# A COMPUTER-AIDED SYSTEM FOR SITE SELECTION OF MAJOR CAPITAL INVESTMENTS

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**Abstract**: Site selection for capital investments is a crucial complex decision for owners and analysts. Difficulties are caused by the inclusion of the numerous possible sites that may qualify, multiple objectives that could also contradict each other, intangible objectives that are difficult to quantify, diversity of interest groups, uncertainties regarding external factors such as government legislations, uncertainties regarding the timing required for permitting the sites in question, and unknown construction challenges for the different sites. As such, these exercises are multi-facetted and necessitate the employment of analysts who possess in-depth knowledge in a number of fields. More importantly, a solution must satisfy a number of physical suitability criteria, as well as, meeting a number of social, economical, environmental and political requirements. Consequently, a number of specialized tools is frequently utilized to ensure reaching an optimal decision. This paper presents a new system that integrates Analytic Hierarchy Process (AHP) operations within a Geographic Information System (GIS) application to determine the optimum site for a specified facility. The system was validated through a facility for a selected metropolitan area.

## 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.

In a site selection exercise, the analyst strives to determine the optimum location that would satisfy the selection criteria. The selection process attempts to optimize a number of objectives. 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 determine the proper site for a capital improvement facility including Expert Systems (ES), geographic information systems (GIS), and Multi-criteria decision-making (MCDM) techniques. 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.

This paper presents a new approach in which these three tools were integrated to facilitate the decision-maker's job.

## 2. Selection Process and Characteristics

The process of industrial site-selection begins with the recognition of a need to meet new or growing markets. Once a need is recognized, the screening of geographic areas of specific interest starts. Suitable sites are selected on economical and technical criteria as well as social and environmental aspects (SIOR and NAIOP 1990, Stafford 1979, Barbaro 1975). Sites that satisfy the screening criteria are subjected to a more detailed evaluation and are compared as possible alternative sites for the proposed facility.

In today's society, site selection problems are characterized by their multi-objectives and numerous stakeholders. Table 1 shows a listing of decision factors that generally characterize sitting problems and affect final selection (Williams and Massa 1983, Keeney 1980):

Table 1. Decision Factors that Characterize Site Selection Problems

| Factors | Description | Impact |
|---|---|---|
| Numerous Possible Sites | There could be tens/hundreds of potential sites that could be chosen for the facility | Additional effort and time required to complete the analysis |
| Multiple Objectives | It is fairly common to find contradictions between the multiple objectives for a sitting problem. For instance, the objective of keeping minimum capital investment may contradict with the objective of keeping a long-term safe environment. | Difficulty of weighing each objective against the others and the delicate balance of keeping all stakeholders satisfied |
| Intangible Objectives | Many objectives lack means of quantitative measurements. Examples of those are the aesthetic deterioration of the view of a mountain scene as a result of the installation of transmission towers/lines, the social disruption felt by a community as a result of the expected rapid influx of workers during construction, and similar issues. | Difficulty of determining qualitative measures that describe the significance of each objective |
| Numerous Interest Groups | Within an owner's organization the management, shareholders, and employees may hold different positions regarding the selected site. In addition to their own organizations, several public groups frequently impact owners/investors decisions. Examples of public groups include consumers, local citizens, environmentalists, heritage committees and similar groups. | Difficulty of sorting out in-house and external views and reaching an acceptable balance to reach an approval by all participants |
| Impact Assessment | Placing a value on the impact of each objective could be problematic. It is not enough to state that there would/wouldn't be some impact. A value (number or quantity) is needed to support the comparison process. | Difficulty of determining qualitative measures that describe the impact of each objective |

| | | |
|---|---|---|
| Timing Impact | The impacts identified by a sitting study may not all occur at the same time and may/may not continue over the lifetime of the project. | Difficulty of determining qualitative measures that describe the net impact of each objective with respect to the impact time |
| Uncertainties Impact | It is practically impossible to accurately forecast all possible impacts of all factors affecting the site selection for a facility. There will always be uncertainties regarding environmental outcome, actual costs, accidents, and similar issues. | Difficulty of determining qualitative measures that describe the risk of uncertainties |
| Uncontrollable Delays | Licensing and construction issues are examples of common unpredictable delays that may significantly impact the economic viability of the project | Difficulty of determining qualitative measures that describe the impact and risk in uncontrollable issues |
| Operation Reliability | Impact of natural phenomena such as storms, floods, quacks and similar phenomena can impact site suitability and add to the process uncertainty | Difficulty of determining qualitative measures that describe the impact of possible natural phenomena for each candidate site |
| Equity | Determining equity and fairness among all interest groups involves complex value judgments | Difficulty of determining qualitative measures that guarantees equity among stakeholders |
| Stakeholders' Risk Attitudes | Determination and compilation of the stakeholders' risk attitudes is important to the proper site selection | Difficulty, time and effort in determining qualitative measures that describe the utility functions of all stakeholders |
| Uncertainties in Government Decisions | Laws and regulations enforced by federal and state governments can greatly influence the relative desirability over time of various sites for a proposed facility | Difficulty of determining qualitative measures that describe the impact of external factors such as legislations, etc. |

## 3. Proposed Approach

Geographic information systems (GIS), Multi-criteria decision making (MCDM), and Expert Systems (ES) techniques have been used in solving site selection problems for the last three decades. Integration of these tools is needed so that each tool is used to address certain aspects of the problem (Vlachopoulu et al 2001, Thomas 2001, Kao et al 1996, Siddiqui et al 1996, Jankowski and Richard 1994, Carver 1991, Janssen and Rietveld 1990).

The proposed system was developed employing a number of COM-compliant software packages. The ArcGIS ® 8.2 was used to manage the spatial data and to conduct the required spatial analysis operations (http://www.esri.com). The Visual Rule Studio® was used to develop the expert systems component (http://www.RuleMachines.com). Microsoft® Excel 2002 was used to implement the AHP method. The Microsoft® Visual Basic 6.0 was used to develop the system's user interface and to provide the shell for COM integration. Detailed description of the use of COM can be found else where (Eldrandaly 2003, Goodchild et al 1999, Goodchild et al 1992).

The approach presented here integrates the capabilities of ES, GIS and MCDM by using Microsoft® Component Object Model (COM). COM is a standard protocol that enhances software interoperability by allowing different software components, possibly written in different programming languages, to communicate directly (Microsoft® 2000). In the proposed system, the expert system component was developed using Visual Rule Studio® (http://www.RuleMachines.com), the management of spatial data and spatial analysis operations were conducted by ArcGIS ® 8.2 (http://www.esri.com), Microsoft® Excel 2002 was used to implement the AHP application, and the users' interface was written in Microsoft® Visual Basic 6.0.

Figure 1 presents the components of the proposed system. Provided below is a brief description of the procedural steps for the two phases of the new approach as depicted in Figure 1:

**Step 1**: In this step, the expert system is used to provide the recommended values for the site physical suitability criteria and the GIS is used to determine the alternative sites using the values obtained from the ES. This is accomplished through the following two steps:

(a) Establishment of suitability criteria -- According to the type of industry, the ES would define the suitability criteria (e.g., physical, environmental, geographical, etc) for the sites of interest. The experts of the field and/or the decision makers have the opportunity to review and change the recommended values.

(b) Site Screening – Once a decision is made to build a particular facility, the decision makers select the regions of interest. This is an important consideration as it eliminates all sites outside the selected region from the list of possible sites. The site screening process involves GIS analysis operations to identify candidate sites that meet the desired attributes obtained by the ES. The output of this step is a list of candidate sites for further assessment.

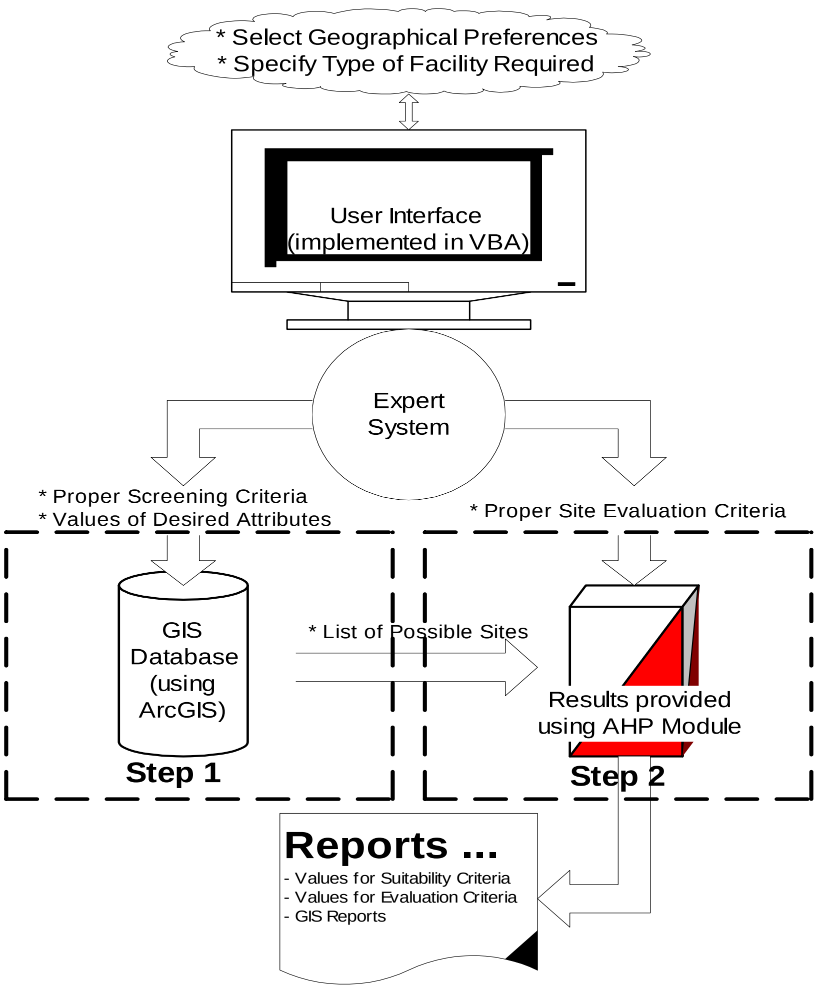


*Figure 1.* Architecture of the Intelligent GIS Approach

**Step 2**: In this step, the expert system is used to provide the recommended values for the site non-spatial selection criteria and the AHP is used to determine the rank of the alternative sites using the values obtained from the ES. This is accomplished through the following two steps:

(a) Establishment of the AHP evaluation criteria – According to the type of industry, the ES would define the AHP evaluation criteria (e.g., labor climate, economic costs, living conditions, etc) for the regions of interest. The experts of the field and/or the decision makers have the opportunity to review and change the recommended values.

(b) Site Evaluation -- The Analytic Hierarchy Process (AHP) is used to evaluate the candidate sites. The output of this module would be a list of sites ranked in the ordered of their level of suitability.

## 4. Case Study

An illustrative example is provided here through the exercise of identifying the optimum site for a water treatment facility that could serve a potential metropolitan area. Table 2 and Figure 2 summarize 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. Twelve layers were created in ArcGIS® to address the physical suitability requirements. Upon the completion of the analysis, two candidate sites were identified.

The following evaluation criteria were used in the site evaluation phase: public opposition to new neighboring industrial facilities, neighborhood previous involvement in major public hearing, and cost of camouflaging the facility. These were the factors used by the AHP module to rank the sites that satisfied the physical suitability requirements.

Table 2. Physical Suitability Criteria for a Water Treatment Case Study

| Criteria | Items | Values | Constraints |
|---|---|---|---|
| Terrain | Size<br>Elevation<br>Floods<br>Slopes<br>Soils* | > 150,000 sq. meter<br>365 meter<br>> 0.5 Kilometer<br>< 5%<br>GW, GP, GM, GC, SW, SP | Minimum lot size<br>To minimize pumping costs<br>Buffer Zone to Avoid Catastrophes<br>Erosion, Drainage, Constructability<br>Stability, Strength, Drainage |
| Infrastructure | Roads<br>Waste Water<br>Residential Properties<br>Public Parks<br>Existing Utilities | < 50 meter<br>500-1000 meter<br>> 150 meter<br>> 150 meter<br>< 2 Kilometer | Distance to existing road<br>Distance to waste water facility<br>Distance to residential properties<br>Distance to recreational parks<br>Communications, Power, Water Connections |
| Natural Resources | Land Use<br>Occupancy<br>Water Bodies | -<br>-<br>< 1000 meter | Avoid land of Environ/Cultural Sensitivity<br>Vacant lots to minimize acquisition costs<br>To minimize pipeline construction |

Note: Soils classification followed the Unified Soil Classification System (USCS). The system follows a letter description in which the first is the group symbol (G= Gravel, S = Sand, M= Silt, C= Clay, PT= Peat), and the second describes the gradation (W= well graded, P= poorly graded) in the case of granular soils or the liquid limit (L= liquid limit under 50, H= liquid limit over 50) in the case non-granular soils. For example, GW= gravel well graded and SP= sand poorly graded.

## 5. Conclusions

Site selection is a crucial, multifaceted process that could significantly impact the profit and loss of capital investments. The proposed process includes four steps: establishment of suitability criteria, site screening, establishment of the AHP evaluation criteria, and site Evaluation. An integrated system was developed to aid the analyst in finding the optimum site for the facility sought. The system integrates two major tools (GIS and AHP) in a manner that reduces the user involvement with each component/tool and reduces the level of the computer skills required to reach the correct solution. The integration was achieved using Component Object Mode (COM) and the system included an advisory system to assist the decision maker in determining appropriate values for the physical suitability criteria. The system was successfully tested in determining the optimum site for a water treatment facility. This system is the first step in the authors' plan for further automation of the site selection process. The authors are working on developing a fully automated system in which the user interact with all the tools through a simplified user-interface and saves the user from having to develop in-depth expertise in the utilization of any of the necessary tools.

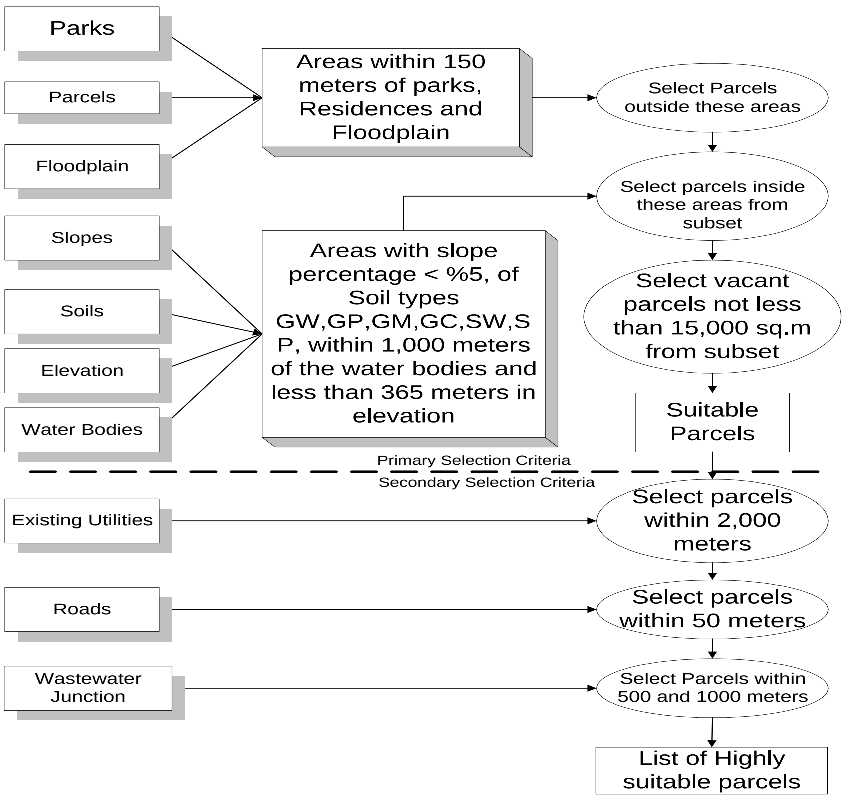


*Figure 2.* Physical Suitability Criteria Classification

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