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Interval-valued facility location model: An appraisal of municipal solid waste management system

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A B S T R A C T

This study presents an interval-valued facility location model to find economically best locations for transfer stations under uncertainty. Transfer stations are the vital part of contemporary municipal solid waste management systems and economical siting of transfer stations using developed model lead to a financially sustainable system. Often, the associated uncertainty of these systems cannot be modeled by conventional probabilistic or fuzzy approaches under a data scarce scenario; however, models based on interval analysis are found to be very effective in such cases. A set of univariate and multivariate sensitivity analyses adduces the need of uncertainty analysis for quantification and propagation of uncertainty. The demonstration of model on city of Nashik (India) provides *(i)* economical feasibility, optimum capacity and economically best locations of transfer stations; and *(ii)* impact of uncertain parameters on the best locations. The developed model felicitates a convenient decision-making to identify economically best locations of transfer stations under uncertain environment.

1. Introduction

Municipal solid waste (MSW) management system covers all the operations, transformations and processing of MSW from its generation sources to the final disposal. This system can be categorized into the following functional elements: *(i)* generation; *(ii)* handling, storage and separation at the source; *(iii)* collection and transportation;*(iv)* processing and transformation; and*(v)* disposal (Yadav et al., 2016a).

A substantial percentage (70% - 80%) of MSW management total expenditure is spent only in the transportation and collection of MSW; whereas processing, transformation and disposal get about 15% to 20% of total budget (Tavares et al., 2009). This distribution of budget should be principally reversed as processing, transformation and disposal are the key engineering components of MSW management system. Also, incidents of landfill fire (Powell et al., 2016) and public opposition/agitation for establishment of disposal sites near to human settlements (Demesouka et al., 2016) have forced municipalities to make these facilities far away from the populated areas. This situation has resulted in longer routes for MSW transportation and large collection vehicles are found to be cost effective for long transportation of MSW as compared to smaller vehicles (Eiselt and Marianov, 2015). This activity has affected the budget distribution severely by putting an extra burden (see Fig. 1) on collection and transportation costs. Transfer stations (TSs) are widely integrated into the MSW management systems of urban centers to address this unevenness of budget allocation (Yadav et al., 2016b, c).

TSs are the junctions of small and large collection vehicles, known as primary collection vehicles (PCVs) and secondary collection vehicles (SCVs) respectively. Inclusion of TSs increases the frequency, efficiency of MSW collection/transportation system and also provides flexibility to choose new locations for processing/final disposal facilities away from the settlements by giving preferences to human health and other environmental issues (Yadav et al., 2016b). However, choosing best locations for the TSs siting is the major challenge (Ramachandra and Bachamanda, 2007).

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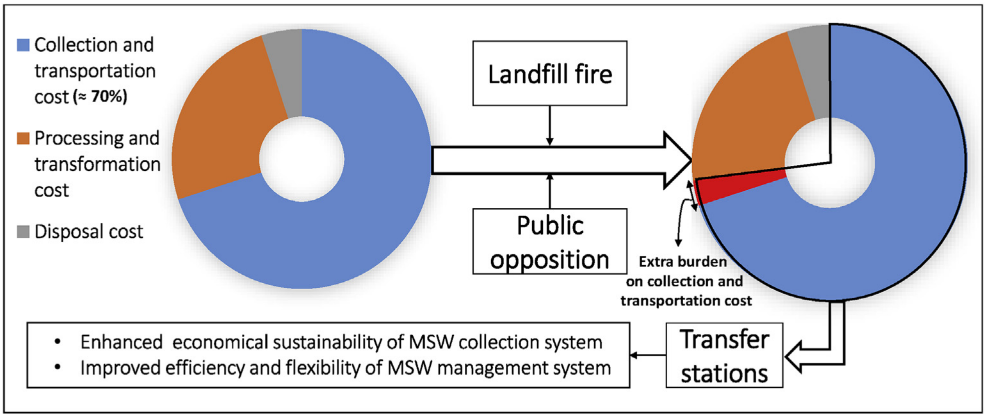

Fig. 1. Problem statement depicting the need of transfer stations in contemporary MSW management systems.

Therefore, this paper presents a facility location model to choose economically best locations and number of TSs required. Facility location models are special classes of optimization models, which have been extensively used to make MSW management system economically sustainable (Eiselt and Marianov, 2014).

Many parameters of a MSW management are uncertain in nature (Wang et al., 2012). The sources of these uncertainties can be considered in terms of *(i)* total MSW generated; *(ii)* composition of MSW generated; *(iii)* fraction of MSW sent to different available facilities; *(iv)* estimated values of parameters for a long-term planning; and *(v)* inadequate skills of staff collecting and maintaining data (IPCC, 2006). This uncertainty of parameters is predominantly modeled using stochastic, fuzzy, grey/inexact programming approaches and hybrid of all these approaches (Fan et al., 2012). Fig. 2 provides insight of these approaches with representative literature, specific advantages and limitations of all these approaches. First two columns of Fig. 2 have information about two conventional approaches (*i.e.* stochastic and fuzzy) in which adequacy of data required to define probability distribution function or membership function. Third column contains information about grey/interval number based approaches in which knowledge of extreme bounds is required. However, grey programming based approaches fail to capture all intermediate possibilities and sometimes result with infeasibility and nonoptimality of the solution space (Rosenberg, 2009). To overcome all these limitations, Bhurjee and Panda (2012) proposed an algorithm for finding efficient solutions to a linear programming problem with interval parameters. However, this algorithm had a limitation in terms of addressing bilinear functions, interval decision variables and integers. Further, Yadav et al. (2017) developed an algorithm to

MSW management systems under uncertainty			
Stochastic	Fuzzy	Grey/Inexact/Interval	Hybrid
Expression of uncertainty			
Random variables	Fuzzy sets/possibilistic	Grey/interval numbers	Mixed type
Past efforts			
Linear (Zhu and Huang, 2011); Non-linear (Li et al., 2008); Two-stage (Maqsood and Huang, 2003); Chance-constraint (Xu et al., 2009)	Linear (Wiehn et al., 1996); Non-linear (Chang and Wei, 2000); Flexible programming (Srivastava and Nema, 2012); Possibilistic programming (Zhang and Huang, 2014)	Linear (Huang et al., 1992); Non-linear (Wu et al., 2006); Integer (Huang et al., 1995); Dynamic (Huang et al., 1994); Functional intervals (He et al., 2009)	Fuzzy with chance-constrained (Zhang and Huang, 2010); Fuzzy with stochastic (Li et al., 2012); Fuzzy, stochastic with interval (Wang et al., 2012)
Advantages			
Effective dealing with probabilistic uncertainties in the situation of data abundance (Dellino and Meloni, 2015)	Opportunity to model subjective imaginations precisely with stack-holder involvement (Rommelfanger, 2004)	Effective and direct communication of uncertain information into model under the situation of data scarcity(Sun et al., 2014)	Collective advantages of different possible combinations
Limitations			
High data requirements for probability distributions (Huang et al., 1992)	Inefficient incorporation of imprecise/subjective information (Huang et al., 1993)	Infeasibility and nonoptimality of solution generated (Zou et al., 2009; Rosenberg, 2009)	Collective limitations of different possible combinations

Fig. 2. Past efforts in modeling of MSW management systems under uncertainty. (Chang and Wei, 2000; Dellino and Meloni, 2015; Doğan and Süleyman, 2003; Ghose et al., 2006; He et al., 2009; Huang et al., 1992; Huang et al., 1993; Huang et al., 1994; Li et al., 2008; Li et al., 2012; Maqsood and Huang, 2003; Rommelfanger, 2004; Simsek et al., 2014; Srivastava and Nema, 2012; Sun et al., 2014; Weichenthal et al., 2015; Wiehn et al., 1996; Wu et al., 2006; Xu et al., 2009; Zhang and Huang, 2014; Zhang and Huang, 2010; Zhu and Huang, 2011; Zou et al., 2009.)