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An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management

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Abstract

This paper reports on an integration of multi-criteria decision analysis (MCDA) and inexact mixed integer linear programming (IMILP) methods to support selection of an optimal landfill site and a waste-flow-allocation pattern such that the total system cost can be minimized. Selection of a landfill site involves both qualitative and quantitative criteria and heuristics. In order to select the best landfill location, it is often necessary to compromise among possibly conflicting tangible and intangible factors. Different multi-objective programming models have been proposed to solve the problem. A weakness with the different multi-objective programming models used to solve the problem is that they are basically mathematical and ignore qualitative and often subjective considerations such as the risk of groundwater pollution as well as other environmental and socio-economic factors which are important in landfill selection. The selection problem also involves a change in allocation pattern of waste-flows required by construction of a new landfill. A waste flow refers to the routine of transferring waste from one location in a city to another. In selection of landfill locations, decision makers need to consider both the potential sites that should be used as well as the allocation pattern of the waste-flow at different periods of time. This paper reports on our findings in applying an integrated IMILP/MCDA approach for solving the solid waste management problem in a prairie city. The five MCDA methods of simple weighted addition, weighted product, co-operative game theory, TOPSIS, and complementary ELECTRE are adopted to evaluate the landfill site alternatives considered in the solid waste management problem, and results from the evaluation process are presented.

Keywords: Decision-support; Environmental impact; Multi-criteria decision analysis; Landfill selection

1. Introduction

A solid waste management program often involves conflicting economical, environmental, and socio-ecological impacts. For example, locating a new site for landfill development at minimal cost is feasible, but the tradeoff could be the likelihood of groundwater pollution. The question then arises as to how the decision maker can reach a compromise among the conflicting impacts and select the optimal landfill location.

The landfill selection problems have often been tackled using multi-criteria decision analysis (MCDA). For example, Hipel (1982) proposed an early version of multi-criteria modelling that incorporated fuzzy set theory and applied the method to a solid-waste disposal problem in Canada. Chen et al. (1997) developed the fuzzy DRASTIC for landfill siting which used a geological information system (GIS) to evaluate potential sites in Taiwan. A different approach is adopted by Hokkanen et al. (1997) who applied a MCDA method called PROMETHEE for facility allocation. Hokkanen et al. (1994) and Vuk et al. (1991) also demonstrated effectiveness of using MCDA methods to solve the selection problem in solid-waste management.

In this paper, we present our work in locating a new and optimal landfill site in the city of Regina that would cause the least negative economical and socio-environmental impacts. Multi-objective linear programming (MOLP) models are applicable for handling this type of problems, but the complexity of constructing a MOLP model and the lengthy computation involved render such models inconvenient. A weaknesses in MOLP modelling is that after the result from MOLP has been generated, further analysis may still be

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required. Also, a MOLP model cannot support input parameters for landfill selection which are based on the subjective opinions of the decision maker or analyst and which can change over time. Therefore, an integration of MCDA with a single-objective linear programming model is proposed to deal with the landfill allocation problem. First, inexact mixed integer linear programming (IMILP) is applied to determine the waste flow in Regina with an objective of minimizing the total cost. Then the total cost and other criteria will be taken into account in a MCDA model in order to determine the best landfill site alternative.

In the rest of the paper, Section 2 provides an overview of the problem of selection of a new landfill in the city of Regina. In Section 3, the proposed integrated approach is described. Section 4 discusses considerations on how to deal with uncertainties in the problem. Sections 5 and 6 describe the formulation of IMILP and MCDA models that are applied in the problem, and the result from the analysis is discussed in Section 7. A brief conclusion is given in Section 8.

2. Background

The study site is the City of Regina which has a population of about 187,500 (City of Regina, 2000). There is only one landfill in the city, located in the northeast, to handle 138,750 tonnes of waste as of 1998. The waste generation rate in 2000 was 0.74 tonne/person/year. Compared to 1.23 tonne/person/year in 1988 (Saskatchewan Environment and Resources Management, 1999; City of Regina, 1999), the waste generation rate has been reduced by almost 40%. This measure indicates the City of Regina's commitment to solid-waste management.

Since the early 1980s, the city has been concerned about two problems with the existing landfill, specifically, the risk of its contaminating groundwater and its limited capacity. This concern motivated the Regina Waste Management Study. Phase 1 of the study completed in 1983 evaluated the existing landfill and tried to find alternative sites (City of Regina, 1983). A follow up study was conducted in 1986 which aimed at re-evaluating the alternative landfill sites and recommended the next landfill location (City of Regina, 1989). Aside from planning for a new landfill, the City of Regina has also promoted waste diversion programs to help reduce waste generation in an effort to prolong the lifetime of the existing landfill. These programs, some of which were promoted since 1990, include the Big Blue Bin paper recycling program, backyard composting, the Garbage Reduction Zero Waste program, and other similar special waste programs. Moreover, the city also encouraged the community educational system to promote awareness of the importance of waste reduction.

In general, the existing landfill in the City of Regina is facing two major problems. First, the landfill is close to its maximum capacity and is going to expire within the next 10 years. Hence, it is essential that a new landfill be built before the expiry date. More importantly, the existing landfill might cause groundwater contamination because it is located on top of the Regina Aquifer. This problem has been discussed since the early 1980s. In 1981, a sensitivity analysis was conducted to investigate possible aquifer contamination caused by the existing landfill and other industrial activities (City of Regina, 1983). After 1984, a leachate monitoring well was installed at the existing landfill to collect data on groundwater quality, location, elevation and flow. In 1990, the Environmental Protection Branch of Saskatchewan Environment and Resources Management Division initiated the Regina Aquifer Groundwater Monitoring Project (Ballagh, 1998). The project findings indicated that the existing landfill might be one of the sources of contamination for the aquifer. It was also suspected that the adverse groundwater quality impacts of the landfill site had been ongoing over the last 30 years and had progressively worsened each year. Since this aquifer provides about 10% of drinking water for the residents of the city, groundwater contamination due to leachate leaks from the landfill would seriously affect the drinking water of both urban and rural residents. Fortunately, even though the risk exists, no sign of significant groundwater pollution has yet been discovered. However, it became apparent that a new landfill site was needed.

3. Integration of MCDA with IMILP

Cost is the major criterion in selecting a landfill. However, allocating a new landfill can cause a change of waste flow, which in turn would affect the cost. Waste flow refers to the routine of transferring waste from one location in the city to another. When a new landfill is developed, the waste flow will be rerouted. Therefore, the waste flow associated with each potential landfill site has to be determined in order to calculate the total cost of each landfill site. An integrated IMILP–MCDA approach was adopted to model the process as shown in Fig. 1. This figure presents a framework for the study of solid-waste management in Regina. First, IMILP is used to determine the municipal waste flow at minimal total cost for each potential landfill site. The main advantage of using IMILP model is that it accepts uncertain input parameters in the form of interval values, which was the format of data obtainable in many real world problems. The constraints of the IMILP model include the period of time, mass balance, capacity, and facilities available at different periods. The main results generated from the IMILP model