.Visible = True
End Sub
```

This macro uses the process of early binding, which simply means that variables were declared with an explicit type and thus bound to that type. Some advantages of early binding is its potential improvement in run-time performance, the ability to use automatic code completion feature and improved code readability. Early binding requires a reference to a Dynamic Link Library (DLL) or object library containing information about the application's objects, properties and methods. In this manner, this macro can then be used to create a new instance of the application. Once the instance of Excel is created, data can freely pass between ArcGIS® and Excel® to perform the required analysis.

6. Illustrative Example

The process of site selection entails two phases:

1. Site screening (i. e., identification of candidate sites from a broad geographic area using preset selection factors).
2. Site evaluation (i. e., in depth examination of each candidate site).

Table 1 summarizes the physical suitability criteria that had to be satisfied in the site-screening phase. Also, additional evaluation criteria were used in the site evaluation phase: Labor availability, labor cost, utilities costs, taxes, public education, and housing. These were the factors used by the AHP module to rank the sites that satisfied the physical suitability requirements. Data for this exercise were obtained from Texas Natural Resources Information System in order to determine the optimum site for a power plant that could serve potential metropolitan areas in either Brazos or Burleson Counties.

The proposed coupling strategy was used to ingrate the GIS-MCDM system to solve a site selection problem. ArcGIS® 8.2 was used to perform the spatial analysis required in the screening phase of candidate sites. Fifteen 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 1. The ADO was used to read the required information from the geodatabase (i. e., the candidate sites and their evaluation criteria). Then the AHP application was used to perform the evaluation/ calculations for ranking the possible candidate sites. The results of the AHP analysis are shown in Figures 2 and 3.

7. Conclusions

Simultaneous use of several decision support tools such as Geographic information systems and multi-

criteria decision-making techniques is necessary for reaching optimum solutions for highly complex spatial decision-making problems. This presents the challenge of integrating these decision support tools. Therefore, developing efficient integration strategies became a high priority to many analysts to facilitate the use of such tools and to increase the feasibility of reaching the optimum solution.

A new integration (coupling) strategy was developed to integrate GIS and AHP, two major tools commonly used in solving special decision-making problems. The proposed strategy employed the Component Object Model (COM) technology, to assure software interoperability. An example was presented to validate the proposed coupling strategy and illustrate the proposed system capabilities. This work is intended as the first step toward a fully integrated scalable intelligent spatial decision support system that provides a user-interface to allow the analyst to use the required various tools without the need for in-depth knowledge of the details of each tool.

Table 1. GIS physical suitability criteria.

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 water bodies	Avoid land of environ/ cultural sensitivity buffer zone to avoid environmental pollution	- 1 Mile

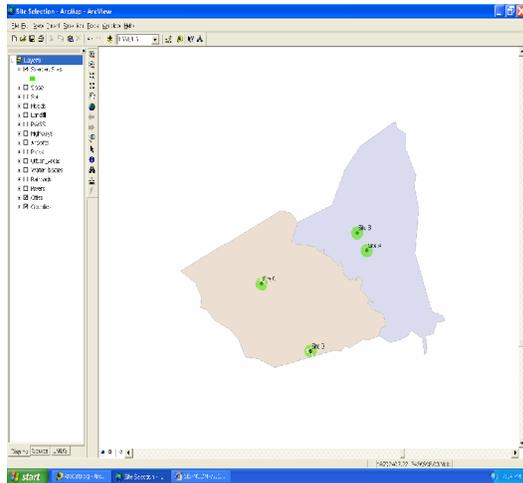


Figure 1. Selected sites satisfying physical suitability criteria.

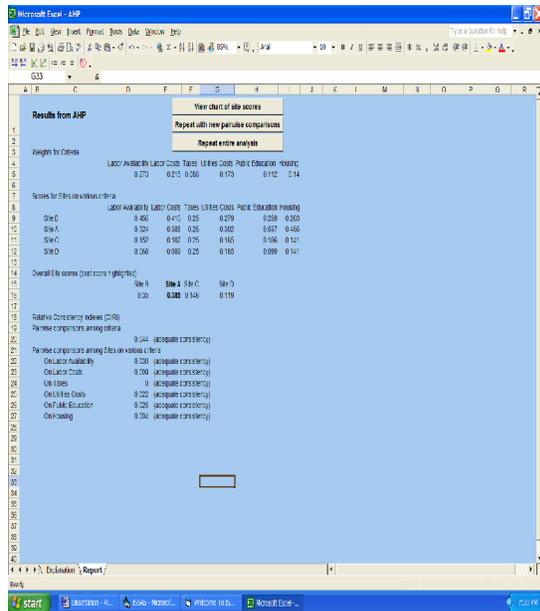


Figure 2. AHP results report.

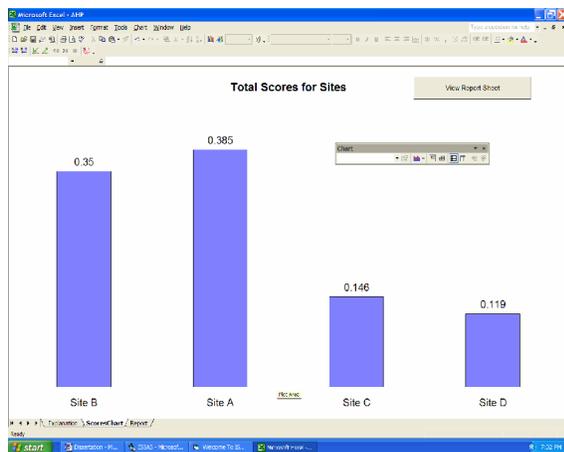


Figure 3. AHP score chart.

References

- [1] Bian L., "Component Modeling for the Spatial Representation of Wildlife Movements," *Journal of Environmental Management*, vol. 59, pp. 235-245, 2000.
- [2] Craver S., "Integrating Multi-Criteria Evaluation with Geographical Information Systems," *International Journal of Geographical Information Systems*, vol. 5, pp. 321-339, 1991.
- [3] Davis B. E. and Davis B., *GIS: A Visual Approach*, World Press, 2001.
- [4] Fedra K., "Distributed Models and Embedded GIS: Integration Strategies and Case Studies," in Goodchild M., Steyeart L., and Parks B. (Eds). *GIS and Environmental Modeling: Progress and Research Issues*, GIS World Books, Fort Collins, USA, pp. 413-417, 1996.
- [5] Finkelstein A., "Interoperable Systems: An Introduction," in Kramer B., Papazoglou M., and Schmidt H. (Eds), *Information Systems Interoperability*, Research Studies Press, England, pp. 1-9, 1998.
- [6] Goodchild M., Haining R., and Wise S., "Integrating GIS and Spatial Data Analysis: Problems and Possibilities," *International Journal of Geographical Information Systems*, vol. 6, no. 5, pp. 407-423, 1992.
- [7] Huang B. and Jiang B., "AVTOP: A Full Integration of TOPMODEL into GIS," *Environmental Modeling and Software*, vol. 17, no. 3, pp. 261-268, 2000.
- [8] Jankowski P., "Integrating Geographical Information Systems and Multiple Criteria Decision-Making Methods," *International Journal of Geographical Information Systems*, vol. 9, no. 3, pp. 251-273, 1995.
- [9] Jankowski P. and Richard L., "Integration of GIS-Based Suitability Analysis and Multicriteria Evaluation in a Spatial Decision-Support System for Route Selection," *Environment and Planning B: Planning and Design*, vol. 21, pp. 323-340, 1994.
- [10] Jun C., "Incorporating Decision Preferences into an Expert Geographic Information System for Industrial Site Selection," *PhD Dissertation*, Texas A&M University, College Station, USA, 1997.
- [11] Karimi H. and Houston B., "Evaluating Strategies for Integrating Environmental Models with GIS: Current Trends and Future Needs," *Computers, Environment, and Urban Systems*, vol. 20, no. 6, pp. 413-425, 1996.
- [12] Kates S., "Retail Site Selection Using GIS and MCDM: A Case Study of the Toronto Retail Jewellery Industry," *MA Thesis*, University of Western Ontario, Canada, 1997.

- [13] Malczewski J., *GIS and Multi-Criteria Decision Analysis*, New York, John Wiley & Sons, 1999.
- [14] Microsoft, *Microsoft Developer Network Online Documentation*, MSDN Library, 2000.
- [15] Mollaghasemi M. and Pet-Edwards J., *Making Multiple-Objective Decisions*, IEEE Computer Society Press, USA, 1997.
- [16] Pullar D. and Springer D., "Towards Integrating GIS and Catchment Models," *Environmental Modeling and Software*, vol. 15, pp. 451- 459, 2000.
- [17] Sui D. and Maggio R., "Integrating GIS with Hydrological Modeling: Practices, Problems, and Prospects," *Computers, Environment, and Urban Systems*, vol. 23, pp. 33-51, 1999.
- [18] Vckovski A., *Interoperable and Distributed Processing in GIS*, Taylor and Francis, London, 1998.
- [19] Wu F., "SimLand: A Prototype to Simulate Land Conversion Through the Integrated GIS and CA with AHP-Derived Transition Rules," *International Journal of Geographical Information Science*, vol. 12, no. 1, pp. 63-82, 1998.
- [20] Zeiler M., *Exploring ArcObjects-ESRI*, Relands, CA, USA, 2001.



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