On the use of expert systems, multi-criteria decision making, and geographic information systems in site selection (quick review)

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Site selection is the generic process of finding locations of features meeting specified conditions or criteria. Site selection is a critical decision making element for a wide range of economic activities, from land use planning to industrial plant site- selection. Building a new plant is a major, long-term investment for any manufacturer. Deciding to put the plant is a critical component within the total investment decision. The selection of an industrial site involves a complex array of critical factors drawing from economic, social, technical, and environmental disciplines. This type of spatial decision making problems requires proper means to handle the multiple socio-economic factors while considering physical suitability conditions. Expert Systems (ES), Multi-criteria Decision-Making (MCDM), and geographic information systems (GIS) techniques have been used to cope with this type of problems. In this paper the industrial site selection problem is reviewed when using ES, MCDM, and GIS techniques for solving such problem. Remarks and tendencies have been reported regard these tools.

ان عملية اختيار الموقع الصناعي والذي يتوافق مع كل خصائص ومواصفات ومميزات المشروع الناجح تبدأ من التعرف على الاحتياجات الحالية والمستقبلية من المشروع والتي يجب أن تتوافق مع احتياجات و متطلبات السوق المحلى والعالمي. في هذا البحث تم استعراض العوامل الرئيسية المؤثرة (التقليدية والاجتماعية و البيئية و العالمية) في اختيار موقع المشروع الصناعي. أيضا تم استعراض دور كل من النظم الخبيرة ونظم المعلومات الجغرافية وأساليب صناعة القرارات متعددة المعايير في اختيار موقع المشروع الصناعي . في نهاية البحث تم استعراض أهم النتائج والتوصيات

Keywords: Industrial site selection, Expert systems, Multi-criteria decision making, Geographic information system

1. Introduction

Site selection is the generic process of finding locations of features meeting specified conditions or criteria [1]. Site selection is a critical decision making element for a wide range of economic activities, from land use planning to industrial plant site-selection. Site selection requires consideration of a comprehensive set of factors and balancing of multiple objectives in determining the suitability of a particular area for a defined land use [2]. Building a new plant is a major, long-term investment for any manufacturer. Deciding to put the plant is a critical component within the total investment decision. As such, industrial location analysis is big business, whether measured in terms of investment dollars, or decision-makers involved, or employees affected, or the economies of area influenced [3]. The process of industrial plant site-selection begins in the recognition of an existing or projected need for expansion to meet new/or-growing markets. This recognition triggers the myriad of actions, which search out and screen geographic areas and specific locations therein. The first proposed sites, those, which meet screening criteria established from value judgments concerning economic, social and environmental factors, are compared as alternative sites for plant location. In the past, the site most suited to the recognized need was selected. The sophistication degree of process selection is much higher, and the number of factors one must contented with has multiplied. The changes that have taken place have de-emphasized the technical and diluted the strictly economic considerations. Especially, in recent years, there has been a trend to put more emphasis on the social and environmental aspects of plant site selection. The environmental factors in plant sitting are reflective of the environmental awareness that has resulted in stringent environmental legislation and regulation. As a result, the process of plant site selection has shifted from artful balancing of the various technical and economic factors in locating a plant to skillful selection of sites, which minimizes potential environmental conflicts without completely disrupting other essential considerations. This trend has significantly expanded the list of factors, which must be considered in evaluating potential industrial plant location. [4] summarized these factors in the following categories: (1) Traditional site selection factors such as market, labor, transportation, raw materials, power supply, etc; (2) Social factors such as climate, living conditions, security, etc; (3) Environmental factors such as federal / state/ local regulations, permits and standards, environmentalist Group active concern for the project and/or site, nature and impact of waste discharges, impact of project on human environment, etc; and (4) International factors which is applicable if the plant is to be located in a foreign country such as federal regulation of overseas investment, political environment in foreign country, economic/ social environment in foreign country, etc.

Geographic Information Systems (GIS), Multicriteria Decision Making (MCDM), and Expert Systems (ES) techniques have played an important role in solving the site selection problem. However, each of these techniques has its own limitations in dealing with spatial decision problems such as site selection problem. The need for improvement of the performance of these techniques has promoted the integration of GIS with ES and MCDM. In the following sections, a brief introduction to ES, MCDM, and GIS techniques and their applications in the area of site selection will be presented.

2. Expert systems

Expert systems, a promising branch of Artificial Intelligence (AI), have achieved considerable success in recent years. Waterman [5] has defined expert system as, a sophisticated computer program that manipulates knowledge to solve problems efficiently and effectively in a narrow area and it is called a system rather than just a program because it contains both a problem solving component and a support component.

An expert system generally consists of knowledge base, inference engine, working memory, user interface, and knowledge acquisition mechanism [6]. Expert systems represent a revolutionary transition from the traditional data processing to a knowledge processing. They offer an environment for incorporating the good capabilities of humans and the power of computers. The main privileges of expert systems are mentioned by [6,7] as their capability of solving problems when no procedure exists and the problem is very unstructured, handling symbolic information, Ability of explanation of their recommendations, providing expert level consultative services to users, being often cost effective when human expertise is very expensive, not available, or contradictory, applying a systematic reasoning process with a very large knowledge base that is often much larger than a human expert can retain or utilize, being objective, and are not influenced by perceptions that are not relevant.

Although expert systems have several advantages, they also have some drawbacks. Huang and Zhang [6] summarized the disadvantages of expert systems as the human expert must be available in order to build an expert system and to articulate the rules that define the solution and not lapse into vagueness or incoherence, the rules must be cogent, correct, and consistent, the development of an expert system may be lengthy, the expert system's performance drops off sharply if the problem deviates even slightly from the expected problem domain, and debugging, maintenance, and execution time of expert system may be very difficult.

2.1. Expert systems in site selection

Many expert systems have been developed to solve various site selection problems that are heavily dependent on human judgment and experience. These systems use symbolic knowledge to construct human understanding of problems in the area of site selection and evaluation. Because symbolic knowledge is not well suited to describe the spatial nature of site selection problems, expert systems lack a mechanism to derive solutions based on spatial knowledge of different sites. Spatial knowledge is critical to spatial reasoning and decision making in many site selection applications. Unfortunately, current expert systems can't handle spatial knowledge. They don't have an appropriate method to encode and represent the spatial nature of knowledge. Furthermore, they are lacking in spatial data handling capabilities such as buffering and overlay that are unique and important to spatial analysis [8,9]. Most of these systems are briefly reviewed in the following paragraphs.

Findikak [10] developed the Site Selection Expert System (SISES) to aid decision-makers faced with site selection problem. The system consists of four units: the knowledge acquisition, induction, design, and decision analysis units. The knowledge acquisition unit is used to collect and organize information provided by expert decision-makers. The induction unit evaluates this information and generates rules and entity evaluation functions expressing the expert judgment. The design unit is used to customize the knowledge of the acquisition system to particular applications by modifying selected elements of the knowledge acquisition unit and expanding it with the addition of new components. The decision analysis unit uses the rules generated by the induction module and employ decision theory techniques for selecting one or more of the available alternatives. The system helps a user to develop a set of site attributes and to determine their weighted relative importance. The knowledge base of SISES consists of knowledge representing basic facts about site selection and heuristic knowledge induced by observing specific examples of judgment made by the expert decision maker.

Suh et al. [11] designed a prototype expert system for site selection of manufacturing establishments funded by foreign investors. The Expert System for Manufacturing Site Selection (ESMAN) makes use of existing survey data collected from managers of existing foreign manufacturing facilities in the United States. The survey data from these experts identifies location factors and measures the respondents' importance ratings of these factors. These importance ratings are combined with information about the specific facility under consideration. Thirteen components to develop a site suitability index for three hypothetical sites are used.

Han and Kim [12] developed a prototype expert system for site selection and analysis. The expert system for site analysis and selection (ESSAS) is a prototype system with 240 decision rules, and was designed to solve a potion of the site selection problem. The system was developed to aid master planners for the army who are responsible for planning future building projects at military bases. The system was designed to aid only in the sitting of administrative office buildings.

Rouhani and Kangari [13] developed a prototype expert system for landfill site selection. The system was intended to be used as a consultant to a waste manager/planner during the preliminary phases of site selection. Environmental Protection Agency (EPA) documents for the ranking of uncontrolled hazardous waste sites for remedial actions. The system includes rules concerning ground water routes, local climate, waste characteristics, and planned features of the proposed landfill facility and targets at risk. The final output is a relative ranking of a set of candidate sites.

Arentz et al. [14] developed an algorithm (ProfMat) for spatial search and implemented it in an expert system for site selection. The ProfMat is able to find the best site in the area of interest even when the number of possible sites is large and many decision criteria are involved. Compared to commonly used search procedures, ProfMat improves the efficiency of spatial search in two ways. First, the best site is identified through an iterative rather than a linear process of selection and evaluation of optional sites. Second, narrowing down the focus to increasingly smaller areas searches an area and, thus, sites are evaluated as much as possible groupwise. The ProfMat procedure was illustrated by analyzing the problem of retail site selection. A comparison with alternative search procedures shows that ProfMat considerably reduces the evaluation costs needed to find the best site.

Witlox and Timmermans [15] developed, MATISSE, a knowledge-based system for industrial site selection and evaluation. The system represents the concept of site suitability as a matching process whereby use is made of Decision Tables (DTs). The system was tested using the locational choice problem of the petrochemical industry in the port of Antwerp. The system uses three major categories of locational determining factors, site conditions, investment considerations, and operating considerations.

Arentz et al. [16] developed a knowledge-based system to support the analysis of problems and formulation of actions in the field of retail location planning. The Decision Table (DT) technique was used to represent expert knowledge in terms of a set of DTs. Each DT represents for a certain problem area an exhaustive and exclusive set of decision rules to identify problems, analyze problems and formulate actions. The rules are heuristic in nature and, therefore, quantitative spatial models are used as complementary tools to predict and analyze the impacts of suggested actions. If actions appear to be insufficiently effective or produce unanticipated side-effects, the same DT- system can be re-constructed to generate corrective actions. The system supports the generation of plan scenarios, but does not support the choice stage when several alternative actions are optional.

3. Multicriteria decision-making techniques

Multi-criteria problems with conflicting objectives have encountered in a number engineering applications, such as facility location. The development of Multi-Criteria Decision Making techniques (MCDM), also known in the literature as Multi-Criteria Analysis (MCA) or Multi-Criteria Evaluation (MCE), is actually relatively recent. Over the past 20 years there has been a plethora of tools and techniques developed for solving these problems. These methods are designed to clarify the decision problem, help generate useful alternative solutions, and help evaluate the alternatives based on a decision maker's values and preferences [17]. The general objective of MCDM is to assist the Decision-Maker (DM) in selecting the best alternative from the number of feasible choice alternatives under the presence of multiple choice criteria and diverse criterion priorities [18]. A number of approaches to structuring MCDM problems have been suggested in the decision analysis literature. In general, MCDM problems involve the following components [19]:

1. A goal or a set of goals the decision maker attempts to achieve;
2. The decision maker or group of decision makers involved in the decision-making process along with their preferences with respect to evaluation criteria;
3. A set of evaluation criteria on the basis of which the decision makers evaluate alternative course of action;
4. The set of decision alternatives, that is, the decision or action variables;
5. The set of uncontrollable variables or state of nature; and
6. The set of outcomes or consequences associated with each alternative-attribute pair.

MCDM problems are broadly classified into two main categories: MODM and Multi-Attribute Decision-Making (MADM). MODM problems refer to problems that have a very large number of feasible alternatives, where the objectives and constraints are functionally related to the decision variables [17]. This category of multi-criteria approaches involves the design of the alternatives and searching for the best decision among an infinite or very large set of feasible alternative. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions [19]. MADM problems refer to problems that have a relatively small number of alternatives, where the alternatives are represented in terms of attributes [17]. This implies that attribute-objective relationships are specified in such a form that attributes are regarded as objectives and decision variables. The set of attributes is given explicitly. Attributes are used as both decision variables and decision criteria [19]. The MCDM techniques are usually aspatial in nature as they assume homogeneity within the study area. This assumption is unrealistic in many spatial decision making situations such as site selection problems. Therefore, there is a need for an explicit representation of geographical dimension in MCDM techniques. The combination of GIS and MCDM capabilities will effectively solve this problem [19]. The underlying theory of multi-criteria decision-making and algorithms has been summarized in a variety of operations research, management science, and decision sciences literatures.

4. Geographic information systems

Geographic Information Systems (GIS) is a relatively new branch of information technology. The term GIS didn't appear until the early 1960s when the Canada Geographic Information System (CGIS) was developed [20]. Davis [1] defined GIS as "a computer-based technology and methodology for collecting, managing, analyzing, modeling, and presenting geographic data for a wide range of applications." A GIS generally consists of the following components [21]:

- People—people are the most important component of a GIS. People must develop the procedures and define the tasks the GIS will perform. People can often overcome shortfalls in other components of the GIS, but the opposite is not true. The best software and computers in the world cannot compensate for incompetence.
- Data—the availability and accuracy of data affect the results of queries and analysis.
- Hardware—hardware capabilities affect processing speed, ease of use, and the types of available output.
- Software—this includes not only GIS software, but also various database, drawing, statistical, imaging, and other software programs.
- Procedures—GIS analysis requires well-defined, consistent methods to produce correct and reproducible results.

4.1. GIS in site selection

Sitting analysis with GIS began in the late 1970s [22]. GIS are often used to identify suitable areas for land developments. Site suitability is the process of finding the most suitable location or locations for a particular purpose [1]. The functionality of GIS in this context lies mainly in the ability to perform deterministic overlay, integration of different data layers, and buffer, defining a zone of a specified distance around features, operations. Such abilities, whilst ideal for performing spatial searches based on nominally mapped criteria, are of limited use when multiple and conflicting criteria and objectives are concerned [23]. Also, most GISs have very limited capabilities for integrating geographical information and the decision maker's preferences and hence are of limited use for decision support [19]. The integration of GIS, ES, and MCDM may avoid some of the limitations and difficulties existing in each of them.

[23] developed a combined GIS-MCE approach to facility location. This approach is divided into survey and preliminary site identification. In the survey stage standard GIS facilities are used to input, transform, store, and manipulate digital map data relevant to the problem. Area screening techniques are used to identify all the potentially feasible areas in which to look for sites suitable for development. This is achieved by overlaying relevant sitting factors to identify all the areas, which simultaneously satisfy the specified numerical and qualitative criteria. The sitting criteria used in this stage of analysis are often very deterministic in nature. The second stage of the proposed methodology is aimed to identify compromise solutions from the whole range of alternatives taken from the feasible areas identified by GIS based area screening. This stage is operationalized using MCE techniques embedded in the GIS framework and additional site-specific information relevant to secondary sitting factors. These factors are of a non-deterministic nature and are weighted according to their perceived level of importance. The evaluation matrix contain site information is built using the data handling facilities provided by GIS. MCE techniques are used to identify best compromise solutions on the basis of this site-specific information and associated weights.

Jankowski and Richard [24] designed a GIS-MCE spatial decision support system for route selection. The system was applied to verify a route selection study for a water transmission supply line, which is used to provide water the city of Seattle, Washington, USA. The developed methodology is for integrating a GIS- base suitability analysis and multi-criteria evaluation in a spatial decision support system. In the proposed model a set of decision criteria is formulated. The decision criteria may be quantitative and qualitative and they may concern physical, economic, and social aspects of a decision problem. Next, a set of feasible solutions is generated in a GIS. The feasibility of the alternatives is determined upon the satisfaction of the set of minimal physical and qualitative constraints imposed upon the decision criteria. Spatial analysis operations such as overlay, buffer, and proximity are used to create a composite coverage and the standard logical operators available in the GIS database query language are used to derive sites satisfying the minimal physical and qualitative constraints. The sites that satisfy the minimal constraints constitute the feasible solutions. The solution alternatives are then overlaid with the criterion coverage. This will lead to an output coverage containing the original attribute data of the alternatives and the criterion attribute data. The alternatives, represented by their attribute data are input into the MCE software where the decision maker can attach a relative preference measure to every criterion in the analysis. The alternatives are ranked, based on the criterion scores extracted from the GIS and criterion weights assigned by the decision makers. Finally, a sensitivity analysis can be performed within the MCE software to determine the vulnerability of the analysis to changes in the decision makers' preferences.

Siddiqui et al. [25] developed a spatial multi-criteria decision making approach for landfill site selection. This approach combines the evaluation ability of the Analytic Hierarchy Process (AHP) and the analytic capabilities of GIS to identify areas with best landfill site attributes. It uses selection criteria and area attributes recorded on GIS data maps to identify and rank potential landfill areas. The system uses exclusive criteria to exclude sites from further consideration, based on legal restrictions or physical impracticality. Then it uses non-exclusionary criteria to rank the remaining areas based on attributes recorded on GIS data maps. In Spatial-AHP method the objective is to identify and rank areas, not specific sites. To accomplish this objective, study areas are divided into raster map cells, and AHP is used to rank each raster cell. The suitability of each map cell can be considered to be a function of the utility of the cell's attribute values. In this approach, cell attribute values are pairwise compared for each attribute. By using pairwise comparison of attribute values, rather than alternative sites, AHP can be used to rank very large numbers of alternatives with much less effort expended by the decision maker.

Kao et al. [26] developed a prototypical network expert geographic information system to facilitate municipal solid waste landfill sitting. A forward chaining knowledge base consisting of related sitting rules used to establish the expert system. Sitting analysis is performed by a GIS and evaluated by the rules triggered from the expert system. The expert system and GIS were integrated into an expert GIS to combine the advantages of both systems.

Chulmin [2] designed an intelligent geographic information system for industrial site selection by integrating GIS, expert system, and MCDM. The development of the system was based on two broad phases matching the general decision procedures of industrial site selection tasks – a physically suitable area search and a community search. The first phase is for extracting the spatially feasible areas by means of a land suitability analysis based on the Mapbase or physical conditions for the given industry type, and the other is for searching or ordering the preferred communities according to their social, economic or environmental characteristics. In the site suitability analysis phase, the expert system was used in deriving the necessary map layers and the expert- recommended constraints that should be satisfied in the map overlay process in the GIS to generate the suitable alternatives. The expert system – GIS integration enabled the overlay operations and visualization in the GIS for the suitability analysis to be performed seamlessly based on the stored decision rules while depending on fewer human judgments and operations. After identifying the geographical area beast suited for the given type of industry, the system was designed to allow the decision-maker to select the most appropriate community within the predefined region using the multi-criteria evaluation capability.

Wright et al. [27] developed a GIS-based approach to identify optimal locations for the possible sitting of an artificial reef. The selection criteria, for use in the GIS analysis, were guided by the constraints identified in the artificial reef study conducted in 1991 by the (AURIS) Aberdeen University Research and Industrial Services. The systems begins the selection process by exclusion mapping to generate masks of constraints relevant to Shipping, Military Use, Constructions, and Mineral/Energy Generation. This process generated a total mask, which is then combined with 15 coverage from the environmental database to identify the most suitable, sites for location of an artificial reef.

Mak [28] suggested a GIS- based modeling approach to simulate a site- selection process for identifying permanent sites to accommodate the open storage uses. The approach envisaged that the site selection process is a model of five clearly identifiable modules distributed between two phases. The first phase, site-screening phase, consists of three modules, project-goal and objective specification, screening criteria establishment and site screening process. The second phase, site evaluation phase, consists of two modules, evaluation criteria establishment and site evaluation process. Each of the five modules is an independent module itself commending a fixed set of input and output knowledge. The knowledge input of one module is the knowledge output of the preceding module. The proposed approach is based on the integration of GIS, MCDM, and knowledge acquisition tools. The proposed approach is able to accommodate a wide range sitting projects, and, at the same time, allow rooms for maneuvering individual cases.

Thomas [29] developed a GIS-based decision support system for brownfield site selection in Jackson County, Michigan, USA. A regional level database was complied for Jackson County. Site-specific data on contaminant levels and locations were obtained. These data include physical data, land use characteristics, and demographic and socio-economic data by neighborhood and block group. Representatives of local government units in Jackson County defined the site selection criteria. A basic decision support toolset was assembled and configured for the County. The toolset included site attributes for the inventoried brownfields study areas and selected brownfields site characterization and environmental, social, and economic development indicators. Regional and parcel data were incorporated into GIS as they were complied for each township. Smart places scenarios were used to compile the data, integrate sitting objectives and constraints, and assess impacts of various land-use options. It also, allows non-technical users to interactively review land use scenarios, sketch recommended changes, and evaluate these recommendations against local or regional objectives and constraints.

Valchopoulou [30] developed, GDSS, a geographic decision support system for the evaluation of the warehouse location. The system allows the user to input unlisted factors which are considered most relevant in a particular situation, using information available from previous academic and empirical work, as well as his own experience. Numerical values are grouped into four classes in order for all factors to be scored on the same scale (0-4), according to the user's need. Using pairwise comparison, the weights of the above factors are calculated. "What if" scenarios can be applied since the alternative sites can be seen on one screen and the elasticity of factor weights and ratings can easily be tested.

5. Concluding remarks

In this review, an attempt of the industrial site selection problem and the applications of ES, MCDM, and GIS in the different types of the sitting problem have been presented. The site selection process has become increasingly complex because of the plethora of environmental laws and regulations as well as a greater public awareness of zoning and environmental issues. ES, MCDM, and GIS are very efficient and vital tools for solving the sitting problem but each of them has its own limitations and drawbacks in solving this problem. The integration of these techniques may avoid some of these limitations and difficulties existing in each of them and provide the decision maker with an efficient tool for solving the sitting problem.

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