Expert Systems with Applications 39 (2012) 4657–4678

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

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

Fuzzy parametric programming model for multi-objective integrated solid waste management under uncertainty

Amitabh Kumar Srivastava [a,*], Arvind K. Nema [b]

[a] Bundelkhand Institute of Engineering & Technology, Kanpur Road, Jhansi 284128, India
[b] Department of Civil Engineering, Indian Institute of Technology Delhi, Huaz Khas, New Delhi 110016, India

ARTICLE INFO

Keywords:
Solid waste management
Integrated solid waste management system
Long term planning
Multi-objective and multi-period planning
Fuzzy parametric programming

ABSTRACT

Solid waste management is increasingly becoming a challenging task for the municipal authorities due to increasing waste quantities, changing waste composition, decreasing land availability for waste disposal sites and increasing awareness about the environmental risk associated with the waste management facilities. The present study focuses on the optimum selection of the treatment and disposal facilities, their capacity planning and waste allocation under uncertainty associated with the long-term planning for solid waste management. The fuzzy parametric programming model is based on a multi-objective, multi-period system for integrated planning for solid waste management. The model dynamically locates the facilities and allocates the waste considering fuzzy waste quantity and capacity of waste management facility. The model addresses uncertainty in waste quantity as well as uncertainties in the operating capacities of waste management facilities simultaneously. It was observed that uncertainty in waste quantity is likely to affect the planning for waste treatment/disposal facilities more as compared with the uncertainty in the capacities of the waste management facilities. The relationship between increase in waste quantity and increase in the total cost/risk involved in waste management is found to be non-linear. Therefore, it is possible that a marginal change in waste quantity could increase the total cost/risk substantially. The information obtained from the analysis of modeling results can be effectively used for understanding the effect of changing the priorities and objectives of planning decisions on facility selections and waste diversions.

1. Introduction

The regional solid waste management (SWM) system comprises of many interrelated components including transportation, treatment and disposal. These interrelated components must be considered in integration in order to arrive at an optimal waste management plan. Mathematical models can be used to describe the objective, component interactions and available management options. The mathematical models can be subjected to rigorous methods of systems analysis for planning the integrated solid waste management system (ISWM). The mathematical models provide a systematic means by which the decision-maker can explore the various alternatives in order to identify an optimal management strategy. It is to be noted that the planning for an ISWM system for any urban centre is done for a long term, i.e., 20 or 25 years.

The basic input for municipal solid waste (MSW) management is the solid waste quantities which changes with respect to time at an increasing rate. Also the land available for the waste disposal facilities is increasingly becoming a scarce resource due to growing awareness about the associated environmental risk in the proximity to these facilities. In order to cope with the uncertainties involved in the solid waste quantities and available capacities of waste management facilities, an efficient and sustainable solid waste management plan is required.

2. Literature review

In an optimization model, the uncertainty can be addressed by using interval programming, stochastic modelling and/or fuzzy systems. A number of researchers have applied these techniques to consider the effect of uncertainty in the ISWM models. In interval programming approach the upper and lower bounds of coefficients are determined and then deterministic model is used to address these upper and lower bounds. Interval programming has been widely used by researchers to incorporate uncertainty in ISWM (e.g. Cheng, Chan, & Huang, 2003; Huang, Baetz, & Party, 1994, 1995a, 1995b; Huang, Baetz, Patry, & Terluk, 1997; Huang, Chi, & Li, 2005; Maqsood, Huang, & Zeng, 2004). It is to be noted that, the output of interval programming method is with upper

* Corresponding author.
E-mail addresses: aks107@rediffmail.com (A.K. Srivastava), aknema@civil.iitd.ac.in (A.K. Nema).

0957-4174/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2011.09.022

Nomenclature

Indices

T total planning period
S total number of solid waste source nodes, i.e. population centers
I total number of transfer stations cum segregation/sorting facilities
J_n total number of new landfills
J_e total number of existing landfills
J total number of landfills
R_e total number existing recycling facilities
R_n total number new recycling facilities
R total number recycling facilities
K_e total number of existing compost facilities
K_n total number of new compost facilities
K total number of compost facilities
M total number of waste components
t index for time $(1, \ldots, t)$
s index of solid waste source nodes, i.e. population centers
i index of transfer stations cum segregation/sorting facilities
j_n index of new landfills
j_e index of existing landfills
j index of existing landfills ($j = j_e \cup j_n$)
r_e index of existing recycling facilities
R_n index of new recycling facilities
R index of recycling facilities ($r = r_e \cup r_n$)
k_e index of existing compost facilities
k_n index of new compost facilities
k index of compost facilities
m index for solid waste composition (m = 1 for paper; m = 2 for plastic; m = 3 for food; m = 4 for metals; m = 5 for glass and m = 6 for others mainly inert)

Input data

TC_{sit} unit transportation cost for unit quantity of waste between source/population center and transfer stations (in $s \times i \times t$ matrix)
TC_{ijt} unit transportation cost for unit quantity of waste between transfer stations and landfills (in $i \times j \times t$ matrix)
TC_{ilt} unit transportation cost for unit quantity of waste between transfer stations and incinerators (in $i \times l \times t$ matrix)
TC_{ikt} unit transportation cost for unit quantity of waste between transfer stations and compost plants (in $i \times k \times t$ matrix)
TC_{irt} unit transportation cost for unit quantity of waste between transfer stations and recycling centers (in $i \times r \times t$ matrix)
TC_{rjt} unit transportation cost for unit quantity of waste between recycling centers and landfills (in $r \times j \times t$ matrix)
TC_{rlt} unit transportation cost for unit quantity of waste between recycling centers and incinerators (in $r \times l \times t$ matrix)
TC_{kjt} unit transportation cost for unit quantity of waste between compost plants and landfills. (in $k \times j \times t$ matrix)
TC_{klt} unit transportation cost for unit quantity of waste between compost plants and incinerators (in $k \times l \times t$ matrix)
TC_{ljt} unit transportation cost for unit quantity of waste between incinerators and landfills (in $l \times j \times t$ matrix)
OC_{it} operating cost of transfer stations cum segregation '*i*' facilities during time '*t*' (in $i \times t$ matrix)
OC_{rt} operating cost of recycling centers '*r*' during time '*t*' (in $r \times t$ matrix)
OC_{kt} operating cost of compost plant '*k*' during time '*t*' (in $k \times t$ matrix)
OC_{lt} operating cost of incinerators '*l*' during time '*t*' (in $l \times t$ matrix)
OC_{jt} operating cost of landfills '*j*' during time '*t*' (in $j \times t$ matrix)
$CC_{j_n t}$ capital cost of new landfills 'j_n' during time '*t*' (in $j_n \times t$ matrix)
$CC_{k_n t}$ capital cost of new compost plants 'k_n' during time '*t*' (in $k_n \times t$ matrix)
$CC_{l_n t}$ capital cost of new incinerators 'l_n' during time '*t*' (in $l_n \times t$ matrix)
IC_{tm} unit selling rate of waste material '*m*' during time '*t*' (in $t \times m$ matrix)
IK_t unit selling rate of compost during time '*t*' (in $t \times 1$ matrix)
G_{st} quantity of waste generated at population center/source '*s*' during time period '*t*' (in $s \times t$ matrix)
L_{js_air} attenuation factor from landfill '*j*' to source/population center '*s*' for dispersion of risk through air (in $j \times s$ matrix)
L_{js_sub} attenuation factor from landfill '*j*' to source/population center '*s*' for dispersion of risk through subsurface medium (in $j \times s$ matrix)
L_{ls} attenuation factor from incinerator '*l*' to source/population center '*s*' for dispersion of risk (in $l \times s$ matrix)
R^j_{air} risk factor from landfill '*j*' through air medium (in $j \times 1$ matrix)
R^j_{sub} risk factor from landfill '*j*' through air medium (in $j \times 1$ matrix)
R^l_{air} risk factor from landfill '*l*' through air medium (in $l \times 1$ matrix)
H_{st} population at source/population centers '*s*' during time '*t*' (in $s \times t$ matrix)
HV_m calorific value of individual waste component '*m*' (in $m \times 1$ matrix)
RHV_l rated heating value of incinerator '*l*' (in $l \times 1$ matrix)
CQ_j cumulative capacity of landfill '*j*' (in $j \times 1$ matrix)
Qu_{jt} maximum operating capacity of landfill '*j*' during time '*t*' (in $j \times t$ matrix)
Qu_{lt} maximum operating capacity of incinerator '*l*' during time '*t*' (in $l \times t$ matrix)
Qu_{kt} maximum operating capacity of compost '*k*' during time '*t*' (in $l \times t$ matrix)
Ql_{jt} minimum operating capacity of landfill '*j*' during time '*t*' (in $j \times t$ matrix)
Ql_{lt} minimum operating capacity of incinerator '*l*' during time '*t*'. (in $l \times t$ matrix)
Ql_{kt} minimum operating capacity of compost '*k*' during time '*t*' (in $k \times t$ matrix)
ω ratio of rejects and incoming waste at recycling centers (in single number)
ξ ratio of rejects and incoming waste at compost plants (in single number)
ψ ratio of residue and incoming waste at incinerators (in single number)
d_{ij} direct radial distance between locations *i* and *j* (in $i \times j$ matrix)
a_j exponent term depends on site conditions such as wind speed, turbulence (in $j \times 1$ matrix)
ϕ_j angle between directions of plume centerline from the reference axis (in $j \times 1$ matrix)