Developing a GIS-Based MCE Site Selection Tool in ArcGIS Using COM Technology

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Abstract: *Site selection is a complex process for owners and analysts. This process involves not only technical requirements, but also economical, social, environmental and political demands that may result in conflicting objectives. Site selection is the process of finding locations that meet desired conditions set by the selection criteria. Geographic Information Systems (GIS) and Multi Criteria Evaluation techniques (MCE) are the two common tools employed to solve these problems. However, each suffers from serious shortcomings and could not be used alone to reach an optimum solution. This poses the challenge of integrating these tools. Developing and using GIS-based MCE tools for site selection is a complex process that needs well trained GIS developers and analysts who are not often available in most organizations. In this paper, a GIS-based multicriteria evaluation site selection tool is developed in ArcGIS 9.3 using COM technology to achieve software interoperability. This tool can be used by engineers and planners with different levels of GIS and MCE knowledge to solve site selection problems. A typical case study is presented to demonstrate the application of the proposed tool. In addition, the paper presents a comprehensive discussion of the site selection process and characteristics.*

Keywords: *Site selection, GIS, MCE, AHP, OWA, AHP-OWA.*

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1. Introduction

Site selection is a critical decision made by private and public owners that affects a wide range of activities ranging from land use planning to sitting of industrial facilities. 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 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 area 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. As a result, 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. Geographic Information Systems (GIS) and Multi Criteria Evaluation techniques (MCE) are the two common tools employed to solve these problems. 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 solution. GIS, which deals mainly with physical suitability analysis, has very limited capability of incorporating the decision maker's preferences into the problem solving process. MCE, 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 MCE. 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 [5]. To alleviate the drawbacks of these techniques, the recent technological advances in software engineering, such as Component Object Model (COM) technology, are now being utilized to achieve the required software interoperability.

There is now a well-established body of literature on integrating GIS and MCE techniques for solving site selection problems (see for example [1, 2, 3, 6, 12, 13, 14, 19, 20]). However, developing and using GIS-based MCE tools for site selection is a complex process that needs well trained GIS developers and analysts to carry out these projects. Due to insufficient experts and limited funds for training in most organizations, an inappropriate site may be selected as a result. In this study, a GIS-based MCE tool is developed to overcome the above limitations. The proposed tool is developed as a toolbar in ArcGIS9.3, a widely used GIS software package, using COM technology. This tool pursues two major tasks:

1. Customizing and categorizing the existing built-in ArcGIS tools required for solving the siting problems.
2. Developing a MCE toolbox that contains three of the most commonly used techniques for solving the siting problems (Analytical Hierarchy Process (AHP), Order Weighted Averaging (OWA), and the extension of AHP using OWA operators).

2. Site Selection Process and Characteristics

Since the topic of the paper is rather specialized, a brief description of the site selection process and characteristics are described first. The process of site selection begins with the recognition of an existing or projected need to meet new or growing markets. This recognition triggers a series of actions that starts with the broad screening of geographic areas of specific interest that meet the desired physical suitability criteria. 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 additional decision parameters as social and environmental aspects today are enforced by legislations and government regulations [5]. Some of the issues that add to the complexity of the site selection process include:

a. Large numerous of possible sites.
b. Requirements that could have contradicting objectives.
c. Intangible objectives that are difficult to quantify.
d. Diversity of stakeholders.
e. Uncertainties regarding future issues that impact of the validity of the decision [5].

To fully appreciate the complexity of the site selection process, a detail description of the decision factors characterizing sitting problems is provided elsewhere [5, 6].

3. Software Interoperability and COM Technology

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 [11]. 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 [21]. The GIS community has recently embraced well-known standards, such as Microsoft-COM technology, to develop specifications for GIS data and functionality exchanges. COM is a standard that enhances software interoperability by allowing different software components, possibly written in different programming languages, to communicate directly. 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 [17]. Leading commercial GIS software vendors have adopted COM in their software design. For example, ArcGIS Desktop (an integrated suite of professional GIS application) developed by Environmental Systems Research Institute (ESRI), is based on a common modular component-based library of shared GIS software components called ArcObjects. ArcObjects includes a wide variety of programmable components which aggregate comprehensible GIS functionality for developers [4, 5].

4. Proposed GIS-Based MCE Framework for Solving Site Selection Problems

GIS-based MultiCriteria Evaluation (GIS-MCE) can be defined as a process that integrates and transforms geographic data (map criteria) and value judgments (decision maker's preferences) to obtain overall assessment of the decision alternatives [15]. The procedural steps of the proposed GIS-based MCE approach entails five steps as explained below and depicted in Figure 1.

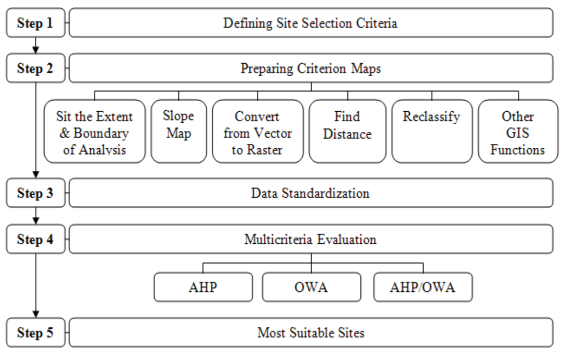

Figure 1. GIS-based MCE approach.

- *Step 1. Defining Site Selection Criteria:* In the first step, the analyst declares the type of facility and defines the regions of interest. Based on the facility type and the regions of interest, the analyst defines the siting criteria.

- *Step 2. Preparing Criterion Maps:* After defining the siting criteria, the analyst prepares the criterion maps based on the predefined siting criteria. Central to spatial multicriteria decision making is the fact that an attribute can be represented in a GIS database as an attribute (criterion) map layer. A criterion map represents the spatial distribution of an attribute that measures the degree to which its associated objective is achieved [18]. The procedure for generating criterion maps is based on different GIS functions.
- *Step 3. Data Standardization:* Given a variety of scales on which each criterion can be measured, MCE requires that values contained in the various criterion map layers be transformed to comparable units (standardized to a common scale). Two common approaches to standardizations are linear and nonlinear. The simplest formula for linear standardization is called the maximum score procedure. The formula divides each raw criterion value by the maximum criterion value as shown in equation 1:

$$x'_{ij} = \frac{x_{ij}}{x_j^{\max}} \quad (1)$$

where x'_{ij} is the standardized score for the ith decision alternative and the j^{th} criterion, x_{ij} is the raw data value, and $x_j^{\max}$ is the maximum score for the j^{th} criterion. The values of standardized scores can range from 0 to 1 and are linearly related to the raw data values. In the nonlinear standardization procedure, the standardized criterion value is computed by dividing the difference between a given criterion's raw data value and the minimum value of the value range as shown in equation 2:

$$x'_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \quad (2)$$

Detailed descriptions of standardization approaches are reported elsewhere [15, 18].

- *Step 4. Multicriteria Evaluation:* A number of MCE techniques have been implemented in the GIS environment for tackling site selection problems. AHP, OWA, and the extension of AHP using OWA operators are three of the most commonly used techniques for solving the siting problems.

4.1. Analytic Hierarchy Process (AHP)

Is one of the most common used MCE 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 by Thomas Saaty, AHP has been applied in a wide variety of practical applications in various fields including site selection. 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., 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 AHP is reported elsewhere [15].

4.2. Ordered Weighted Averaging (OWA)

Is a family of multicriteria aggregation procedures. It has been developed in the context of fuzzy set theory. OWA involves two sets of weights: criterion, or importance weights and order weights. A criterion weight is assigned to a given criterion or attribute for all locations in a study area to indicate its relative importance, according to the decision-maker's preferences, in the set of criteria under consideration. The order weights are associated with the criterion values on a location-by-location basis. They are assigned to a location's attribute values in decreasing order with no consideration of the attribute source of each value. The re-ordering procedure involves associating an order weight with a particular ordered position of the weighted attribute values. The first order weight is assigned to the highest weighted attribute values for each location, the second order weight to the second highest values, and so on. The nature of the OWA procedure depends on some parameters, which can be specified by means of fuzzy (linguistic) quantifiers. The GIS-based OWA provides a tool for generating a wide range of decision strategies by specifying an appropriate linguistic quantifier and the associated set of the OWA weights. The position of the OWA operator can be identified on the continuum ranging from the all quantifier to the at least quantifier. There are two commonly used measures for identifying the position of the OWA operator on the continuum: the tradeoff and ORness measures. The tradeoff is a measure of compensation (criterion substitutability). It indicates the degree to which a poor performance on one criterion can be compensated by a good performance on other criteria under consideration. The position of OWA on the continuum between the quantifier all and at least one can also be identified by specifying the degree of ORness. It measures the degree to which an OWA operator is similar to the logical OR (or the at least one quantifier) in terms of its combination behavior [1, 16, 22, 23].

4.3. AHP-OWA

Yager and Kelman [23] introduced an extension of the AHP using OWA operators (AHP-OWA), suggesting that the capabilities of AHP as a comprehensive tool for decision making can be improved by integration of the fuzzy linguistic OWA operators. The inclusion of AHP and OWA can provide a more powerful multicriteria decision- making tool for structuring and solving decision problems including spatial decision problems.

5. Developing the Site Selection Tool

To implement the proposed GIS-based MCE approach for site selection, a site selection tool is developed as a toolbar within ArcGIS desktop to help the GIS analysts to solve complex site selection problems. ArcGIS Desktop is a scalable set of state-of-the-art software for geographic data creation, management, integration, analysis, and presentation. ArcGIS Desktop includes a suite of integrated applications: ArcMap, ArcCatalog, and ArcToolbox. Detailed descriptions of ArcGIS are reported elsewhere [7, 9]. ArcGIS Desktop is built on a technology framework known as ArcObjects. ArcObjects is a set of platform-independent software components, written in C++, which provides services to support GIS applications on the desktop in the form of thick and thin clients and on the server. ArcObjects makes use of the Microsoft COM. COM is often thought of as simply specifying how objects are implemented and built in memory and how these objects communicate with one another. Code running under the control of the .NET Framework is called managed code; conversely, code executing outside the .NET Framework is called unmanaged code. COM is one example of unmanaged code. The .NET Framework interacts with COM via a technology known as COM Interop. For COM Interop to work, the Common Language Runtime (CLR) requires metadata for all the COM types. This means that the COM type definitions normally stored in the type libraries need to be converted to .NET metadata. This is easily accomplished with the Type Library Importer utility (tlbimp.exe) that ships with the .NET Framework Software Developer Kit (SDK). This utility generates interop assemblies containing the metadata for all the COM definitions in a type library. Once metadata is available, .NET clients can seamlessly create instances of COM types and call its methods as though they were native .NET instances [8].

The developed Site Selection Toolbar contains a collection of commands. Commands are components that implement the ICommand interface of ArcObjects, ArcGIS development platform. In order to deliver Site Selection Tool as an extension, a COM-Compliant component is created as a Dynamic Link Library using Visual Studio 2005 (C# Programming Language) and ArcObjects. ArcObjects libraries are used to read criterion maps and layer, perform spatial analysis, and create the final map result. Detailed descriptions of these libraries can be found elsewhere [8].

Site Selection Toolbar is comprised of three main menus (data preparation, data standardization, and MCE Tools) as shown in Figure 2. Data Preparation menu contains the most common GIS functions used in preparing the criterion maps. Data Standardization menu contains the command used for preparing the standardized criterion maps. MCE Tools menu contains the three used multicriteria evaluation techniques (AHP, OWA, and AHP-OWA).

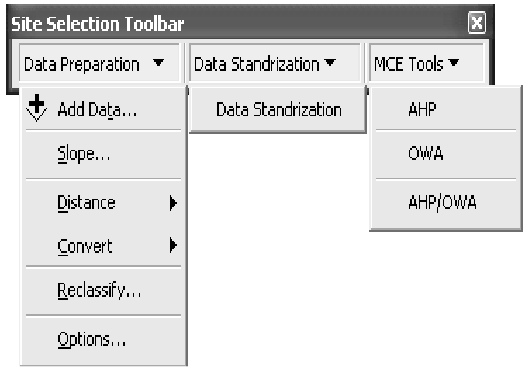

Figure 2. Site selection toolbar.

6. Example Application

To illustrate the application of the Site Selection Toolbar, ESRI data [10] is used for solving a site selection problem in the Stowe, Vermont, USA. In order to identify the most suitable sites for a new school, the following criteria are considered:

1. Near recreational facilities.
2. Near to major roads.
3. On relatively flat land.
4. On suitable landuse.
5. Away from existing schools.

The first three criteria are to be minimized: that is, the closer the area to the recreational facilities, major road, and on relatively flat land (small slopes), the better. The last two criteria are to be maximized that requires the suitable areas to be located on suitable landuse and away from existing schools. After identifying the siting criteria, the second step of the proposed framework is preparing the criterion maps. Several GIS functions are used to drive the criterion maps using five different data sets as shown in Figure 3.

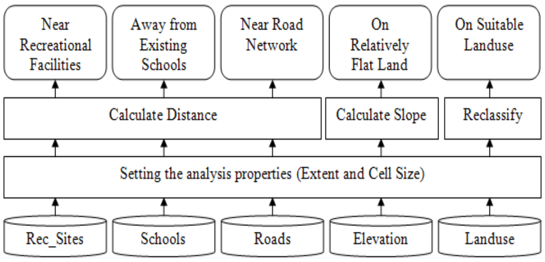

Figure 3. Preparing criterion maps.

Figures 4, 5, 6, and 7 are samples of the GIS functions used to prepare the criterion maps.

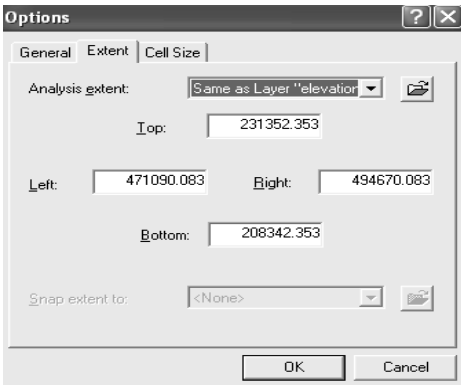

Figure 4. Setting the analysis properties.

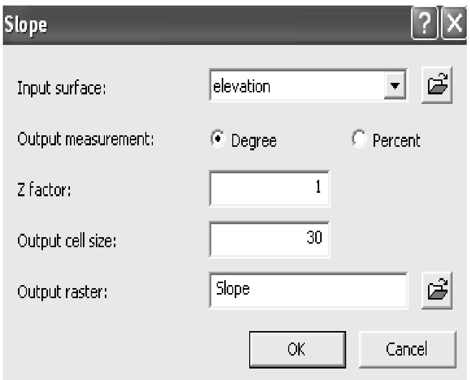

Figure 5. Deriving slope.

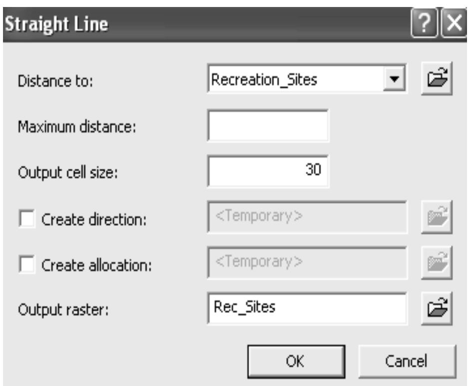

Figure 6. Deriving distance from recreation sites.

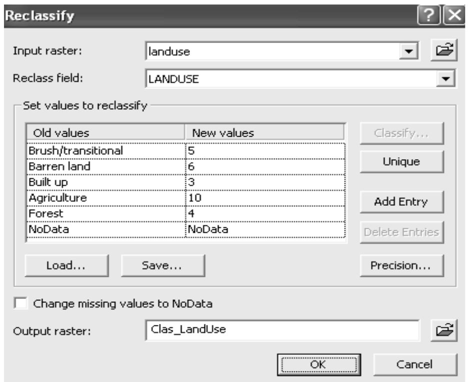

Figure 7. Reclassifying landuse.

The third step of the proposed framework is data standardization as shown in Figure 8.

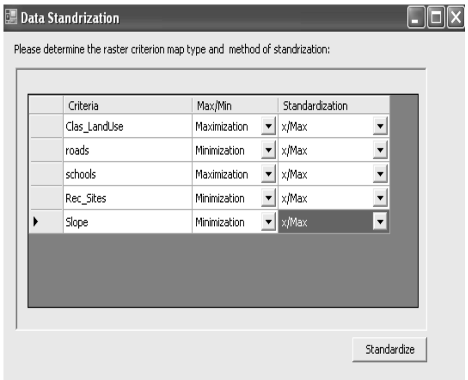

Figure 8. Data standardization.

After preparing the standardized criterion maps, the fourth step is using one of the three available MCE methods to identify the most suitable locations for the new school according to the predefined five criteria. In this example, OWA is used and the five criteria are ranked as follows: near to recreational facilities (the most important criterion ranked first), away from existing school, near to major roads, on a suitable landuse, and on a relatively flat land (the least important criterion) as shown in Figure 9.

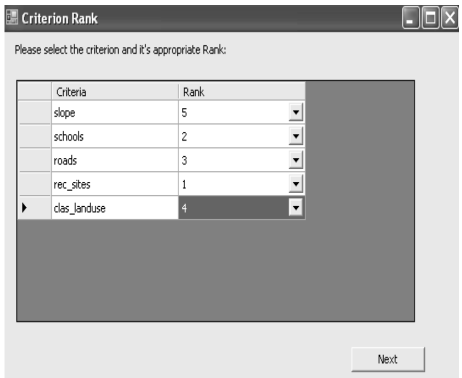

Figure 9. Criterion ranking.

To generate a wide range of decision strategies (alternative landuse suitability patterns), different fuzzy quantifiers could be used as shown in Figure 10.

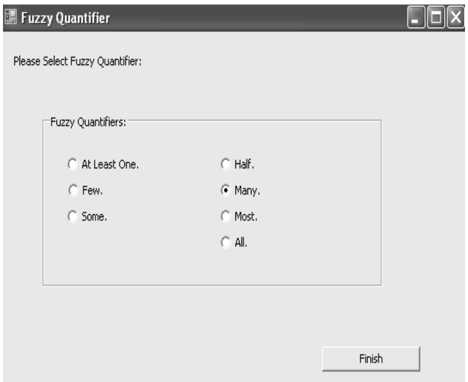

Figure 10. Fuzzy quantifier.

In this problem, two different quantifiers are used (Many and All). Figures 11 and 12 show two alternative land suitability patterns for building the new school, each pattern is associated with a given quantifier.

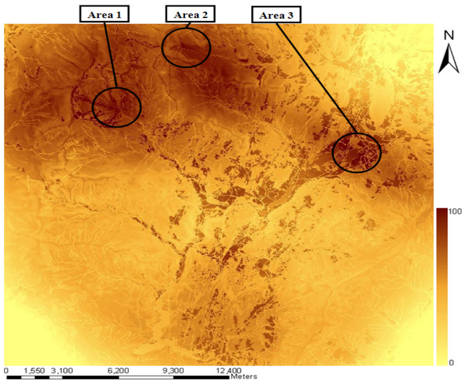

Figure 11. Suitable sites using many quantifier.

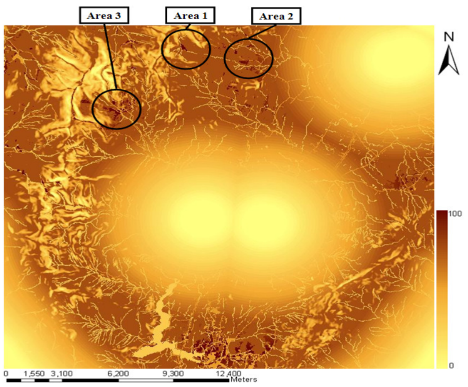

Figure 12. Suitable sites using all quantifier.

7. Conclusions

Developing and using GIS-based MCE tools for site selection is a complex process that needs well trained GIS developers and analysts to carry out these projects. In this study, a GIS-based MCE Site Selection Tool has been developed to overcome the above limitations. This tool has been developed as a toolbar in ArcGIS9.3 using COM technology to achieve software interoperability. This tool pursues two major tasks:

1. Customizing and categorizing the existing built-in ArcGIS tools required for solving the siting problems.
2. Developing a MCE toolbox that contains three of the most commonly used techniques for solving the siting problems (AHP, OWA, and the extension of AHP using OWA operators).

This tool can be used by engineers and planners with different levels of GIS and MCE knowledge to solve site selection problems. A typical case study has been presented to demonstrate the application of the tool. In addition, the paper has presented a comprehensive discussion of the site selection process and characteristics.

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