Sustainable Production and Consumption xx (xxxx) xxx–xxx

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Contents lists available at ScienceDirect

Sustainable Production and Consumption

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

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Research article

Decentralized bi-level decision planning model for municipal solid waste recycling and management with cost reliability under uncertain environment

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ARTICLE INFO

Article history:
Received 6 November 2017
Received in revised form 14 May 2018
Accepted 27 May 2018
Available online xxxx

Keywords:
Waste management
Bi-level programming
Uncertainty
Cost reliability
Controlling factors

ABSTRACT

This study presents bi-level decision making model for the management of municipal solid wastes (MSW). The model starts with waste disposals by the people, followed by its collection and distribution to the respective waste treatment facilities (WTF) and disposal centre. The loop continued to the transportation of untreated waste from treatment facilities to disposal centres and finally the transportation of products from treatment facilities to different markets. Minimizing the net transportation cost and maximizing the revenues generated from treatment facilities are considered as objective functions of first and second level respectively. Assuming the uncertainty in transportation, concept of cost reliability in the transportation cost is incorporated. Decisions are made successively from the first level to the second level. Decision variables are partitioned between the two levels and are called as controlling factors. Linear membership functions for fuzzily described objective functions and controlling factors are constructed to obtain the final solutions. Fuzzy Goal Programming is then applied to obtain the final solutions. Finally, we provide a numerical illustration to illustrate and justify the proposed model. The model could be extended by including the transportation mechanism of the used and rejected products from the customers forming a closed loop network of solid waste management.

1. Introduction

With an increasing rate of population, the generation rate of wastes has also been increased over several years. Management of wastes thus becomes one of the prime concerns for urban communities throughout the world. With insufficient landfill capacities and inefficient waste management systems, an optimal solution considering economic and technical aspects is greatly needed. Many deterministic models have been formulated for planning solid waste management. Hsieh and Ho (1993) and Lund et al. (1994) used linear programming techniques to plan the disposals and recycling management for solid waste. Chang and Wang (1997) consider various environmental impacts such as air pollution, noise and leachate effects, traffic congestion as multi-objective decision planning model for solid waste management. Waste management modelling may involve multiple objectives to be dealt with such as minimization of transportation cost, maximization of profits, reducing environmental impacts etc. Management system for MSW consists of landfills and WTF to deal with unusable and useable wastes respectively. Useable wastes can be processed under different operations to be used for generating different products under different treatment facilities, whereas unusable wastes need to be dumped into landfills. Moreover, untreated waste from different treatment facilities finally dumps into landfills. Municipal Solid Waste Management (MSWM) needs to be composed with wastes collection centres and wastes distribution centres. Waste distribution centres separate and distribute wastes to WTF and landfills. Wastes that are reached to WTF, after undergoing different operations are turned into useful products. This paper also considers the transportation plans for WTF to different markets. The loop ends when the products reach to the customers, who initially dump waste to collection centres. The waste flow rate over the network of a place depends upon the rate of generation of wastes, inventory holding capacities of collection centres, distribution centres, WTF and disposal centres.

Inventory capacity is the ability of a centre to hold certain amount of waste at any time during the operational process. The waste under different treatment facilities is used for different purposes. Some facilities utilize waste in the manufacture of different products while some utilize them for the production of electricity also known as incinerators. The delay in the transportation of waste causes operational problems for treatment facilities utilizing waste as the raw products for the manufacture of desired

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https://doi.org/10.1016/j.spc.2018.05.009
2352-5509/

Please cite this article in press as: Muneeb S.M., et al., Decentralized bi-level decision planning model for municipal solid waste recycling and management with cost reliability under uncertain environment. Sustainable Production and Consumption (2018), https://doi.org/10.1016/j.spc.2018.05.009.

products. Moreover incinerators need continuous and timely supply of wastes, failing of which compels them to search for other supplies of wastes causing an extra burden and an extra cost. MSW management decisions involve uncertainties at different steps to be dealt, ignoring of which result in less efficient and costlier management system. Waste generation rate differs under different times resulting an uncertainty in the system.

Decision making under waste management systems is generally decentralized where decision makers are present at different levels. The main objective or the leader‘s interest lies mainly in minimizing the system cost where as the sub units under the control of leader may have their different objective functions or interests. Considering the needs of continuous and timely supplies of waste to treatment facilities and the uncertainties prevailing in the process, the concept of cost reliability in transportation costs is introduced. Municipal solid waste management becomes more complex when decision makers are considered to be present at different levels. Moreover addition of cost reliability in system cost makes the problem more complex to solve. These complexities have been dealt in this paper by formulating the MSW management problem as a bi-level decision making model when the concept of cost reliability is incorporated in system cost. In order to reflect the practicability of the proposed model, the objectives or the goals of the problem are considered uncertain and are known as fuzzy goals. MSW management problem has not been formulated yet as bi-level decision making model as per the best knowledge of authors. Also, incorporation of cost reliability in MSW management is also the first attempt to the best of our knowledge. Thus it is the first attempt to formulate MSW management problem as a decentralized bi-level decision making problem when the system costs are represented by cost reliabilities.

The rest of the paper is organized as follows. Section 2 contains a relevant literature of solid waste management problem and bi-level programming. Section 3 contains the methodology to deal with the proposed model in the paper and this section thus contains the general formulation and the procedure for solving bi-level programming problems. Section 4 contains the model formulation for fuzzy bi-level MSW management problem when cost reliability is incorporated in system cost. Section 5 contains the implementation of proposed bi-level decision making model using LINGO13.0 and the analysis of results generated. Conclusions are present in Section 5 along with some future directions.

2. Literature review

2.1. Solid waste management

There is a good amount of work present in literature related to waste management. Solid waste management involves different criteria to be handled and it involves different parameters to be considered. Perlack and Willis (1985) presented multi-objective modelling for waste disposal planning. The study involves the objectives of net economic benefit, environmental impact and variability of impacts. Sheu (2007) presented a multi-objective reverse logistic model for the treatment of multi-source hazardous waste. They consider a high technology manufacturing zone for data collection and numerical implementation. The study includes total reverse logistics operating cost and corresponding risks to be minimized as objective functions. Ahluwalia and Nema (2006) proposed a reverse logistic model for optimum configuration of computer waste management facilities. The model also involves the allocation of wastes to the facilities (segregation, storage, processing, recycle and disposal). The objectives of minimizing environmental risk and cost are considered under the model which is solved by the linear programming method. Yu et al. (2012) proposed a decision support system for simulation and optimization of municipal solid waste based upon multi-objective programming. The study consists of conflicting objectives namely minimization of operating costs and environmental risks as well as the maximization of resources utilization and equity. The model presented in the study is a five level model starting from waste collection to distribution and then to recycling. Fourth level comprises of waste treatment facilities and disposal unit forming the last level. Chen et al. (2014) proposed a chance constrained model based on inexact inventory theory for solid waste management. The model aimed at minimizing the system cost when the uncertainties are present in co-efficient and/or parameters of both objective functions and constraints. Zhai et al. (2016) presented a programming approach based on factorial dual interval programming to deal with uncertainties in waste management system. The approach handle the single and dual interval uncertainties present in the objective functions and constraints. Zhang et al. (2016) proposed an approach for the management of flow back and produced water during the production of shale gas. They considered the objective of minimizing the total system cost constrained by capacity restrictions and demand fulfilments. Xiong et al. (2017) presented a model for waste management system where the service providers also known as operators not only compete in the waste market but also require the service of other units. The model thus presented in the study is also termed as symbiotic in nature. Yadav et al. (2017) proposed a model for selecting the economically best locations of transfer stations for the management of solid waste considering multi-parameter uncertainty prevailing in different parameters such as waste generation rates and costs. They used the interval optimization approach to solve the model proposed in the study. An efficient waste management system is one that results the minimum system cost and produces maximum benefits in terms of revenue. Soltani et al. (2017) analysed the impacts of uncertainty on decision making using different assessment methods such as sensitivity analysis, fuzzy analytical hierarchy process and Bayesian games. Assessing the present literature of solid waste management, the present paper certainly fills the gap by introducing a model with decentralized structure alongside incorporating cost reliability.

2.2. Bi-level programming

Bi-level programming executes the hierarchical structure of decision making where leader first solves his problem in isolation and then provides the values of his controlling factors. Follower tries to find his solutions in view of the policies adopted by the leader in the form of his controlling factors. Various approaches (Bialas and Karwan (1984), Sakawa and Nishizaki (2002) are present in the literature to deal with bi-level programming problems. Cutting plane methods and parametric solution approaches for bi-level programming is developed by Dempe (1995). Baky (2009) used fuzzy goal programming technique to solve bi-level multi-objective problems and extended the algorithm to deal with fractional objectives under the bi-level structure. The study considers the formulation of membership functions for fuzzily described goals and decision variables under the control of leader using fuzzy set theory. Zhang et al. (2012) proposed an improved particle swarm optimization algorithm to solve bi-level programming problems with multiple objectives at each level. Emam (2013) presented an interactive approach for solving bi-level multi-objective problem under two stages. The first stage is concerned with finding the convex hull formed by the set of constraints and the conversion of fractional objectives into equivalent linear objectives while final results using constraint method are obtained under second stage. Birla et al. (2017) presented an alternative approach for solving bi-level programming problem by removing the redundant constraints causing the elimination of cycling so as to reach the solution

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