Journal of Environmental Management 92 (2011) 1484–1494

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

An interval-based regret-analysis method for identifying long-term municipal solid waste management policy under uncertainty

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ARTICLE INFO

Article history:
Received 8 April 2010
Received in revised form
11 November 2010
Accepted 11 December 2010
Available online 1 February 2011

Keywords:
Environment
Interval analysis
Optimization
Planning
Waste management
Minimax regret
Uncertainty

ABSTRACT

In this study, an interval-based regret-analysis (IBRA) model is developed for supporting long-term planning of municipal solid waste (MSW) management activities in the City of Changchun, the capital of Jilin Province, China. The developed IBRA model incorporates approaches of interval–parameter programming (IPP) and minimax–regret (MMR) analysis within an integer programming framework, such that uncertainties expressed as both interval values and random variables can be reflected. The IBRA can account for economic consequences under all possible scenarios associated with different system costs and risk levels without making assumptions on probabilistic distributions for random variables. A regret matrix with interval elements is generated based on a matrix of interval system costs, such that desired decision alternatives can be identified according to the interval minimax regret (IMMR) criterion. The results indicate that reasonable solutions have been generated. They can help decision makers identify the desired alternatives regarding long-term MSW management with a compromise between minimized system cost and minimized system-failure risk.

1. Introduction

For decades, many regions and nations have been paying attention to the planning of effective municipal solid waste (MSW) management systems due to the population growth and economic development. In MSW management systems, there are many processes that should be considered by decision makers, such as waste collection, transportation, treatment, and disposal (Wilson, 1985). Moreover, many system parameters (e.g., waste-generation rate, waste treatment cost, and facility–capacity), impact factors (e.g., energy price, labor fee, and management expenses) and their interactions are associated with uncertainties. Furthermore, the spatial and temporal variations of many system components may further multiply these uncertainties (Thompson and Tanapat, 2005). These complex uncertainties could result in difficulties in the long-term planning of MSW activities. Therefore, in response to these uncertainties and complexities, more effective systems analysis techniques are desired for managing MSW systems in a more efficient way.

Previously, a number of inexact optimization techniques were developed to deal with such uncertainties and complexities in the MSW management systems, including fuzzy mathematical programming (FMP) (Chang and Wang, 1997; Wilson and Baetz, 2001a,b; Cai et al., 2007; Nie et al., 2007; Li et al., 2008a; Guo and Huang, 2009; Xu et al., 2009, 2010), stochastic mathematical programming (SMP) (Huang et al., 2001; Maqsood and Huang, 2003; Li and Huang, 2006a; Li et al., 2006, 2008a,b), and interval–parameter programming (IPP) (Huang et al., 1992, 1997, 1998; Chanas and Kuchta, 1996; Davila and Chang, 2005; Su et al., 2008; Liu et al., 2009). For example, Chang and Wang (1997) proposed a fuzzy interval multiobjective mixed integer programming model for the evaluation of solid waste management strategies in a metropolitan region, in which the uncertain information could be quantified by specific membership functions and combined through the use of interval numbers in a multiobjective linear programming framework. Huang et al. (1997) advanced an interval–parameter integer programming model for the long-term planning of waste management facility expansion/utilization in the Regional Municipality of Hamilton–Wentworth, Ontario, Canada; the proposed model could effectively reflect dynamic, interactive, and uncertain

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0301-4797/$ – see front matter
doi:10.1016/j.jenvman.2010.12.006

characteristics of the MSW management system in the study city. Wilson and Baetz (2001a,b) presented a derived probability model for supporting municipal solid waste collection systems, where the stochastic aspects existing in waste-generation rate and vehicle capacity could be estimated. Davila and Chang (2005) proposed an interval–parameter mixed integer programming-based game theory approach for addressing optimization and cost-benefit analysis at two competing landfills in the Lower Rio Grande Valley, Texas, USA. Li and Huang (2006b) developed an interval–parameter two-stage mixed integer linear programming method for supporting long-term planning of waste management activities in the City of Regina, in which uncertainties expressed as both probability density functions and discrete intervals could be reflected. Guo and Huang (2009) proposed an inexact fuzzy-stochastic chance-constrained two-stage mixed integer linear programming method, where uncertainties existing in the MSW management systems were treated as intervals and dual probability distributions within a general optimization framework. In general, IPP has advantages in reflecting uncertainties expressed as interval numbers without knowing their distributions; the FMP and SMP methods can effectively reflect probabilistic and possibilistic uncertainties in the right-hand sides of a linear model. Nevertheless, the main limitations of the FMP methods remain in their difficulties in tackling uncertainties expressed as probabilistic distributions in a non-fuzzy decision space (Li et al., 2009); SMP requires probabilistic specifications for uncertain parameters, while in MSW management problems, it is often associated with difficulties in acquiring probability distribution for the date of waste generation.

Minimax regret (MMR) analysis, which was proposed to determine the hedging alternatives under uncertainty but without probability information for the states of the world, was proved to be an effective method that could help to address the above shortcomings (Savage, 1954; Inuiguchi and Tanino, 2000; Li and Huang, 2006b; Chang and Davila, 2006, 2007; Aissi, et al., 2009). MMR only needs a list of possible scenarios without any assumption on their probabilities, and then seeks to minimize the maximum regret among all possible scenarios (Loulou and Kanudia, 1999). Each regret value corresponds to the difference between the cost of the alternative selected by decision makers and that of the best alternative for a special state of the world. Previously, several researchers employed MMR analysis to plan MSW management systems under uncertainty. For example, Chang and Davila (2006) introduced a grey minimax regret integer programming model for the management of MSW in the Lower Rio Grande Valley, South Texas, which could outline an optimal regional coordination of solid waste routing and possible landfill/incinerator construction under various forms of systematic and event-based uncertainty. Li and Huang (2006b) developed an interval minimax regret programming method for the planning of municipal solid waste management, which can address uncertainties expressed as interval values in MSW management systems and make the final decision based on inexact minimax regret analysis. Li and Huang (2009) developed an inexact minimax regret integer programming method and applied it to a real case study in the City of Regina, Canada. However, Regina is a very small city with around 100 km^2 and has low population of about 195,000; transfer stations and multiple districts were not considered in the modeling formulation. In comparison, Changchun City covers an area of approximately 379.9 km^2 and has high population of about 2.78 million, including five main districts. In addition, a number of transfer stations that can decrease vehicle traffic going to-and-from the facility, recycle various useful wastes, and contribute to a reduction in the waste volumes because of the compaction process considered. Therefore, the complexities of MSW management in the City of Changchun are much higher than those in the City of Regina, which drive the local decision makers to look for effective and forward-looking solutions to address various waste management issues. However, many big cities in China lack effective systems analysis techniques for MSW management planning (e.g., the City of Changchun).

Therefore, as an extension of previous efforts, this study aims to develop an interval-based regret-analysis (IBRA) model for planning municipal solid waste (MSW) management in the City of Changchun, China. In this study, transfer stations and multiple districts will be considered in the modeling formulation, which is different from that proposed by Li and Huang (2009) and applied to the City of Regina. The IBRA model will reflect the complex nature of the waste management system in the City of Changchun and make the final decisions based on minimax regret analysis. The detailed tasks of IBRA model include: (i) tackling uncertainties expressed as interval-random variables without knowing their probability distributions, (ii) analyzing all possible scenarios associated with different system costs and risk levels, (iii) identifying the optimal regional coordination of solid waste routing among districts, transfer stations and waste disposal facilities, (iv) reflecting dynamic complexities in waste management systems in planning capacity–expansion schemes for waste management facilities, and (v) generating alternatives under different decision criterions for supporting the real-world (i.e., Changchun City) MSW management and planning.

The paper is organized as follows: Section 2 describes the statement of MSW management problems for the City of Changchun; Section 3 formulates an interval-based regret-analysis (IBRA) model for supporting MSW management of the study city; Section 4 provides the results analysis for all possible scenarios, based on IBRA model; Section 5 provides discussion for the results under different risk attitudes or different decision criterions; and Section 6 presents conclusions of the work.

2. Solid waste management in the City of Changchun

Changchun is the capital city of Jilin Province, located in the northeast of China. The region covers an area of approximately 379.9 km^2, including five main districts (abbreviated as LY, CY, NG, KC and ED, as shown in Fig. 1). The various components of the system that process these wastes include: a waste-to-energy facility called the Xinxiang incinerator, two landfills, and six waste transfer stations. Under the present operating structure, each district assumes sole responsibility for the collection of its own solid waste, whilst all the collected solid wastes are delivered to transfer stations and waste processing facilities via a number of routes. The city has a population of 2.78 million, with 0.57 (LY), 0.74 (CY), 0.61 (NG), 0.47 (KC), and 0.39 (ED) million. Recent population projections assumed a growth rate of 0.8% per year in the City (CUPC, 2004). The results of a waste yield prediction study for the city indicate that the city generates waste at an average rate of approximately 1.09 kg/capita/day (Su and Yan, 1999); a waste-generation rate of approximately 1.30 kg/capita/day is predicted in 2020 (CUPC, 2004). In China, high population density is one of the most important characteristics. Moreover, due to the rapid economic development and high population growth, populations of Changchun could be fluctuated within a very wide interval. The population characteristics and individual waste-generation rate can both lead to highly uncertain waste amounts. Therefore, for a long-term planning exercise, a general waste-generation rate of 1.01–1.21 kg/capita/day will be used for the City of Changchun in the first period. The study time horizon is 15 years, which is further divided into three planning periods. Several possible waste-generation levels are listed in Table 1, which are expressed as IRVs with their probability distributions being unknown.

Consistent with many communities in China, the city relies mostly on two landfills for disposing of its MSW. The two landfills