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An integrated expert system/operations research approach for the optimization of waste incinerator siting problems

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Abstract

This research aims at developing an integrated decision support system for the optimization of waste incinerator siting problems. In this integrated approach, both expert system and operations research techniques are used to model the siting problems of waste incinerator. Furthermore, an expert decision support system (EDSS) is implemented for the above problem and thus providing the decision makers a useful tool for decision-making. This EDSS is based on multi-criteria decision analysis in finding the best incinerator site by minimizing costs and environmental impacts. The proposed approach identifies a hierarchy of objectives for the siting problem. First of all, several potential sites need to be screened as a set of feasible alternative sites. Second, those alternative feasible sites will be further evaluated via the multi-criteria decision making methods. For the evaluation process, we solve a 0/1 combinatorial optimization problem at the upper level and proceed the multi-attribute utility function at the lower level to get the optimal solutions. An empirical application of a real world waste incinerator site selection existing in Taichung City, Taiwan is followed in the end. Computational results both of the cost minimization and of the whole systems are also provided.
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1. Introduction

The research considers the issue of the siting problems of a NIMBY (Not In My Back Yard) type facility location such as a waste incinerator in local areas. Considering the siting of waste incinerator facilities, which has become one of the most pressing problems in local government, various difficulties arise in the setting up process. The purpose of a siting problem is to identify particular locations for a given type of facilities or services. Within any region of interest, there are often several potential locations for a certain type of facility. The desirability of one location relative to another depends on a multitude of factors like economic and socioeconomic concerns, health and safety concerns, environment and public attitudes. A reduction of some objective obstacles will depend on the capacity of decision makers for justifying adequately the choice of areas that,

because of their characteristics, are the most suitable for waste incinerators with considerable environmental and social impact.

The objective of the research is to construct a decision support system that enhances optimized operations of the waste incinerator siting problems in order to satisfy customer demands with minimal transportation cost and environmental impacts. The system consists of an expert system and a mathematical model. The integrated approach of combining two fundamentally different decision-making techniques (the expert system (ES) and operations research (OR)) has been adopted because most planning and evaluation process and cognitive problems cannot be solved by either OR or ES techniques alone. The operator's critical decision-making processes usually involve both qualitative and quantitative information. Hence, both OR and ES techniques are needed for modeling these processes. Expert systems are used in problems where no mathematical models can be formulated to provide acceptable answers, but the knowledge of an experienced human expert can give a satisfactory solution. This technique has shown exceptional performance in inferential process control and evaluating when the working knowledge of the system is

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non-linear and incomplete. Operations research, on the other hand, can be used for problems in which well-constructed mathematical models are available, or can be developed.

In this context, the development of an expert decision support system (EDSS) for the siting of waste incinerator facilities, seems appropriate. The research presented here documents certain aspects of the setting up of such system. The problem faced raises both theoretical and architectural concerns. From a theoretical viewpoint it is in fact well-known that the location and transportation problems that we gave to face can be modeled only by means of complex integer or mixed-integer programming techniques: this bars the possibility of a thorough analysis of large-sized problem instances such as the one under consideration [8], let alone in a multi-criteria framework.

Speaking of the relevant literature of decision support systems, from the architectural standpoint, the need to integrate spatial data with advanced algorithmic techniques has given rise to a research niche in the context of DSSs, considering so called Spatial Decision Support Systems (SDSS) [3,4], concerned with how to integrate spatially referenced information in a decision making environment in order to positively affect the performance of an individual decision-maker. In particular, in recent years it has been shown how, by these means, spatially integrated DSS can be used to bridge the gap between policy makers and complex computerized models [1,5]. It is in this framework that we analyzed and designed a system to support public policy-makers in the study of alternative facility location plans.

On the other hand, expert system technology is well known as a tool to support planners in their decision-making processes in site planning and evaluation tasks. One good example is that O'Keefe [9] provides guidelines and methods for the evaluation of decision support systems, and suggests that expert systems can function as effective decision support systems, and can complete tasks at a level close to human performance.

However, there are problems that expert systems based on human heuristics cannot solve. In the research studied here, human knowledge about the NIMBY facility siting problem is incomplete and uncertain, and an expert system that relies solely on expertise provided by site planners would provide poor guidance to users. By contrast, OR techniques are designed to cope with problems that involve constraints such as penalty costs, transportation costs, and planning seasons.

In our research, expert system and mathematical model, the two techniques complement each other, and are combined to construct the expert decision support system to optimize waste incinerator siting problems. Other objectives of this research also include: documenting the planning knowledge of key and senior urban site planners and engineers, and using the expert system as a training tool for training new planners.

This paper proceeds as follows: Section 2 presents the main algorithmic issues faced. Specifically, it presents the top-level single-criterion problem, the identification of efficient solutions and the formulation of the multi-criteria problem to be solved by advanced off-the-shelf techniques. Then, the integrated expert system/operations research solution for optimizing waste incinerator siting problems is presented. Section 3 discusses the establishment of the incinerator site selection expert decision support system. It also explains the knowledge acquisition and data analysis that precedes system development. Section 4 introduces the real-world empirical example we faced and presents the computational results we obtained. It discusses how the integrated system can function in the real-world operational environment. Section 5 contains a discussion of the conclusions we have drawn from our experience, and discusses some of the benefits of the integrated approach to decision making.

2. Integrated decision support system for optimizing waste incinerator siting problems

This research develops an EDSS which is based on multi-criteria decision analysis in finding the best incinerator site by minimizing costs and environmental impacts. First of all, several potential sites need to be screened as a set of feasible alternative sites. Second, those alternative feasible sites will be further evaluated via the multi-criteria decision making methods. The proposed approach identifies a hierarchy of objectives, where at the top level we solve a 0/1 fixed cost transportation problem (FCTP). This is an NP-hard combinational optimization problem that can only be solved heuristically for real world problem sizes. A number of good solutions of the single objective problem are combined to produce efficient alternatives, to be further evaluated by means of multi-criteria methods at the lower level.

Since our proposed system needs both numeric computation and symbolic processing approaches, a rule-based knowledge base consists of rules, which encode heuristics in the IF-THEN format is proposed. The IF-THEN decision algorithm conceptually borrowed from the expert system is used as the basis of the knowledge base for the proposed EDSS. In the IF-THEN decision algorithm, the costs of waste incinerator installation, the state of the waste incinerator siting conditions, the impact of the waste incinerator on socio-economic strata, the natural environment; and the life quality of neighboring residents are the qualitative variables. The values of the qualitative variables can be represented by linguistic terms used by the users, such as 'decreasing rapidly', 'low', or 'high'. The decision variable of the state of the waste incinerator siting conditions such as the Difficulty in Acquiring Land for the waste incinerator has three values, which are 'fair' (condition is fine for acquiring the land), 'high' (condition is facing problems for acquiring the land), and 'low'